Scientific Goals of DARWIN

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Abstract

Topics discussed during this lecture :

- Two goals

  Planets: basic, but remote, driver: search for exo-live

  General astrophysics: proto-planetary disks, AGN cores, young galaxies... (not developed in present lecture)

- Means (for planets): spectroscopy of their atmosphere
- Mission challenges
- Expected results (for planets)

  Major enlargement of planetary science: determination of atmospheric composition for many planets (different ages, size, distance to star, stellar spectral type...)

  Search for life: atmospheric compositions as ingredients to atmospheric models that will decide how significant are observations regarding the presence of biological activity.

- Next: similar missions but with higher spectral resolution and S/N for a major increase of the information potential.

Related publications :

- Owen T., 1980: The Search for Early Forms of Life in Other Planetary Systems - Future Possibilities Afforded by Spectroscopic Techniques, in "Strategies for the Search of Life in the Universe", Papagiannis ed., pp 177-185, Reidel, Dordrecht
- Angel R. et al., 1986: Detecting Earth-Like Planets, Nature 322, 341-343
- Leger A. et al., 1996: Could We Search for Primitive Life on Extrasolar Planets in the Near Future? Icarus, 123, 249-255

Space Interferometry: the Darwin project

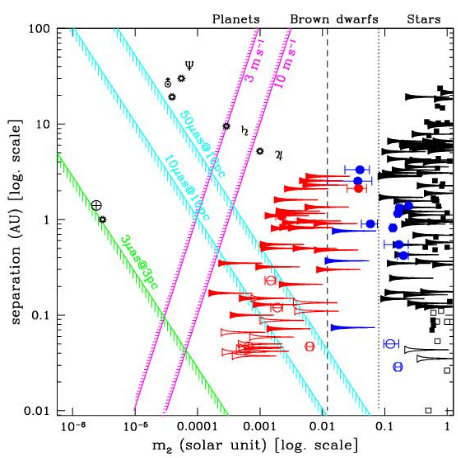
- **First motivation: search for <u>Life</u> in the Universe**

- **Step by step approach:**
  - **are there giant pl. / stars ?**
  - **" terrestrial " ?**
  - **" habitable " ?**
  - **" inhabited " ?**
  - **" evolved civilizations ?**

Darwin

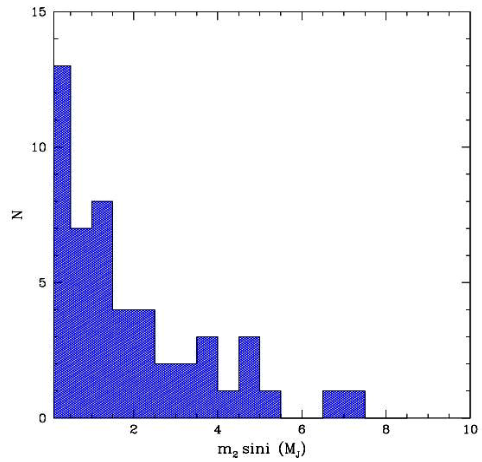
Search For Giant Planets

- **Radial velocity surveys**
  - **+3000 G-M stars observed**
  - **Today 50 planets detected**
  - **Mass-distance threshold**
  - **1 m/s intrinsic limit?**



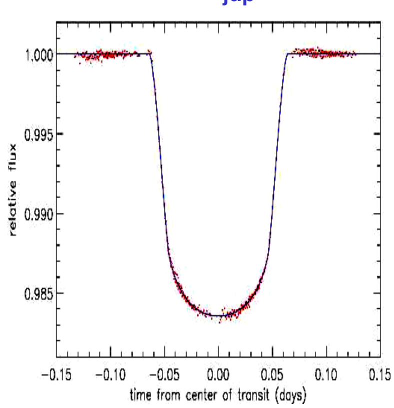
Giant Planets

- **R.V.: results**
  - **3-5% detection rate**
  - **Rising mass function**



Giant Planets

- **Transit detected**
  - **Planet orbiting HD209458**
  - **P = 3.5 days**
  - **M = 0.7 M_{jup}**



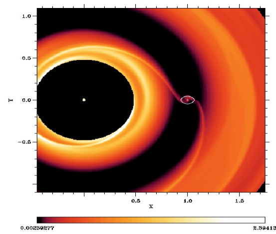
51 Peg systems are real !

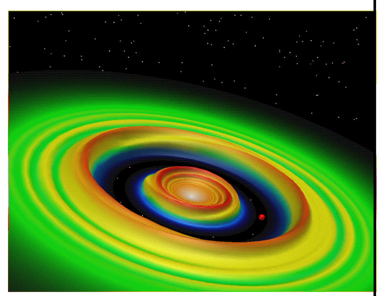
R_p = 1.4 R_{jup}

Giant Planets

- **Planet diversity:**

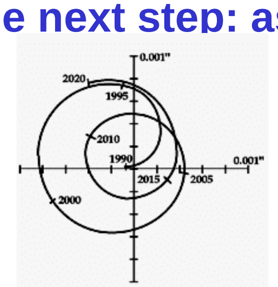
  <u>mass</u>, <u>distance</u> and <u>eccentricity</u> differ from the solar system case

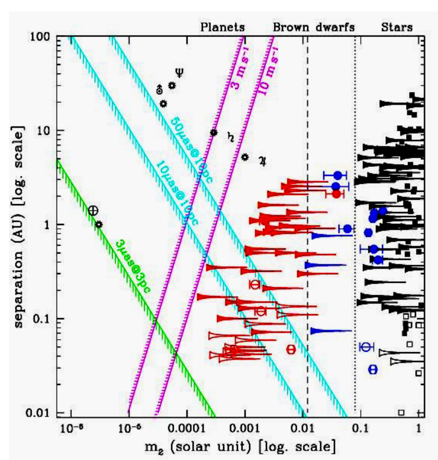




Giant Planets

- **The next step: astrometry**





- **Keck-I, VLTI, LBT**
- **SIM**
- **GAIA**

Search for Terrestrial Planets

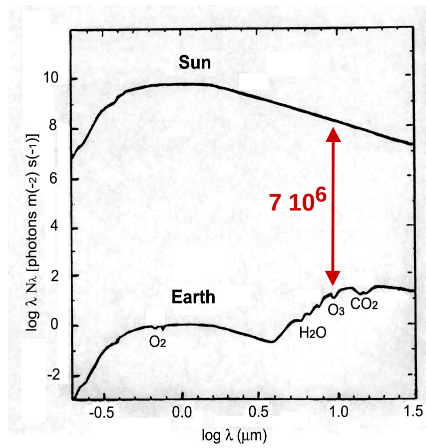
- Finding other Earths
  - Beyond capability of radial velocity observations
  - At least 3 μarcsec precision for astrometry: SIM for nearest stars ?
  - Transit from space (10^{-4} effect), needs quiet stars: COROT, Eddington
  - Micro-lensing: single 1h duration effect, mass ambiguity

... hard to achieve

A NOVEL OBSERVATIONAL CONCEPT IS NEEDED...

Search for nearby earths

- **Direct detection:**
  only foreseen method
- **Allows planet**
  characterization
- **The problem** ➪



Search for earths

Solutions:

- **Coronograph in space**
  ➨ $\Phi_{tel} > 30$ m
  ➨ **Not realistic**
- **Nulling interferometer in space**
  ➨ $\Phi_{tel} = 1.5 - 3.5$ m
  ➨ **Baseline 30 - 500 m**

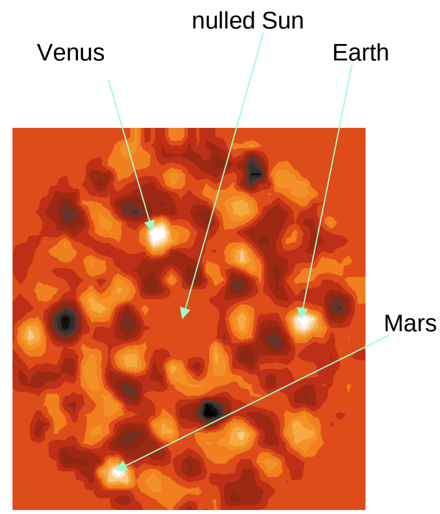
Search for earths

- Nulling interferometer with <u>imaging</u> capabilities

- e.g. reconstruction map by DARWIN of the Solar System ➡

  (planet position at 1st Jan. 2001, orbit seen at 30° inclination)

- several observations ➪ orbital parameters



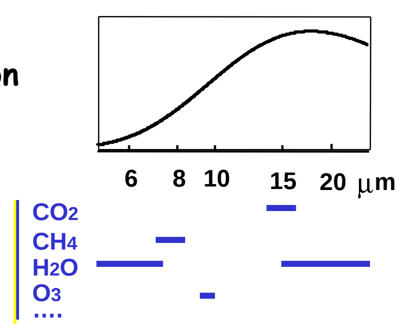
Mennesson and Mariotti (1997)

Characterizing earths

The IR spectrum - what can it tell us?

- 300K BB emission

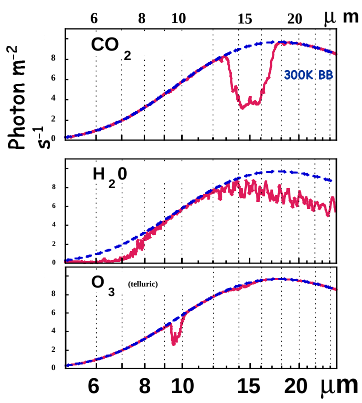
- IR absorptions



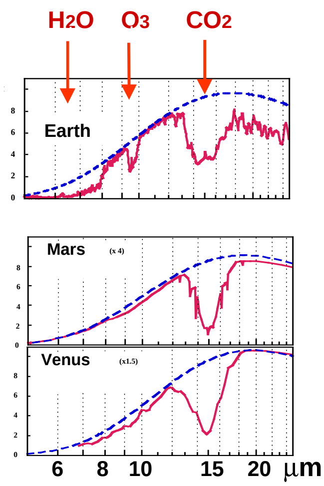
➪ Expected characterization of atmospheres

Characterizing earths

Calculated atmospheric spectra ($\lambda/\Delta\lambda$ = 200)

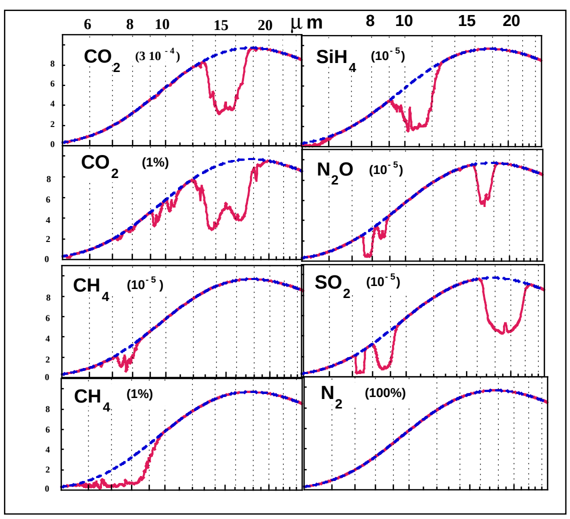


Observed spectra



Characterizing earths

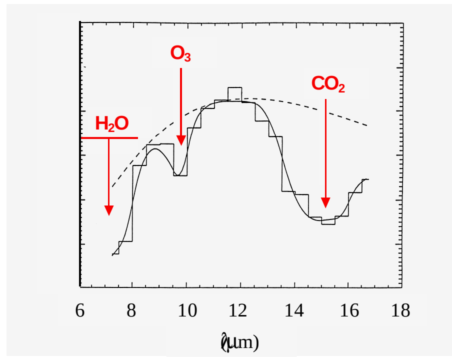
Atmospheres with other species ($\lambda/\Delta\lambda$ =200)



Characterizing earths

Spectra by DARWIN: $\lambda / \Delta\lambda = 20$ **only**
(40 for nearest planets)

- e.g. an earth ➔



- can detect key gases

➪ Goal ❶: exo-planetology

Search for exo-life

- **Ancient fundamental question**

  "Other worlds, with plants and other livings, some of them similar and some of them different from ours, must exist"

  (Epicurus, 300 BC)

- **Question accessible to everyone**

Search for exo-life

- **What is life?**
  - ➨ contains information
  - ➨ can self-replicate
  - ➨ can evolve

- **Life on Earth as a reference:**

  Carbon (organic) chemistry in water solution

Search for exo-life

May be not so restrictive:

1/ Carbon macromolecules are a good way to store information

2/ Life on Earth is very adaptable

Habitable Planets

- A planet with <u>liquid water</u> at its surface

- Can be identified by <u>remote sensing</u>

Inhabited Planets

- Detection by remote sensing? Looks hopeless...

- The case for H_2O / O_2

  1. O_2 produced by life

     $CO_2 + 2\,H_2O + 8\,h\nu \rightarrow (H\text{-}CHO) + O_2 \nearrow + H_2O$

  2. O_2 : very reactive gas / rocks… ($\tau \sim 10^7$ yrs)

     if not continuously produced ➪ vanishes

➨ Presence of O_2 = signature of life
IF no abiotic production

Qualifying / falsifying the H_2O / O_3 criterion

- O_3 better than O_2 (good tracer + IR active)
- for 20 yrs (Owen 1980), no abiotic production found when:
  - O_3 with H_2O
  - planet at T ~ 300 K (Habitable Zone)

• IF criterion stands ➪ wonderful situation:

life can be searched for by remote sensing

➪ **Goal ❷ : astrobiology**

Input catalogue

• Signal to Noise Ratio

$$(t_{int})_{\star\ \text{leaks}} \sim L_\star\, D^2\, R_{pl}^{-4}$$

➨ best systems: - low $L_\star$: M and K stars
- nearby
- big planets
- no companion

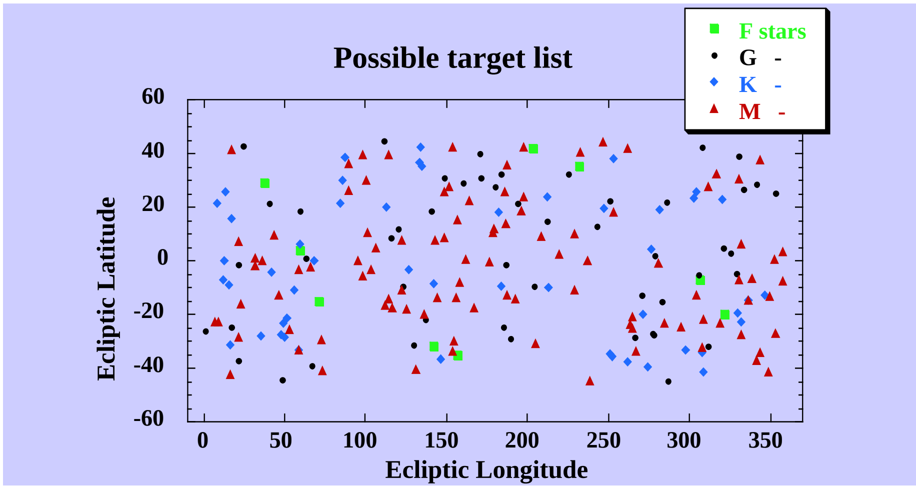
• Angular resolution

$$\theta_{pl} = 100\ (L_\star / L_\odot)^{-1/2}\ (D/10pc) \quad [mas]$$

➨ Adjustable configuration

Input catalogue

- **Possible policy:** equal allocated time / spectral type

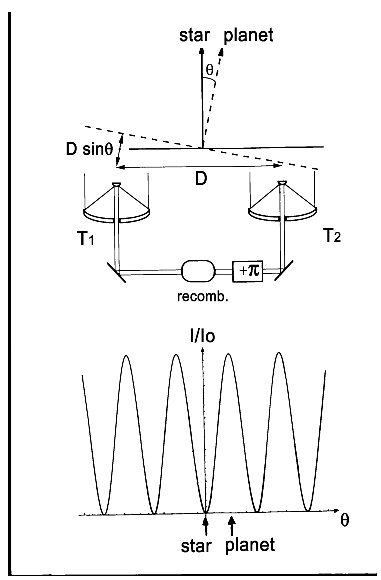


How to ?

Nulling the star light

- **At 10 pc:**

  Sun $\rightarrow m_{10\ \mu m} = 3.6$
  Earth $\rightarrow m_{10\ \mu m} = 20.7$



- **Proposed solution: Nulling Interferometer**
  e.g. Bracewell interferometer

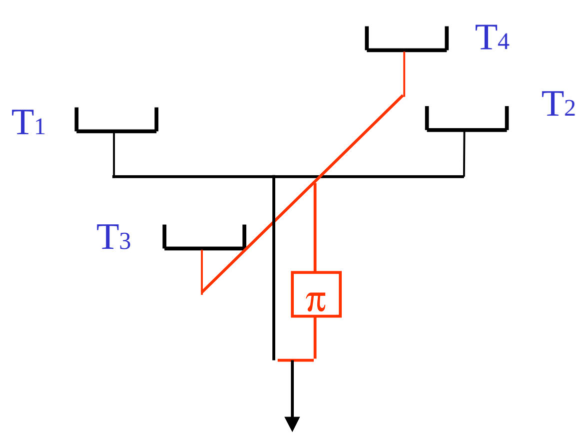
How to ?

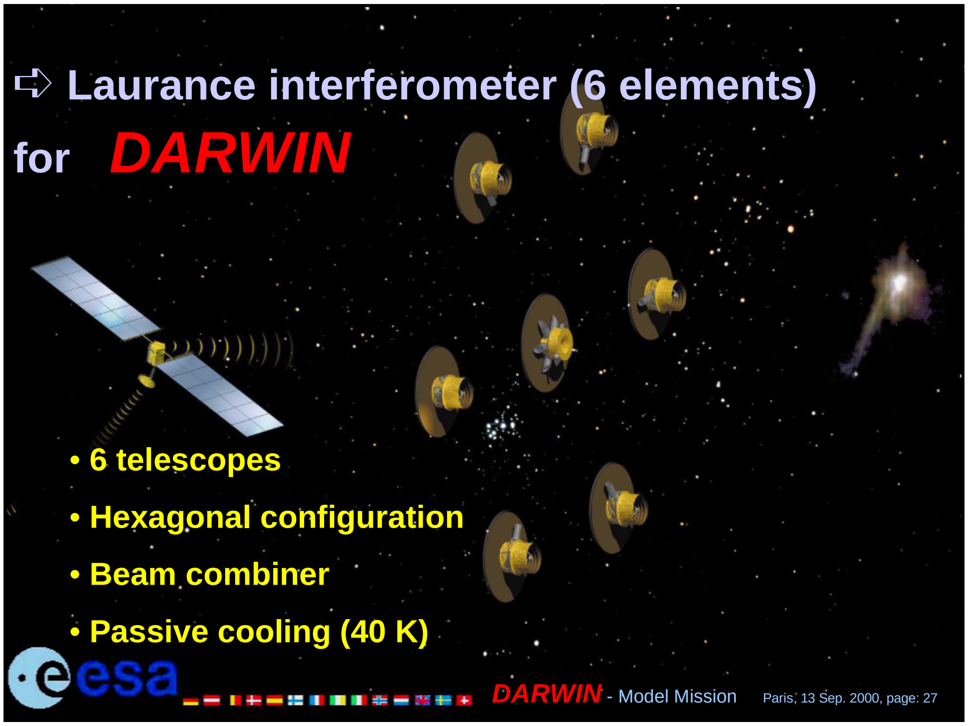
Nulling the star light

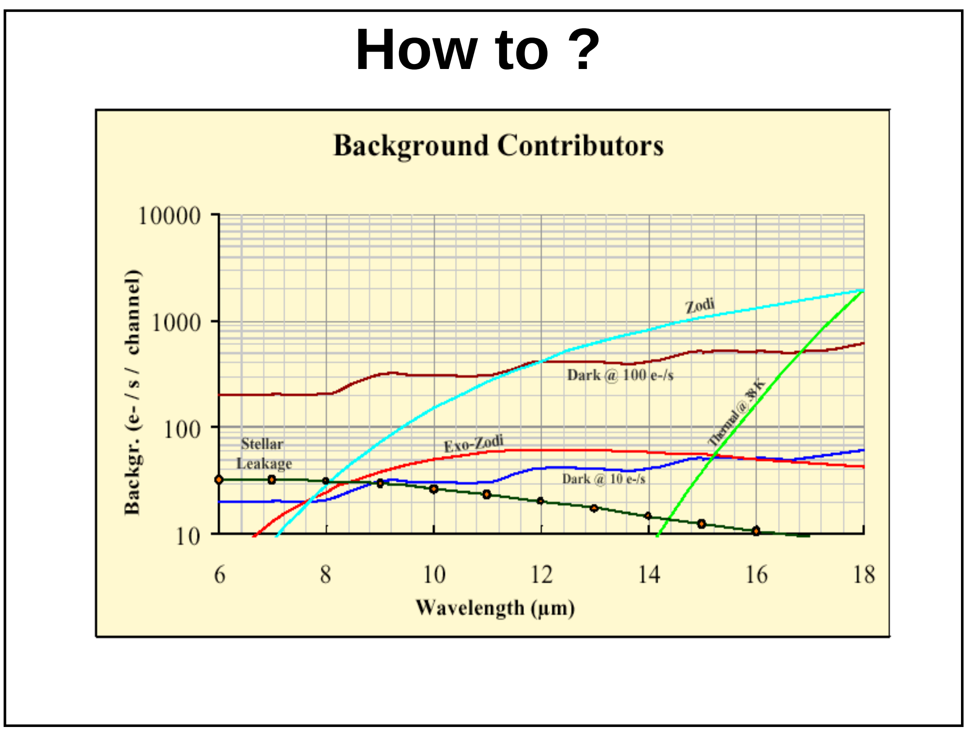
- Rejection required: $\rho = 10^5$
  - optical surfaces at λ_{vis} / 5 **if** optical filtering
  - achromatic phase shifting
  - flatter null $\theta^2 \rightarrow \theta^4$
  - internal modulation

How to ?

- 4 telescope interferometer (R.Angel, 1989)




Laurance interferometer (6 elements)
for DARWIN
• 6 telescopes
• Hexagonal configuration
• Beam combiner
• Passive cooling (40 K)
esa
DARWIN - Model Mission
Paris, 13 Sep. 2000, page: 27


How to ?
Background Contributors
10000
1000
100
10
Backgr. (e- / s / channel)
6
8
10
12
14
16
18
Wavelength (µm)
Zodi
Dark @ 100 e-/s
Thermal @ 38 K
Stellar
Leakage
Exo-Zodi
Dark @ 10 e-/s

How to ?

- **Noise (1)**

Earth + Sun at 10 pc, λ = 10 μm, $\lambda/\Delta\lambda$ = 20

	$e^{-}\ s^{-1}$ channel^{-1}
Planet	0.14
Solar Zodi	140
Exo-Zodi	45
Stellar leaks	$30 * 10^{5} / \rho$

⇨ **background noise must be controlled**

How to ?

- **Noise (2)**

sources: **- shot noise from mean value**

- variation of instantaneous values

e.g. stellar leaks:

$$\sigma_{*\ \mathrm{leaks}} = [\ 1/\langle\rho\rangle\, I_{*} + P_{(1/\rho)}(\nu_o)\, I_{*}^{2}\ ]^{1/2}\ t^{1/2}$$

shot noise **Power Spectral Density**

How to ?

Noises (3)

- internal modulation ($\nu_o \nearrow$)

⇨ - ρ high and stable (ν_o)

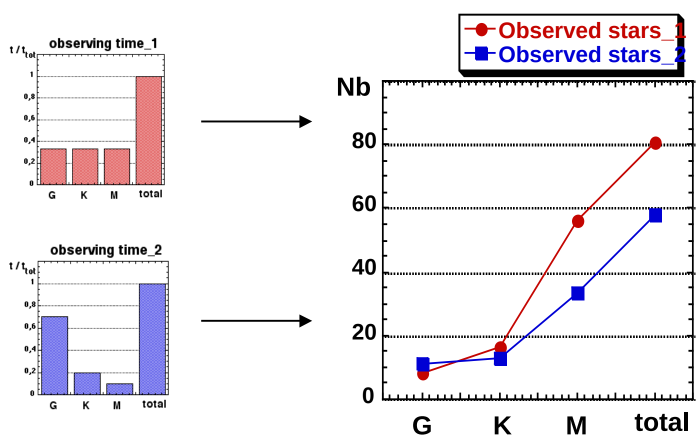
- detector response stable (ν_o)

Expected detections

- $\mathbf{N}_{\mathbf{star}} \sim \Phi^{1.71} \quad \mathbf{t}^{\,0.43}$
- **Possible strategies**

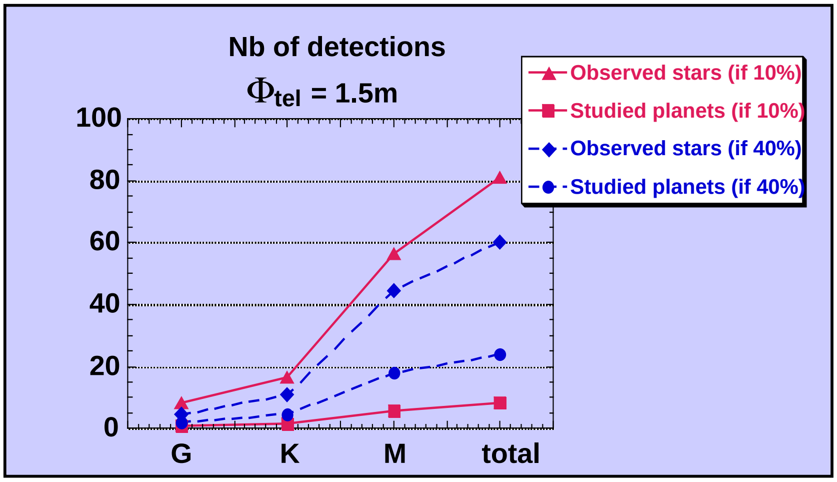
1.

2.



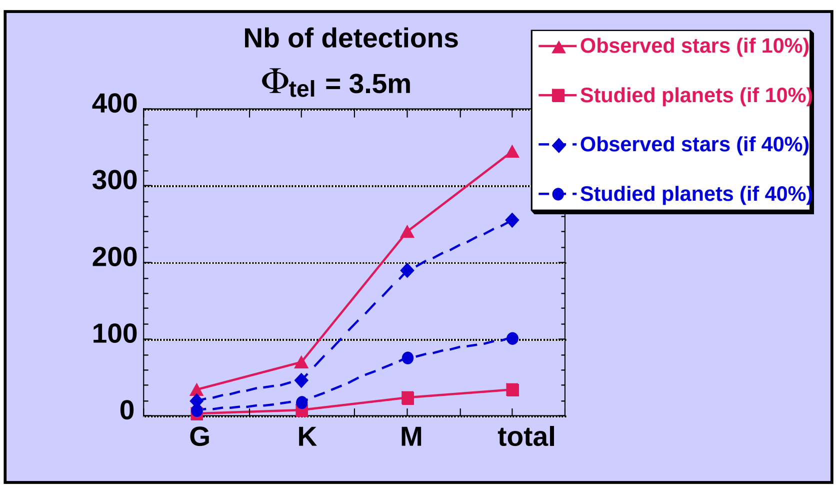
Expected detections

Two scenarios: **10% stars have telluric planets**
40% stars have telluric planets



Expected detections

- **The case for larger telescopes: 1.5 m → 3.5 m**



Conclusion

DETECTION AND

CHARACTERISATION OF

EARTH-LIKE PLANETS IS

INDEED POSSIBLE

Darwin and Astrophysics

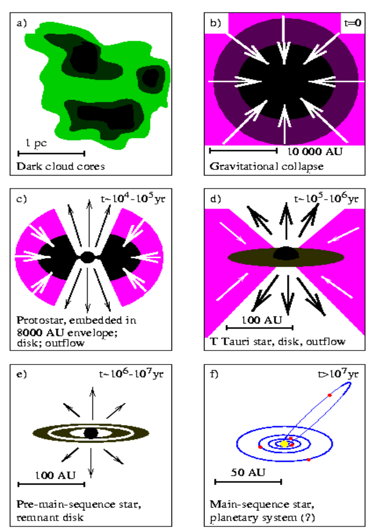
- Imaging performance
- Physical processes
- The BIG questions: formation of
  - Stars and planets
  - Massive black holes
  - Galaxies
- Conclusion

Imaging Performance

- Sensitivity
  - comparable to NGST at $\lambda = 10\ \mu m$
    - 1 hour, S/N = 5: 2.5 μJy (for an unresolved point source)
    - "Image requirement", 1 hour > 25-50 μJy
- Resolution
  - 10-50 times better than NGST at $\lambda = 10\ \mu m$
  - 100m baseline ==> 20 mas resolution
- Field of View: 1 arcsec
- Mapsize: ~ 50 x 50 independent pixels

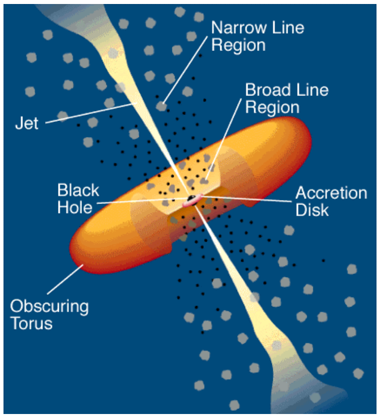
Star and Planet Formation

- Solar system would subtend > 25 resolution elements at 140 pc:
  - Physics of infall, disk and jet formation?
  - Role of binary stars?
  - When and how do planets form?
  - How common is planet formation?



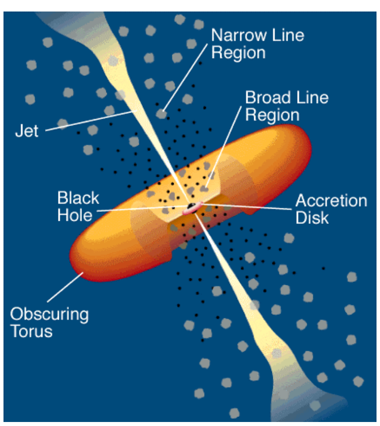
Hogerheijde 1998, after Shu et al. 1987

Active Galactic Nuclei



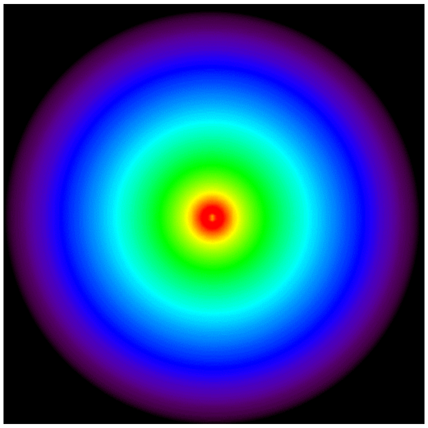
- **Zoo**: Seyferts, Startbursts, Quasars..
- **Building blocks**: synchrotron plasma, jets, tori, broad+narrowline regions, accretion disks. Physics?
- **Unification**: How? orientation, time-evolution, BH-mass, spin BH, environment

Active Galactic Nuclei



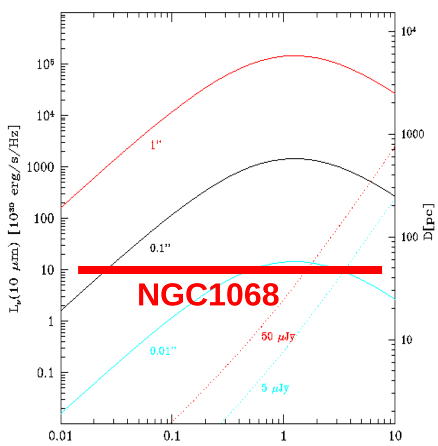
- 1000 times more AGN at **$z = 2$** than at **$z = 0$**. Why?
- Every galaxy has a **central massive Black Hole**. Why?
- When and how do Black Holes **form**? Relation to Galaxy formation?

Models of Dusty Tori



- **AGN may contain dusty tori**
  - **can obscure the central QSO**
  - **feeds the massive Black Hole**
- **Radiative transfer model of a dusty torus**
  - **size scales with QSO luminosity**
  - **SED from λ = 1 - 300 μm**
  - **morphologies at λ = 10 μm**

Observing Tori

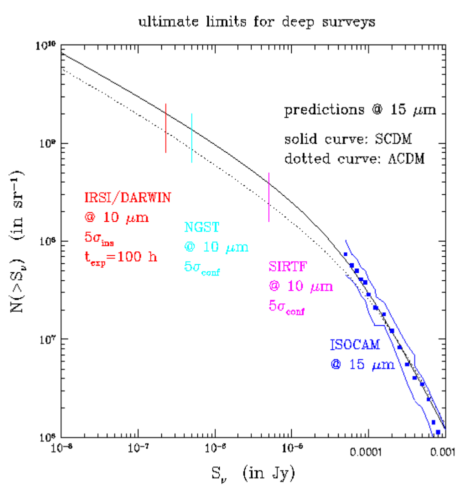


- NGC1068:
  - weak AGN: 1.7$\times$ 10^{31} erg/s/Hz at λ = 10 μm
- **Weak AGN** observable up to **z = 1 - 2**
- **Stronger AGN** up to **z = 10**

Distant Galaxies

- About 1000 observed @ 3 < z < 6
- Issues
  - When do the first stars form?
  - How do they settle into galaxies?
  - When do galaxies obtain their typical profiles?
  - Why are there ellipticals and spirals?
  - Role of dust / supernovae / AGN activity?
- **2 µm** rest frame (peak stellar emission) observed @ **10 µm** for **z = 4** galaxy

Galaxy Formation Models



Guiderdoni et al.

- **Input**

  Cold dark matter, gravity, hydrodynamics, gas cooling, dust, star formation, feedback
- **Results**

  At Darwin limit:
  few hundred / arcmin^2

  Angular sizes good match to Darwin's resolution

Conclusion

- Unique capabilities:
  - High spatial resolution AND sensitivity
  -
- Direct imaging and spectroscopic studies of the formation of
  - Stars and planets
  - Massive black holes
  - Galaxies

Roadmap

QuickTime™ et un décompresseur Cinepak sont requis pour visualiser cette image.