# Performance study of space-based Bracewell interferometers

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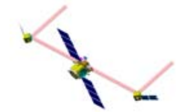
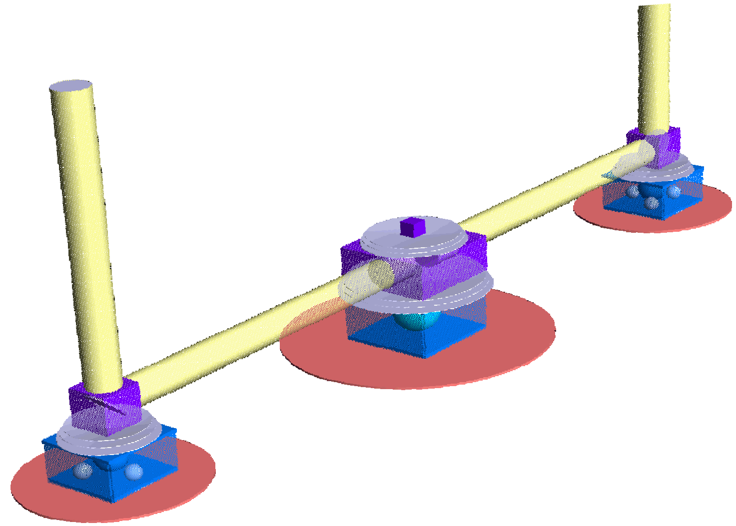
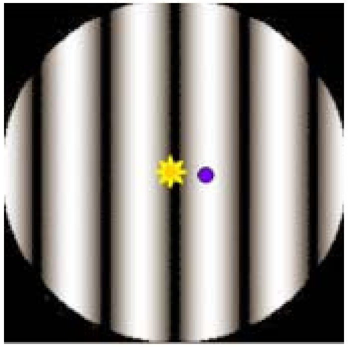
# 1. Pegase, a single Bracewell interferometer

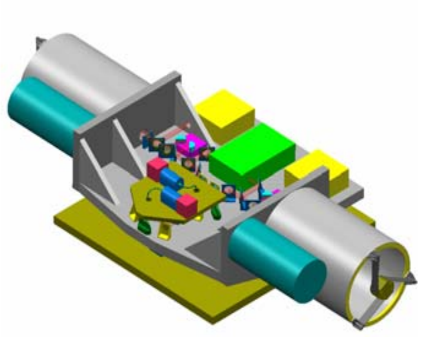




- Description
  - ✓ Simplest scheme for a nuller
  - ✓ CNES formation flying demonstrator
  - ✓ 40 cm diameter collectors
- What Pegase will be able to do ?
  - ✓ IR spectral analysis of Hot Jupiters
  - ✓ IR spectral analysis of brown dwarfs
  - ✓ Formation areas (140 pc)

| Pegase specifications | |
|---|---|
| Telescope diameter [m] | 0.4 |
| Wavelength [μm] | 2.5 - 5 |
| Spectral resolution | 60 |
| Instrument temperature [K] | 100 |
| RMS temperature fluctuations [K] | 1 |
| RMS OPD error [nm] | 2.5 |
| RMS pointing error [mas] | 30 |





# 2. Detecting an Earth with a single Bracewell ?

- What can be done with a more advanced Bracewell ?
  - ✓ 1 m diameter collectors
  - ✓ Operating at 10 μm
- Main requirements for SNR=5
  - ✓ Instrumental leakage (at first order)
    - OPD: $N_{OPD} = \frac{1}{4}\left(\frac{2\pi\sigma_{OPD}}{\lambda}\right)^2 \longrightarrow \sigma_{OPD} = 0.47$ nm
    - Tip/tilt: $N_{t/t} = \frac{(\pi D \sigma_\theta)^4}{64\lambda^4} \longrightarrow \sigma_{t/t} = 22.5$ mas
  - ✓ Integration time 3000 days !
  - ✓ Exo-zodi subtraction
    - Ratio planet/exo-zodi ~ 1/420 (Kelsall model)
    - Exo-zodi subtraction: 99.95 %

| Target system | |
|---|---|
| Distance | 20 pc |
| Star radius | 1 Rsun |
| Star eff. Temperature | 5770 K |
| Planet radius | 1 Rearth |
| Planet albedo | 0.39 |
| Planet eff. Temperature | 265 K |
| Exo-zodi dust mass | 1 solar zodi |
| Exo-zodi inclination | 60° |

Detecting an Earth with a single Bracewell ?

# Mission specifications - results

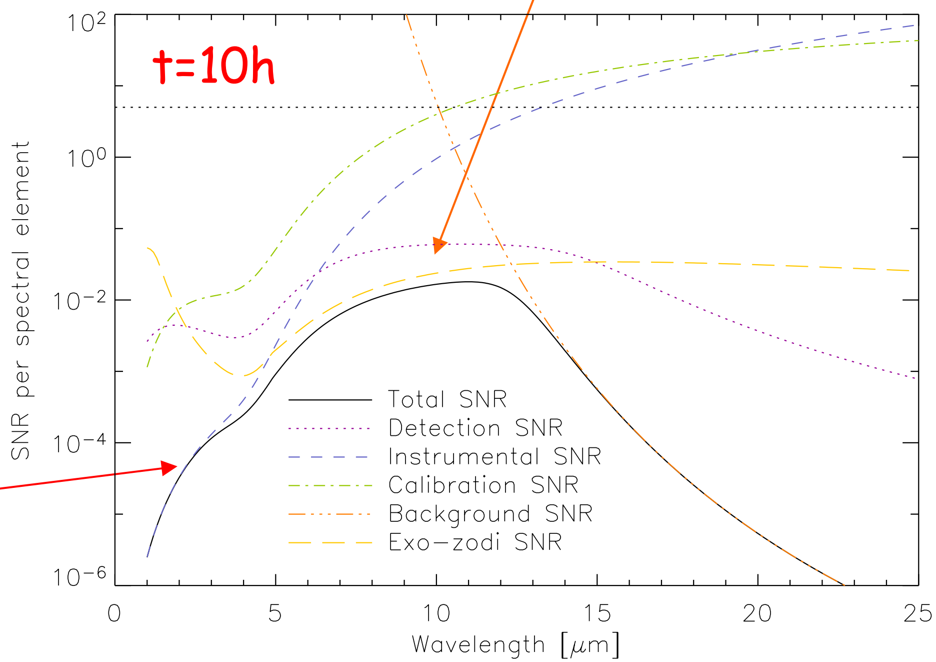
- Mission requirements and specifications

| | Req. | Spec. | Rmin |
|---|---|---|---|
| OPD [nm] | 0.47 | 1 | 2.1 |
| Tip/tilt [mas] | 22.5 | 20 | 0.8 |
| Stellar diamater [%] | 0.8 | 1 | 1.1 |
| Residual EZ [%] | 0.05 | 10 | 11.2 |
| Instrument temperature [K] | 45.3 | 45 | 1 |
| Integration time | 3000 d | 10 hours | 7.2 |

~ 50 surveys/year

5-13 μm
Residual Exo-zodi dominates

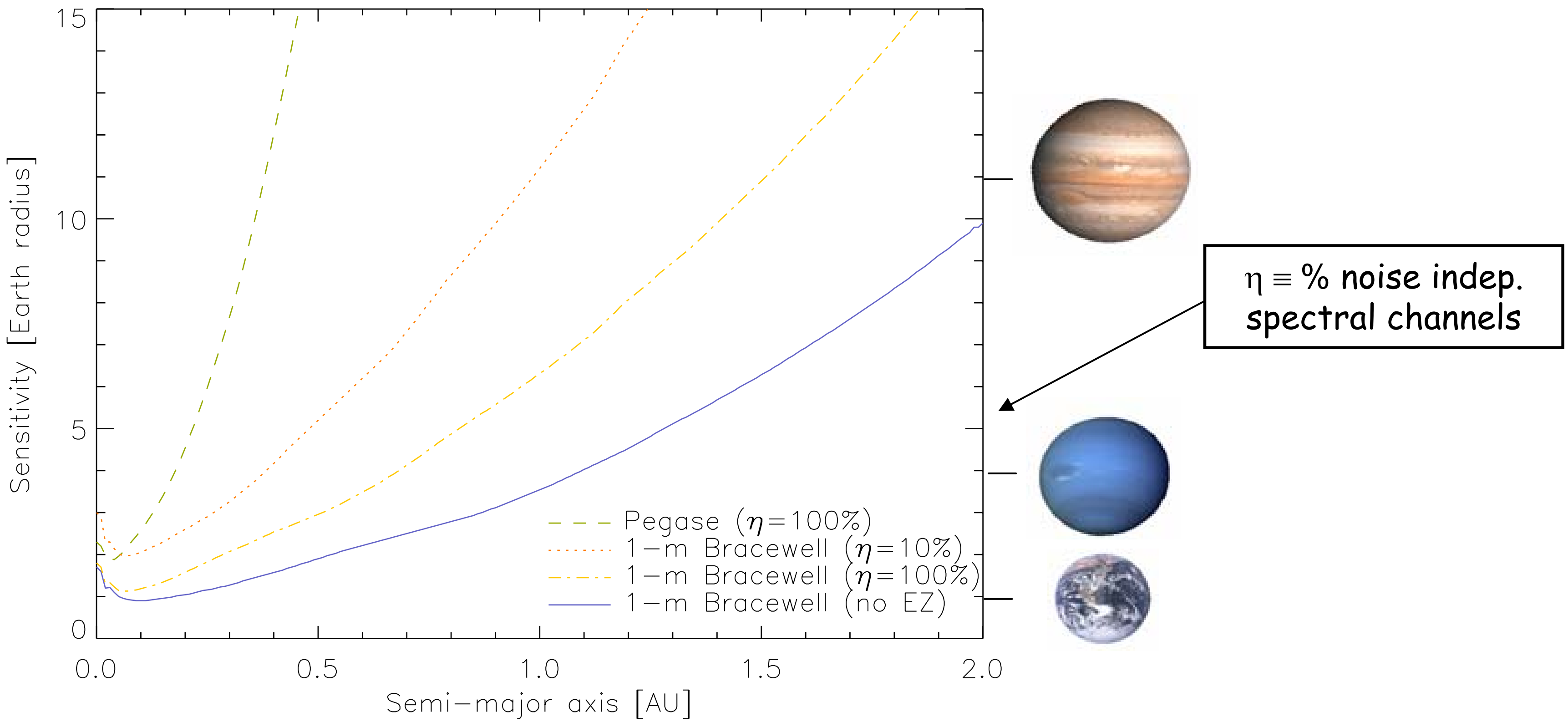
0-5 μm
Instrumental leakage dominates




- Can detect a Jupiter-size planet in the middle of the HZ
- Can be improved by combining the spectral channels

# 3. Detection threshold

- Results for 10 hours integration time (Sun at 20pc)

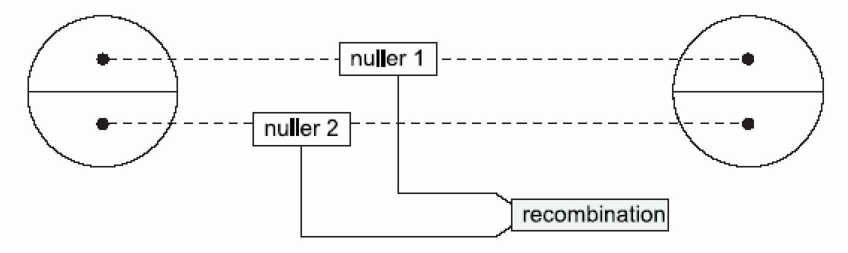


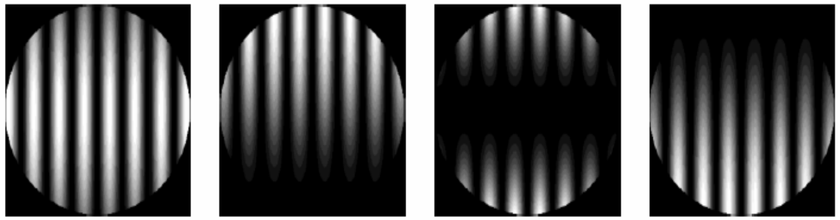

- In the HZ, can detect a 6 Earth-radii (potentially a Neptune-size) planet
- Full potential required fast modulation techniques

# 4. Removing the EZ emission

## A. Split-pupil method (cf. *Serabyn et al., Proc SPIE, vol 4006, 328-339*)

- EZ flux dominates (420x brighter for an Earth at 20 pc)
- Split-pupil configuration :
  - ✓ 2 nullers with 2 orthogonal systems of fringes
  - ✓ No need to calibrate the geometric leakage



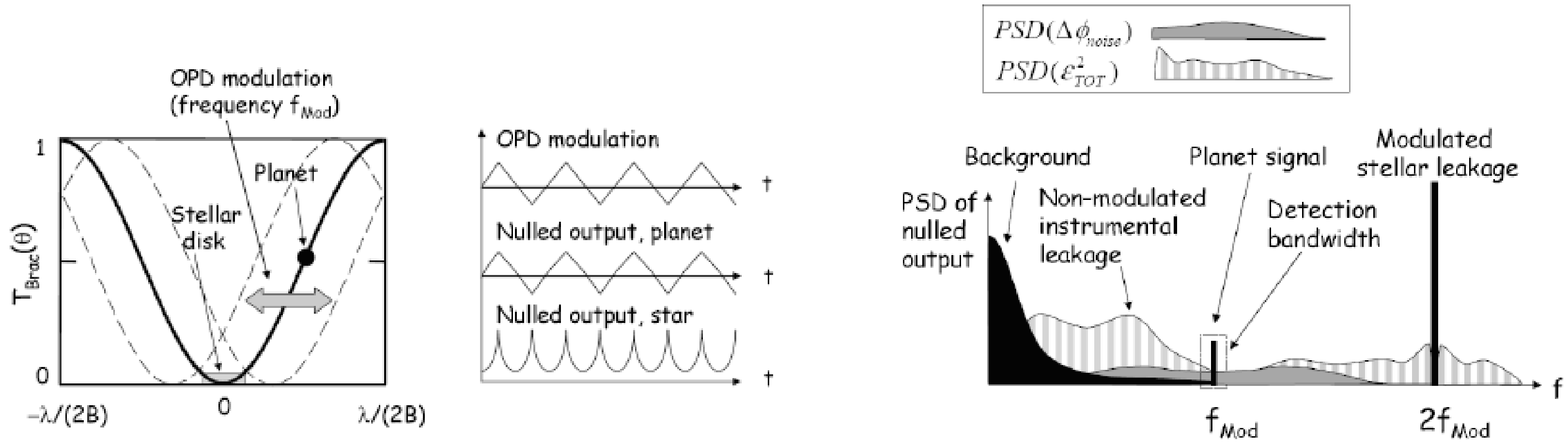
**If symmetric, exo-zodi perfectly subtracted**

Removing the EZ emission

# OPD modulated Bracewell

## B. OPD modulation (cf. *D'arcio et al., Proc SPIE, vol 5491*)

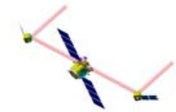
- How does it work?
  - ✓ Sweep back and forth the dark fringe of the TM at frequency $f_{mod}$
  - ✓ The planet is modulated at frequency $f_{mod}$
  - ✓ The star and the exo-zodi are modulated at $2f_{mod}$




**If symmetric, exo-zodi perfectly subtracted**

Removing the EZ emission

# Performance of the methods



• Instrumental errors and any asymmetric emission of the cloud decrease the performances (for an Earth at 20 pc):

1. Offset and inclination of the cloud
   - Offset of the cloud due to giant planets
   - For our cloud, offsets = 0.0119 and 0.00548 AU
   - 60° inclination
   - Optimal contrast planet/residual EZ at 10 μm :
2. Instrumental errors
   - Include also the asymmetry of the cloud
   - Optimal contrast planet/residual EZ at 10 μm including and OPD error of 1 nm :

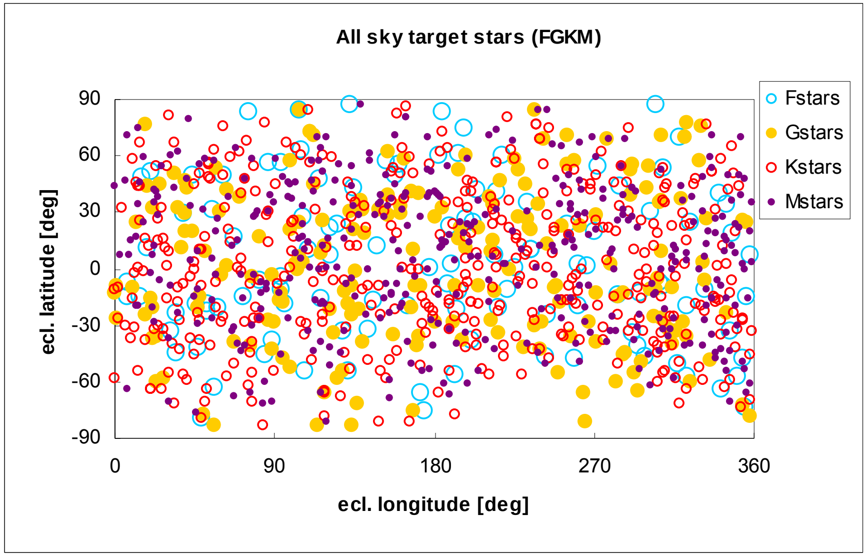
| | Split-pupil | OPD mod. |
|---|---|---|
| 1. Optimal contrast planet/residual EZ at 10 μm | $F_p/\sigma_{EZ} \sim 50$ | $F_p/\sigma_{EZ} \sim 1.6$ |
| 2. Optimal contrast planet/residual EZ at 10 μm including and OPD error of 1 nm | $F_p/\sigma_{EZ} \sim 9$ | $F_p/\sigma_{EZ} \sim 1.4$ |

• Both methods allow to subtract EZ emission below the dominant noise contributor for most Darwin targets

# 5. Study of the HZ: application to the Darwin catalogue

- Assume that EZ emission efficiently removed by previous methods
- Compute integration time for all Darwin catalogue (Nov. 2005):
  - ✓ 628 targets
  - ✓ Close part of the galaxy (< 25 pc)

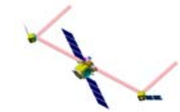
| prime targets | | |
|---|---|---|
| Spec. Type | all ecl. latitudes | +45/-45 |
| F | 43 | 29 |
| G | 100 | 69 |
| K | 244 | 164 |
| M | 241 | 185 |
| sum | 628 | 447 |




- Including 3 inclined observations and 50% of the time for manoeuvrings
- If planet, ephemeris unknown:
  - ✓ Need to observe at least 3 times along the orbit
  - ✓ 90% confidence in non-detection

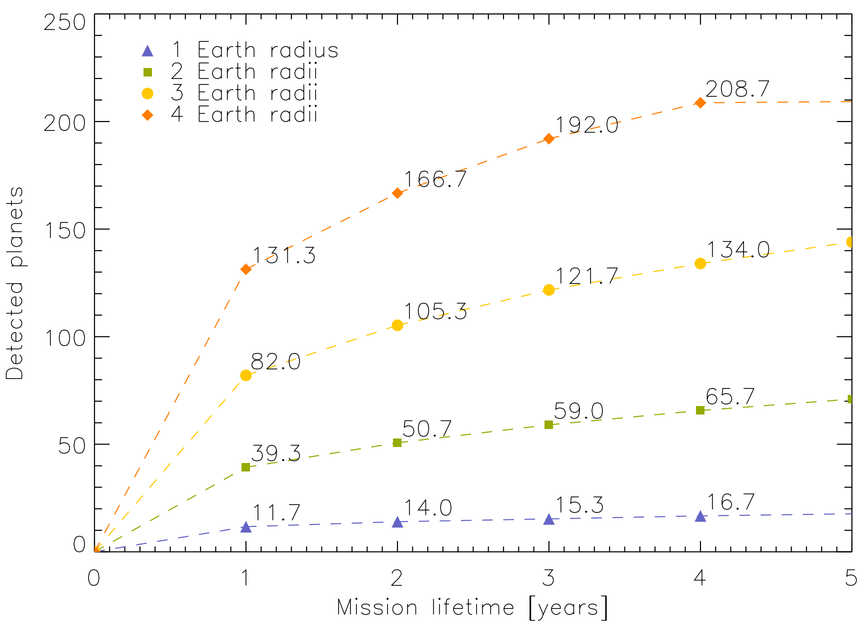
Study of the HZ: application to the Darwin catalogue

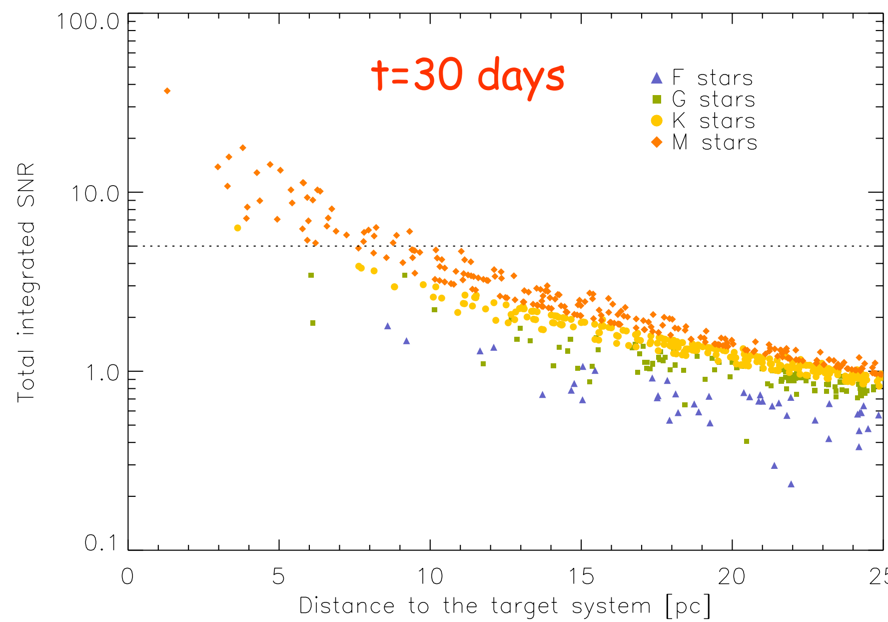
# Performance estimation



Number of stars around which a planet of X Earth radii can be detected (if present) during the mission lifetime

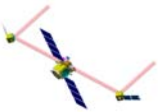
Total SNR for each target of the Darwin catalogue with respect to the distance from the Sun and for an Earth-like planet




- Could detect 12 Earth like planets the first year around closest M stars
- Necessary to survey Neptune-size planets to have good statistics

# 6. Conclusions



What's the messages ?

- A single 1-m aperture Bracewell could
  - ✓ detect in the HZ a 6 Earth-radii planet at 20 pc within 10 hours
  - ✓ go to Neptune-size planets in the HZ with split-pupil or OPD modulation
  - ✓ detect about 12 Earth-like planets around closest M and K stars of the Darwin catalogue within 1 year
- These preliminary results need to be confirmed by detailed simulations, taking particularly into account second order effects of the instability noise