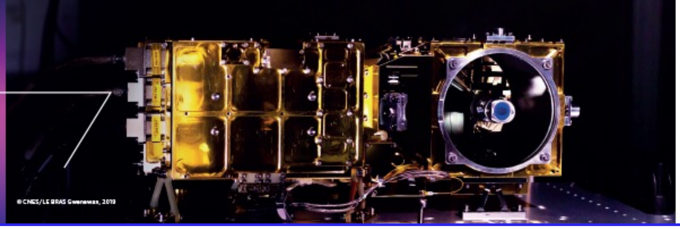

FEASIBILITY STUDY OF AN INTERFEROMETRIC SMALL-SAT TO STUDY EXOPLANETS

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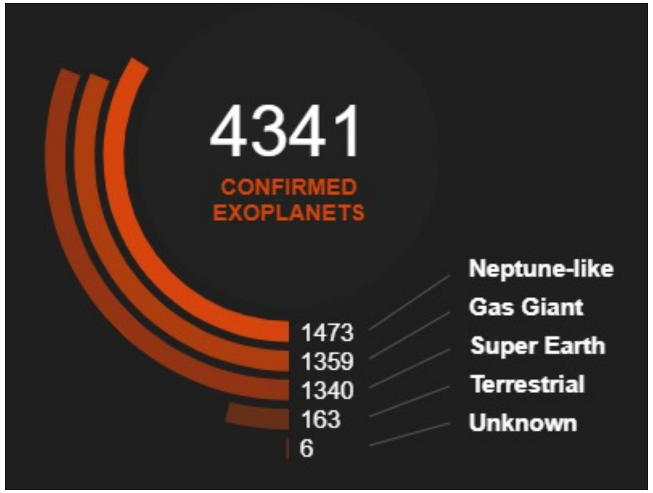
INTRODUCTION



Credit: NASA Exoplanet

Credit: LIFE space mission

- More than 4300 known and confirmed exoplanets
- More than 5700 still waiting confirmation

↓

Next step: Spectral characterization & search for biosignatures (rocky planets in the habitable zone)

↓

Solution: Mid-infrared space-based nulling interferometer

↓

LIFE space mission
(Large Interferometer for Exoplanets)

INTRODUCTION

LIFE space mission:

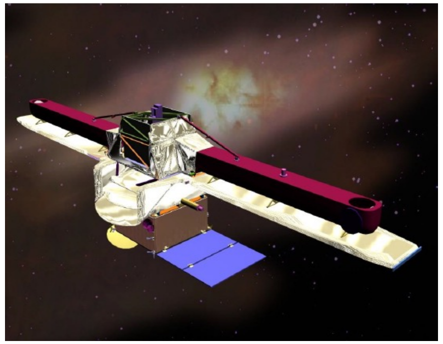
- L-class mission
- Free-flying interferometer
- Earth-Sun L2 point
- Yield: > 500 exoplanets & **10-20 Exo-Earth** (Quanz et al. 2021, submitted)
- Voyage 2050 (Quanz et al. 2019)

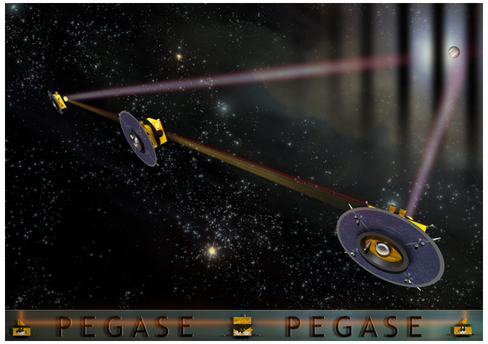
Precursor!
=
Small satellites with **scientific capabilities**

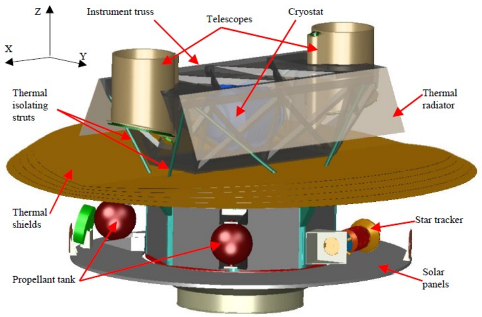
Ideal starting point!

In 2000's, Darwin and TPF-I

- **PEGASE** (Europe)
- Fourier-Kelvin Stellar Interferometer (**FKSI**, US)
- Cold Interferometric Nulling Demonstration in Space (**CINDIS**, US)







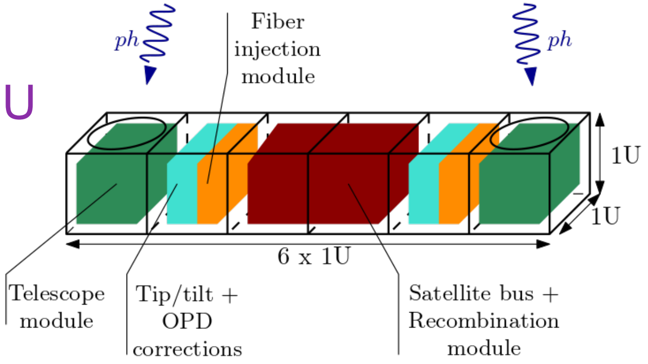
Credits: Danchi et al. 2004 CNES Noecker et al. 2003

INTRODUCTION

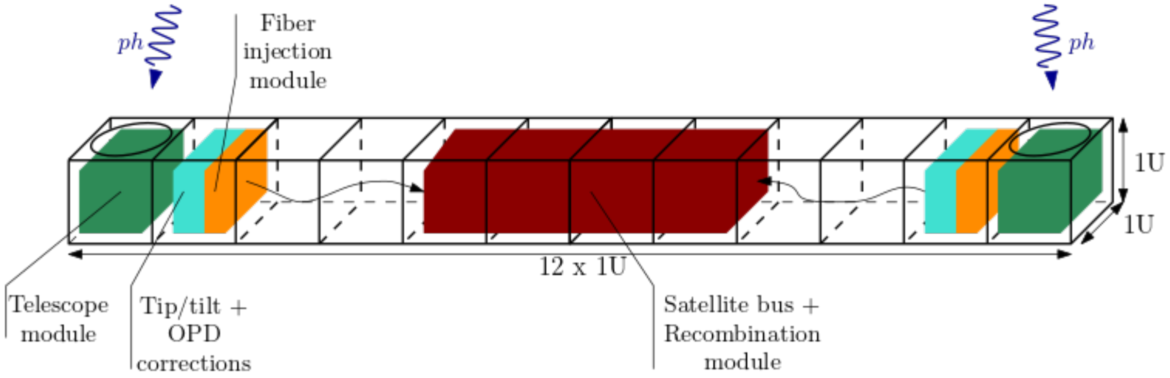
Precursor = Small satellites
with scientific capabilities

- **Goal:** Demonstrate inteferometry in space
- No free-flying (pupils same spacecraft)
- Cost-effective
- Emergence of astronomical CubeSats (PicSat, ASTERIA, CUBESPEC, CUTE)
  - Shkolnik 2018 & Serjeant et al. 2020

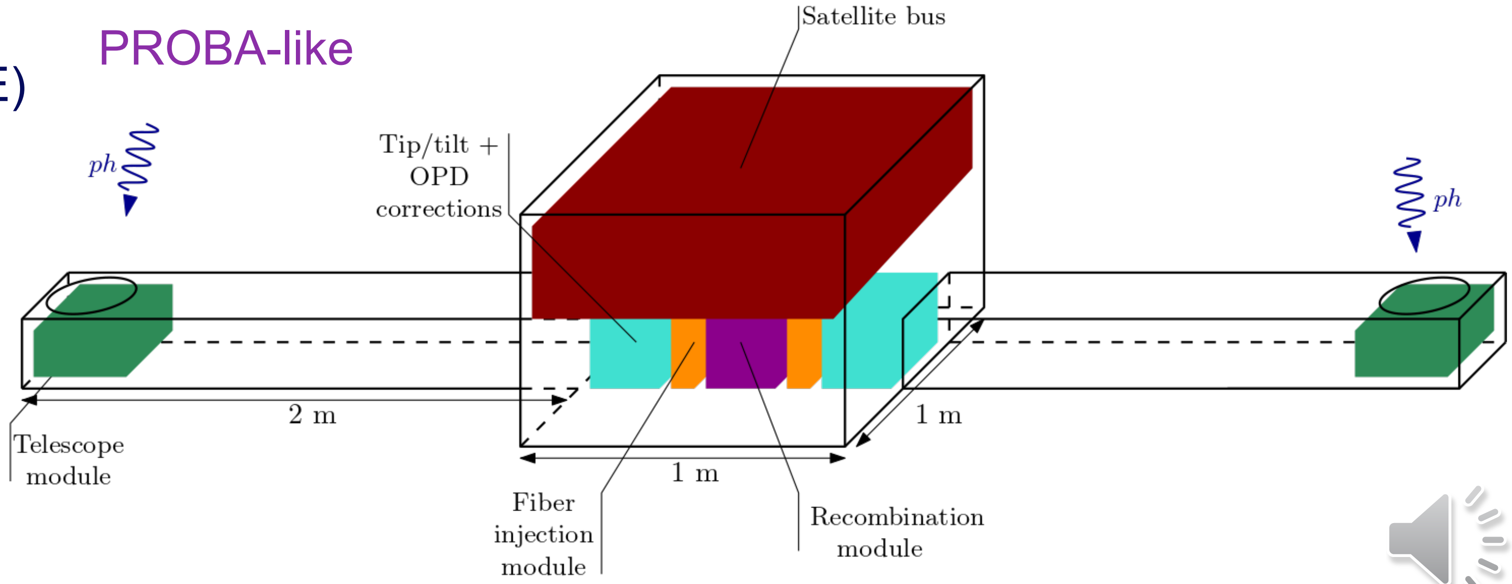
CubeSat 6U



CubeSat 12U

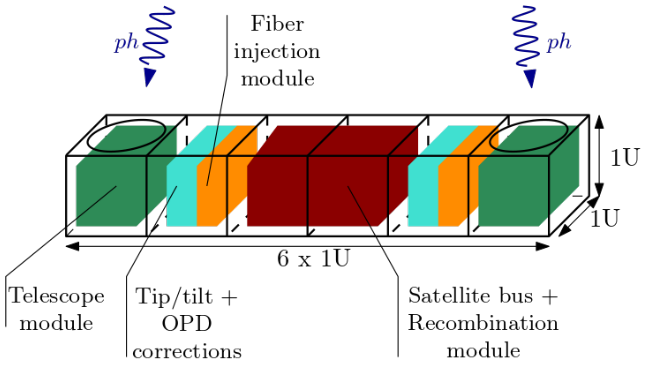


PROBA-like



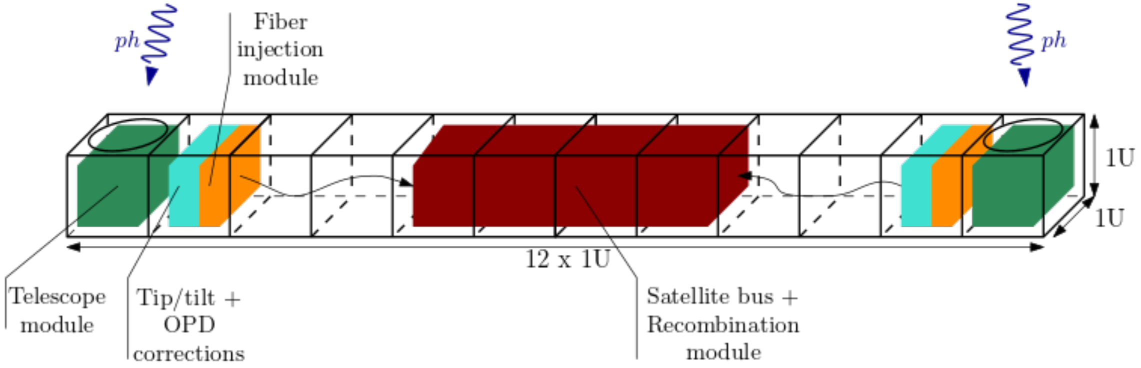
MISSION ARCHITECTURE

CubeSat 6U



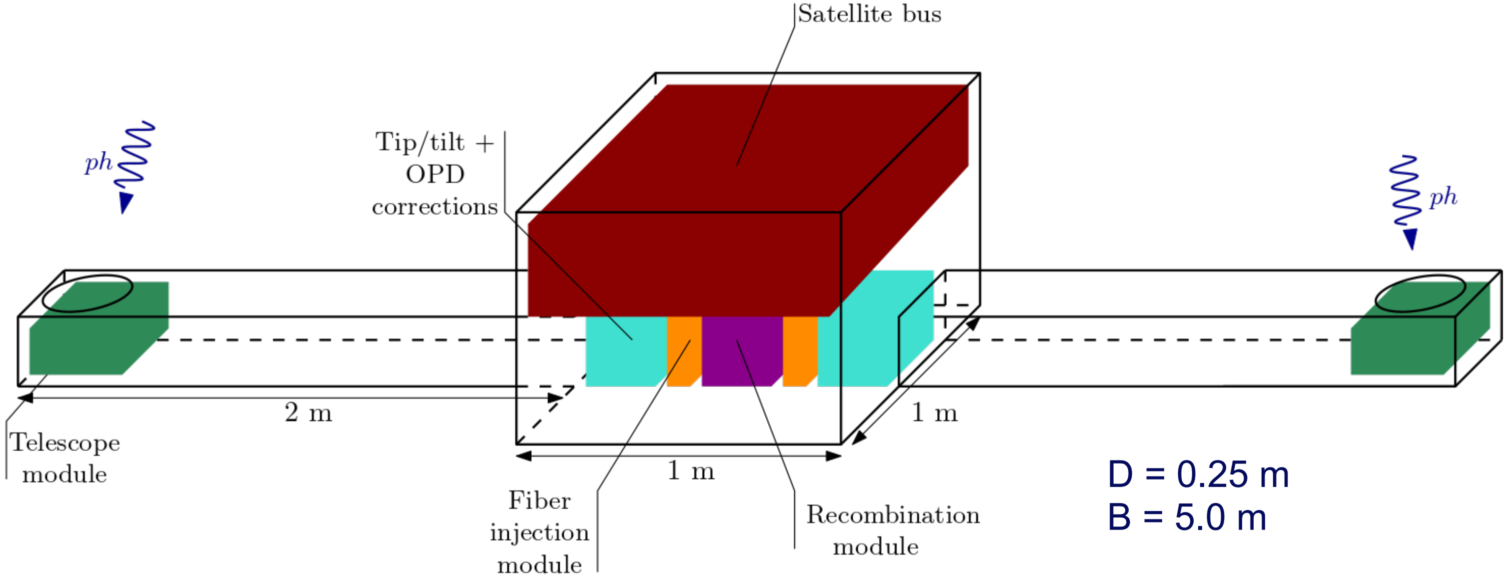
D = 0.08 m
B = 0.5 m

CubeSat 12U



D = 0.08 m
B = 1.0 m

PROBA-like



D = 0.25 m
B = 5.0 m

SCIENTIFIC OBJECTIVES

Precursor!

=

Small satellites with
scientific capabilities

- **Goal:** Detection of exoplanets
- No spectroscopy considered (low flux)
- Bandwidth: 1-4 µm
- Others science case can be investigated

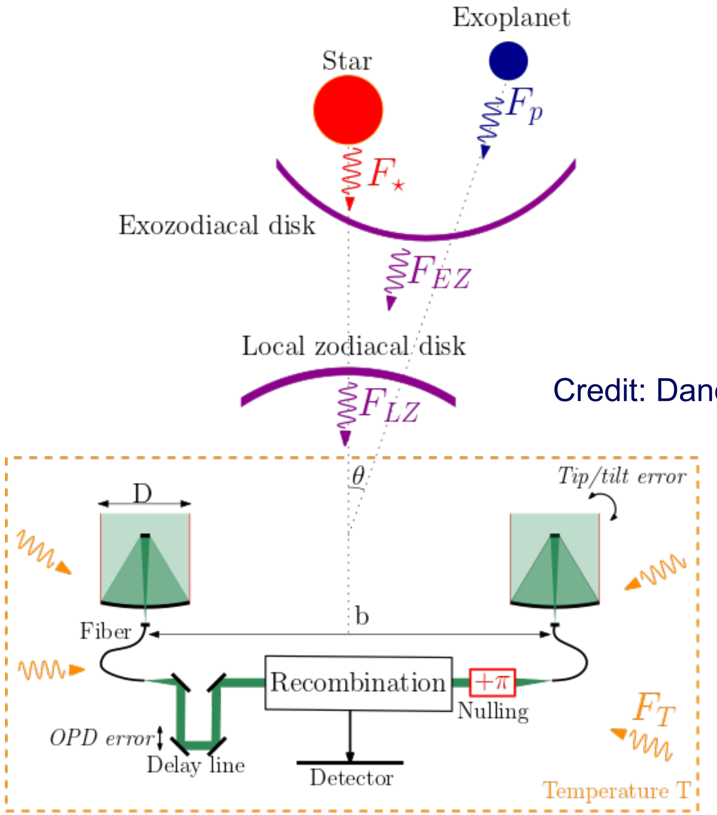
Radiometric budget:

Dandumont et al. 2020a

- Stellar and planetary fluxes
- Local zodiacal disk emission
- Exozodiacal disk emission

- Shot noise
- First-order instrumental noises

- S/N ≥ 5 to detect an exoplanet



Credit: Dandumont et al. 2020b

SCIENTIFIC OBJECTIVES

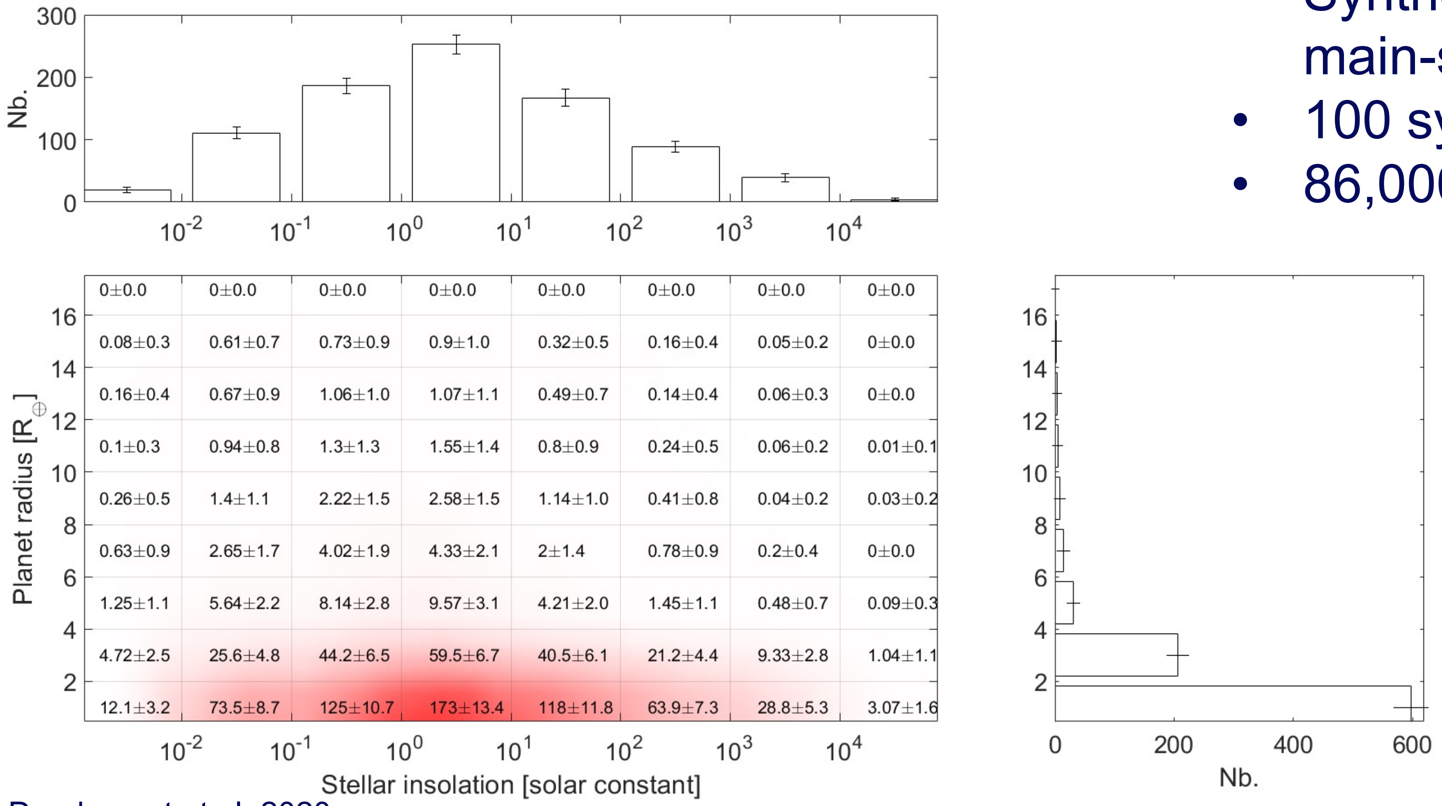
Radiometric budget

Dandumont et al. 2020a

Monte-Carlo simulation tool: P-POP

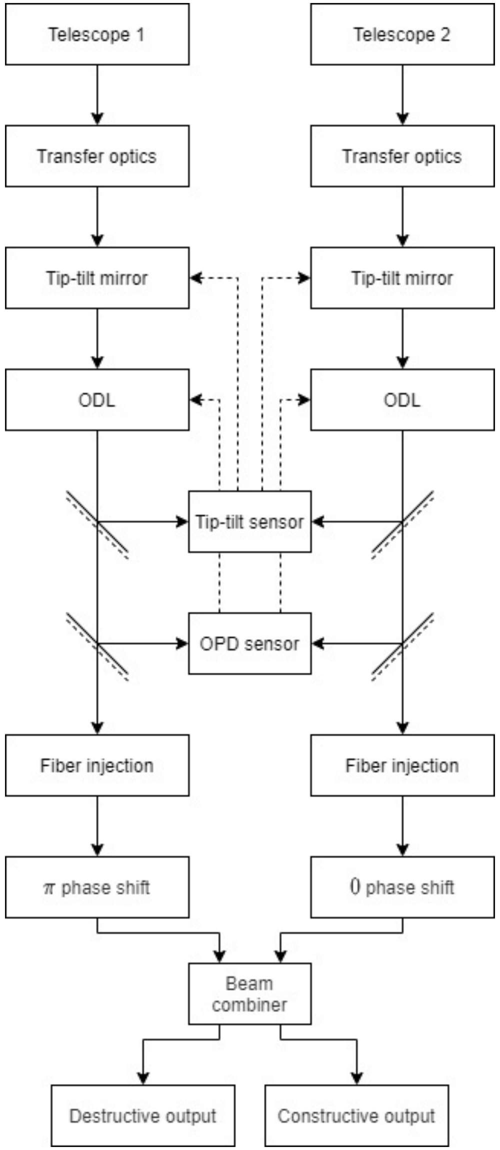
(Kammerer & Quanz 2018)

- Synthetic planet populations around 326 real main-sequence stars (< 20 pc)
- 100 synthetic universes
- 86,000 planets in total

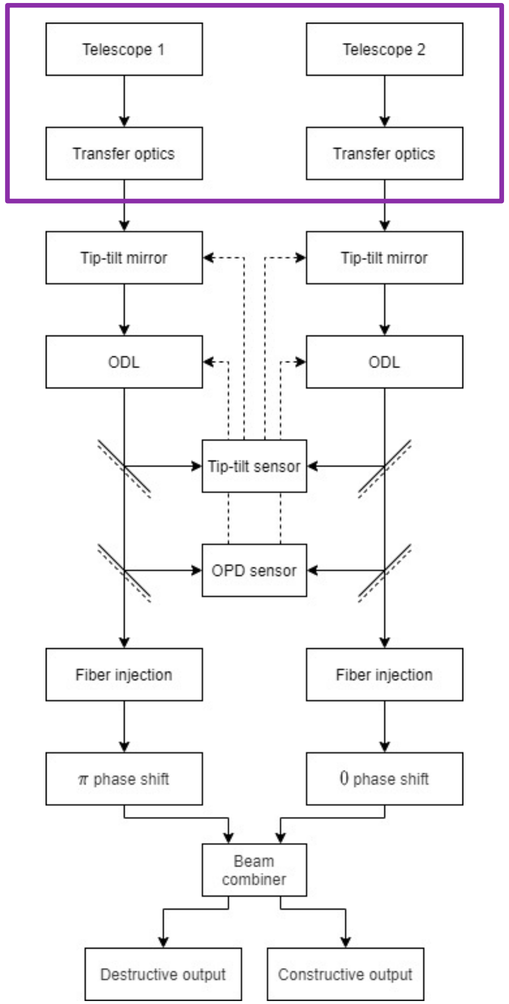


Credit: Dandumont et al. 2020a

PLATFORM REQUIREMENTS



PLATFORM REQUIREMENTS



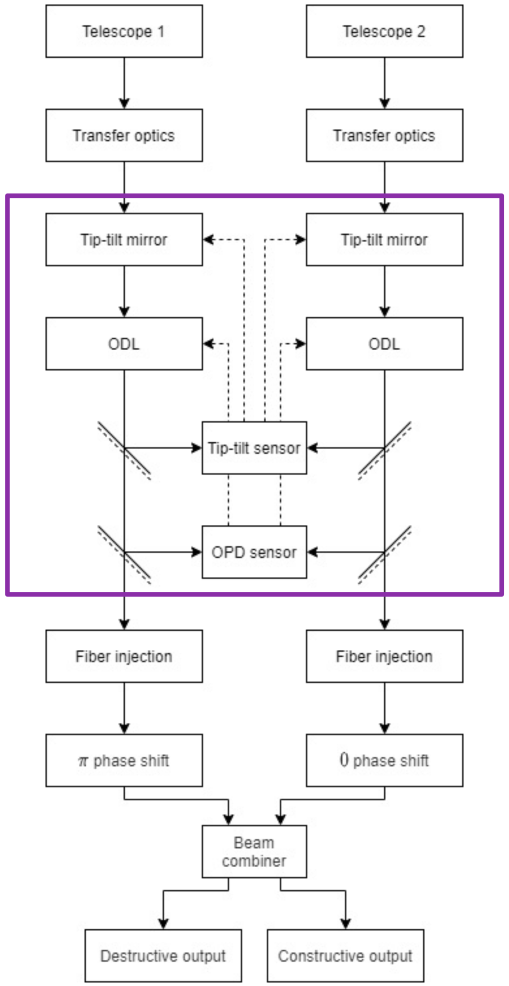
- Few photons (22 ph/s/m^2)
- Increase as much as possible the collecting area
  - CubeSats = limitation to 1U ≈ D = 8 cm (**drastic constraints**)
  - PROBA-like = less limitation ≈ D = 25 cm

- Reflective design to avoid any chromatic effects
- No central obstruction (single mode fiber injection)

- FKSI (50 cm) and PEGASE (70 x 50 cm)

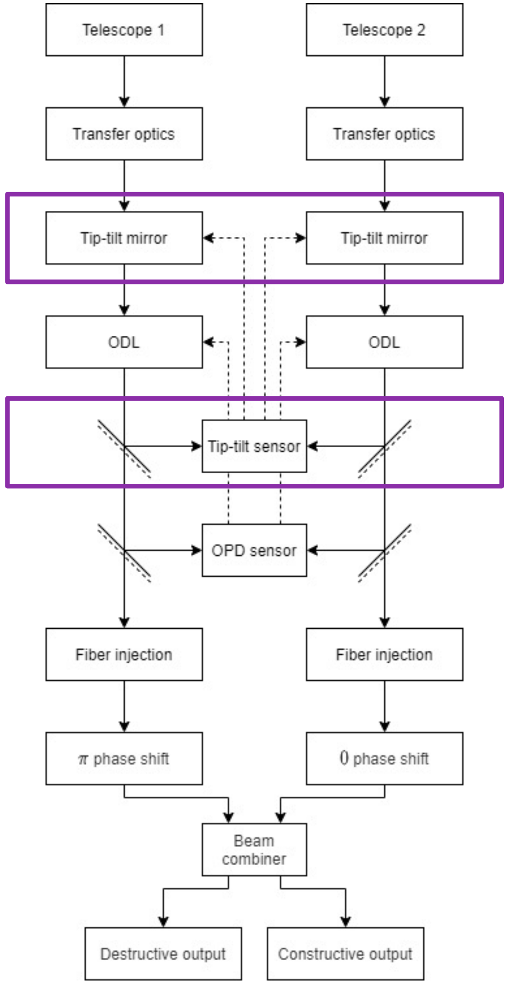
  = siderostats with beam compression

PLATFORM REQUIREMENTS

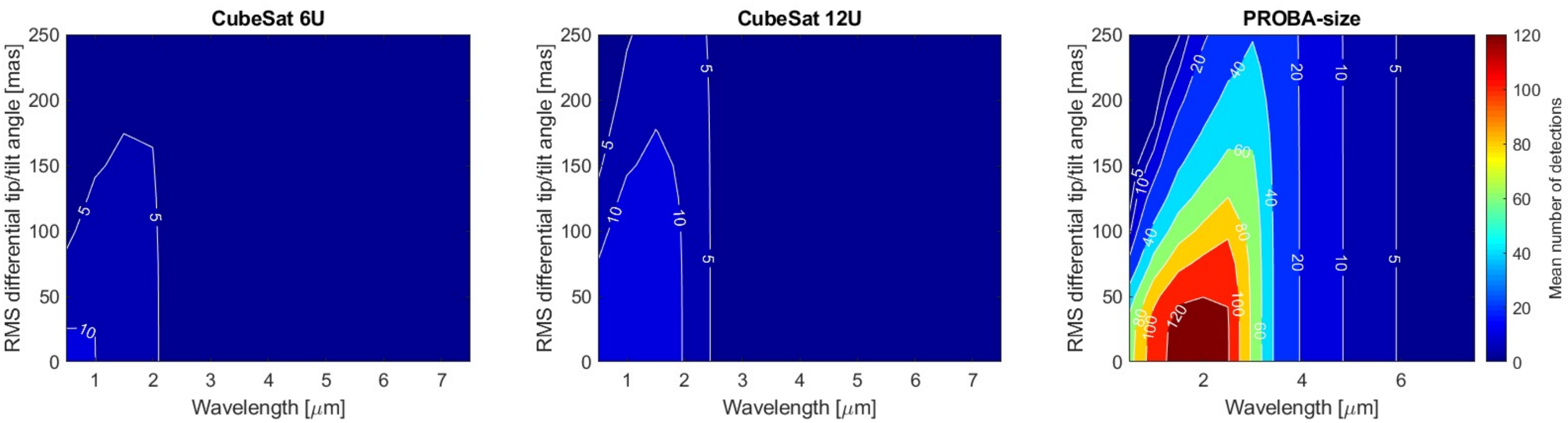


- First-order instrumental noises
- Tip/tilt = intensity imbalance
- Optical Path Difference (OPD) = phase effect

PLATFORM REQUIREMENTS



Tip/tilt errors



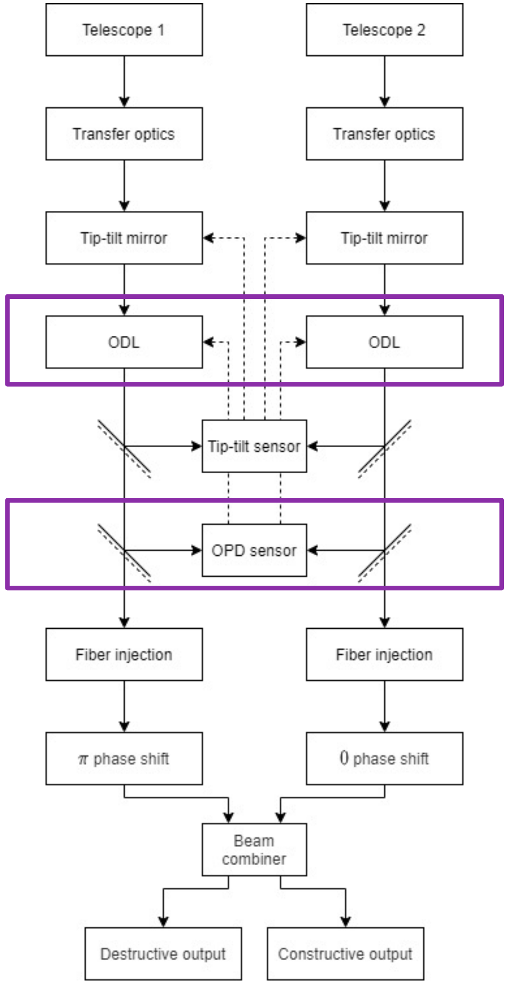
- High precision on the attitude control (pointing and jitter)
- Angle steering mirrors

- 25 mas RMS CubeSat & 35-40 mas RMS PROBA

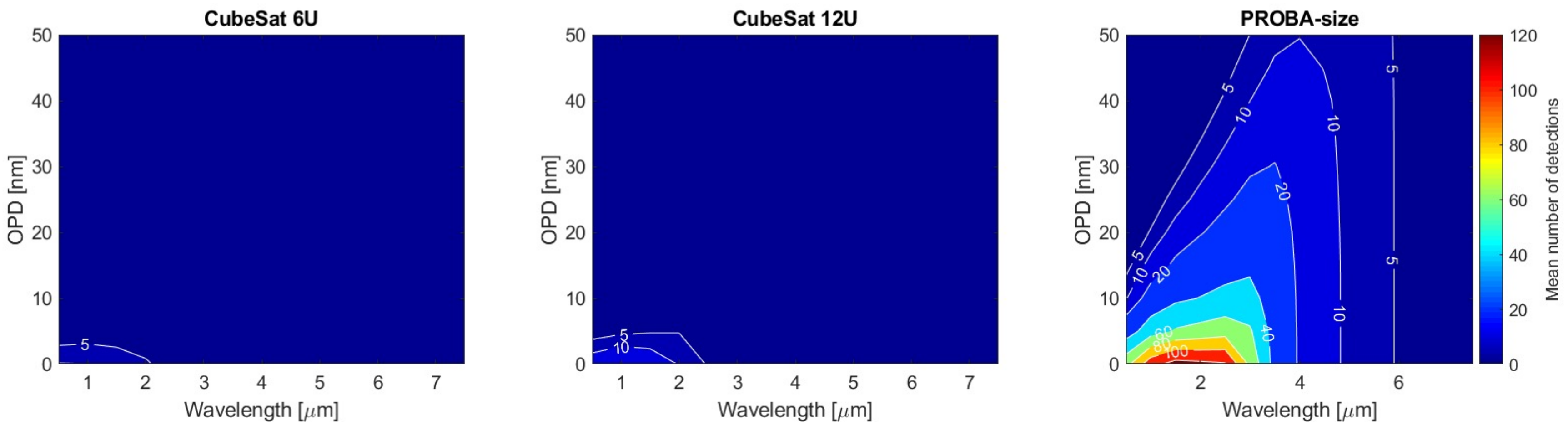
- FKSI (20 mas RMS) – PEGASE (15 mas RMS)

Defrère et al. 2008

PLATFORM REQUIREMENTS



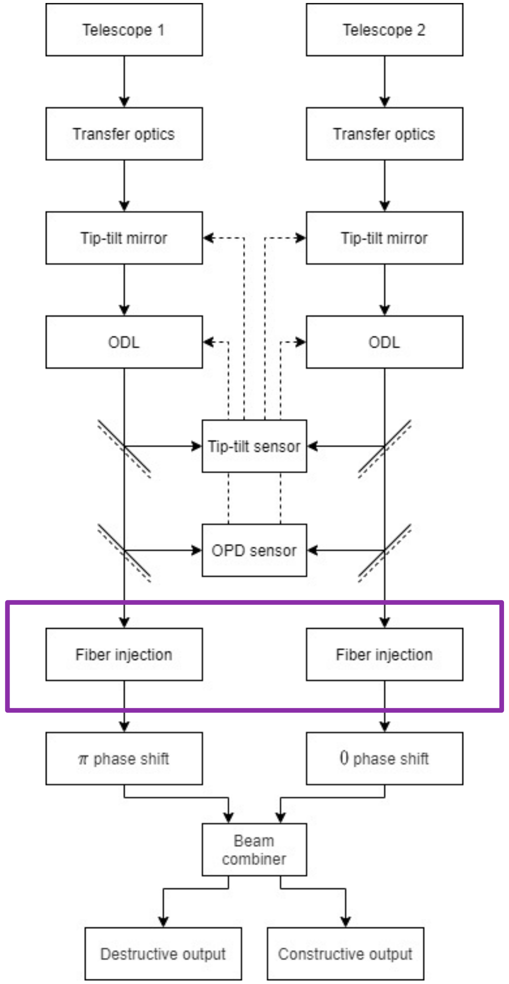
OPD errors



- Correction by a piezo mounted mirror (two corrections stages?)
- ≈ 1 nm RMS CubeSat & 5 nm RMS PROBA
- FKSI (2 nm RMS) – PEGASE (1.7 nm RMS)

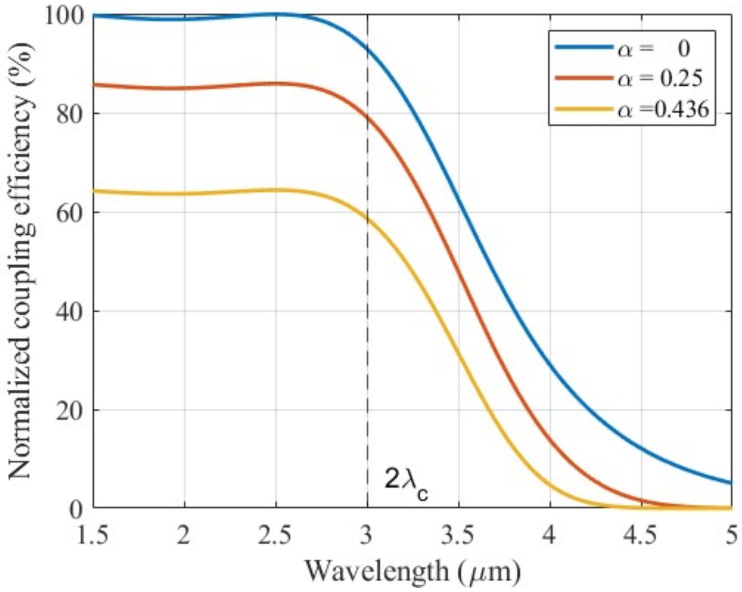
Defrère et al. 2008

PLATFORM REQUIREMENTS



- Single-mode fibers = correction of phase defects

- **Goal**: best coupling efficiency (81% max)
  - Avoid tip/tilt or central obstruction

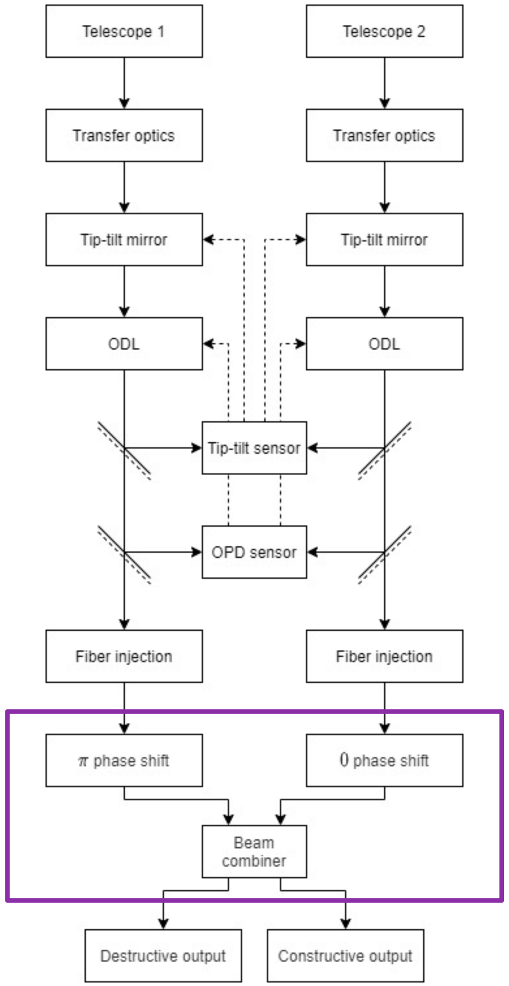


N.A. = 0.16

$\lambda c = 1.5\ \mu m$

Credit: Ait Hocine, 2020

PLATFORM REQUIREMENTS



- Large bandwidth = **achromatic** phase shifter
- Darwin/TPF-I: various possibilities (Rabbia et al. 2003)
- **Now:** integrated optics
- FKSI & PEGASE = 180° reversal of the electric field
- CINDIS = periscope or dielectric plate technique

- Ground-based beam combiner state-of-art = integrated optics

ORBITS

- Earth orbits (not Earth-Sun L2 point)
- Two main categories

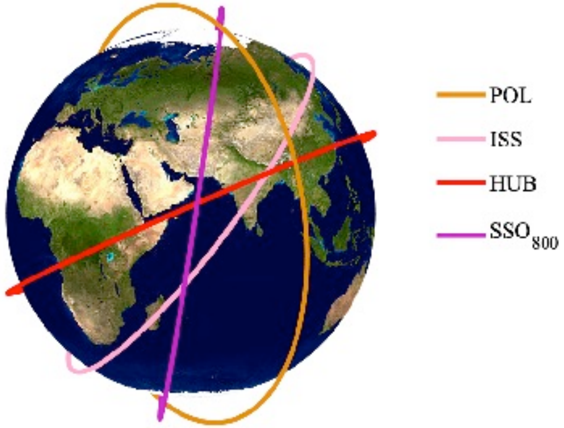
- Sky availibility
  - No obstruction (Sun, Earth, Moon)

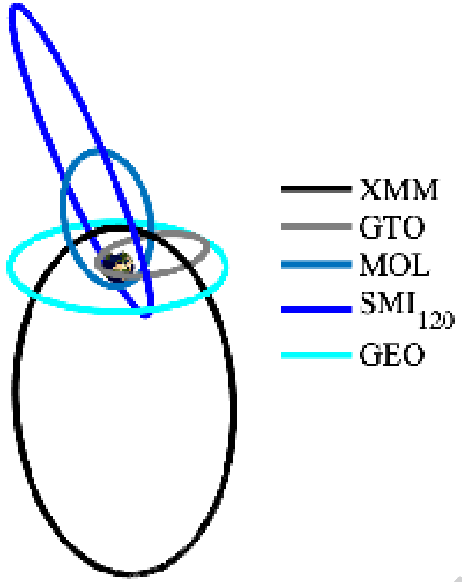
- 5 most promising systems closest to the Earth
  - Proxima Centauri
  - Barnard's Star
  - Espilon Eridani
  - Ross 128
  - Tau Ceti

- **Anti-solar constraints**

- Circular orbits:
  - Hubble
  - ISS
  - Geostationary
  - Sun-synchronous
  - Polar

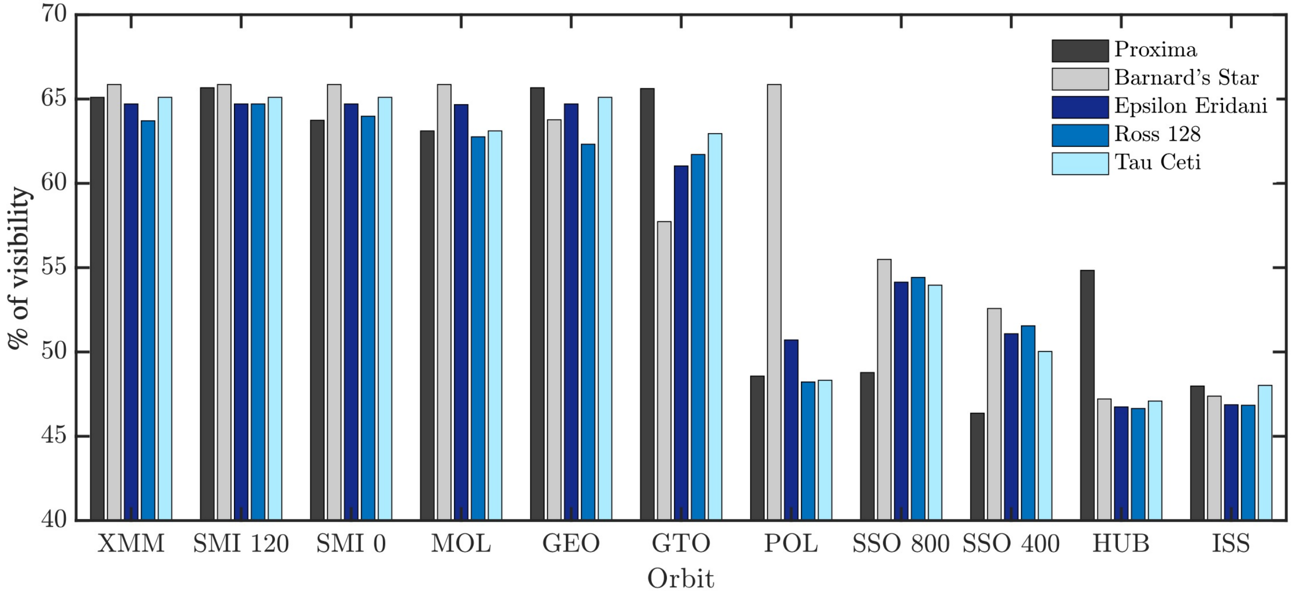
- Elliptical orbits:
  - Molnya
  - XMM-Newton
  - Geostationary transfer
  - SMILE



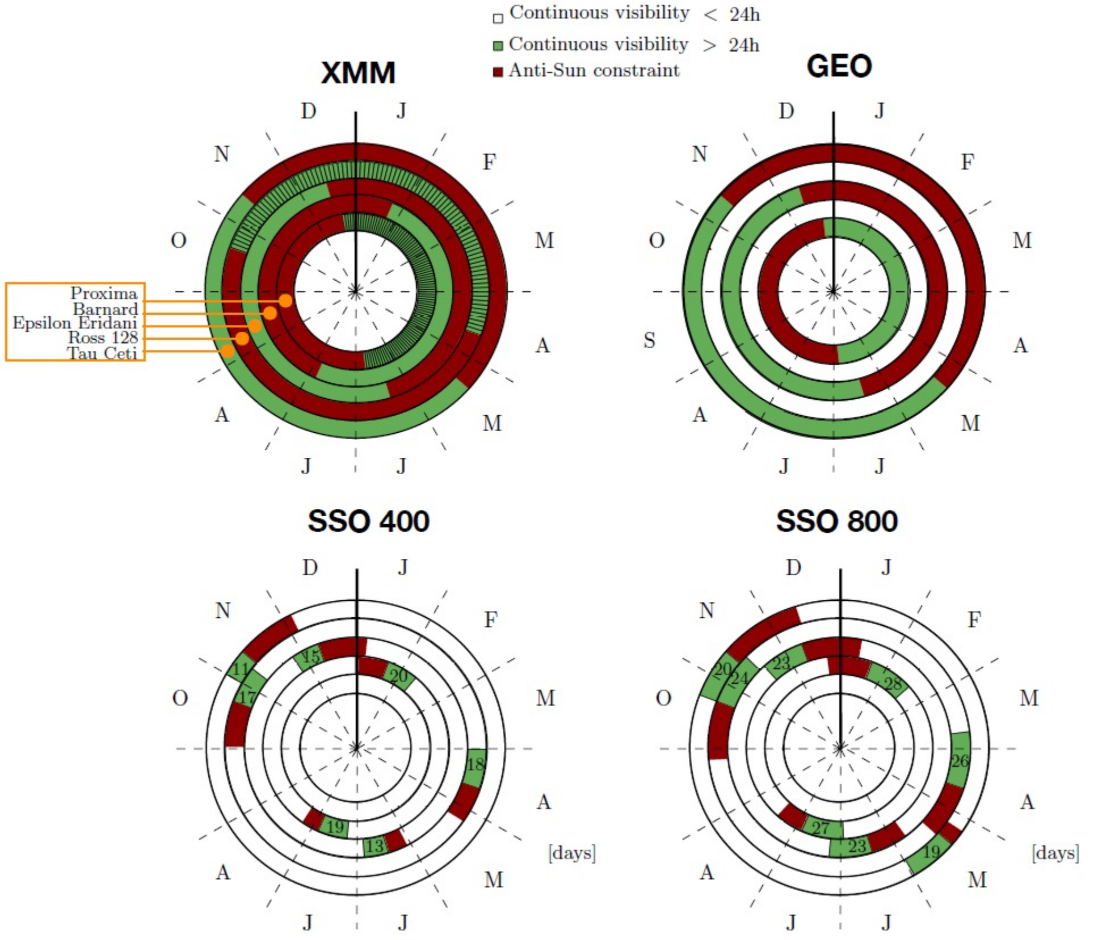


Credit: Dibartolomeo 2019

ORBITS



Visibility may seem good but only a mean value!



24h of integration time

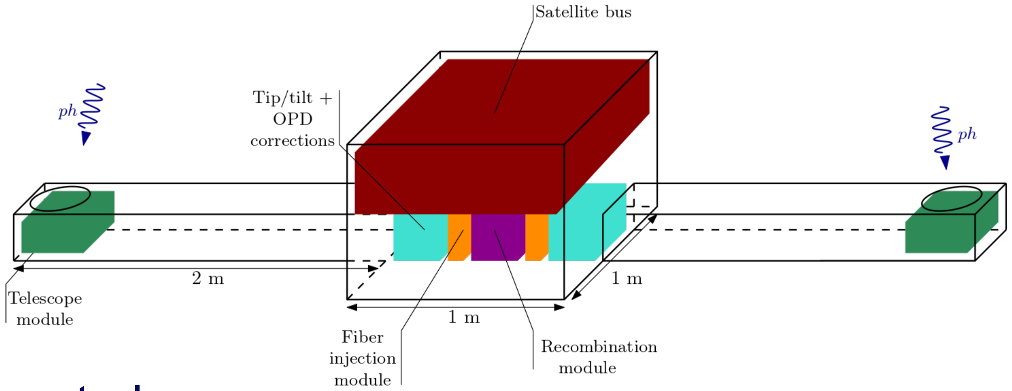
Credit: Dibartolomeo 2019

CONCLUSION

- **Nulling interferometry** is one of the most promising solutions to **spectrally characterize exoplanets**
- **LIFE space mission** under study
- **Precursor:** Small satellite (fibered Bracewell) with scientific capabilities

- Radiometric budget + state-of-the-art planet population synthesis tool
- Stringent requirements on **tip/tilt** & **OPD** (< 40 mas and 5 nm)

- Sun-synchronous orbits



- **Next steps**: thermal study, end-to-end optical simulations and control subsystems.