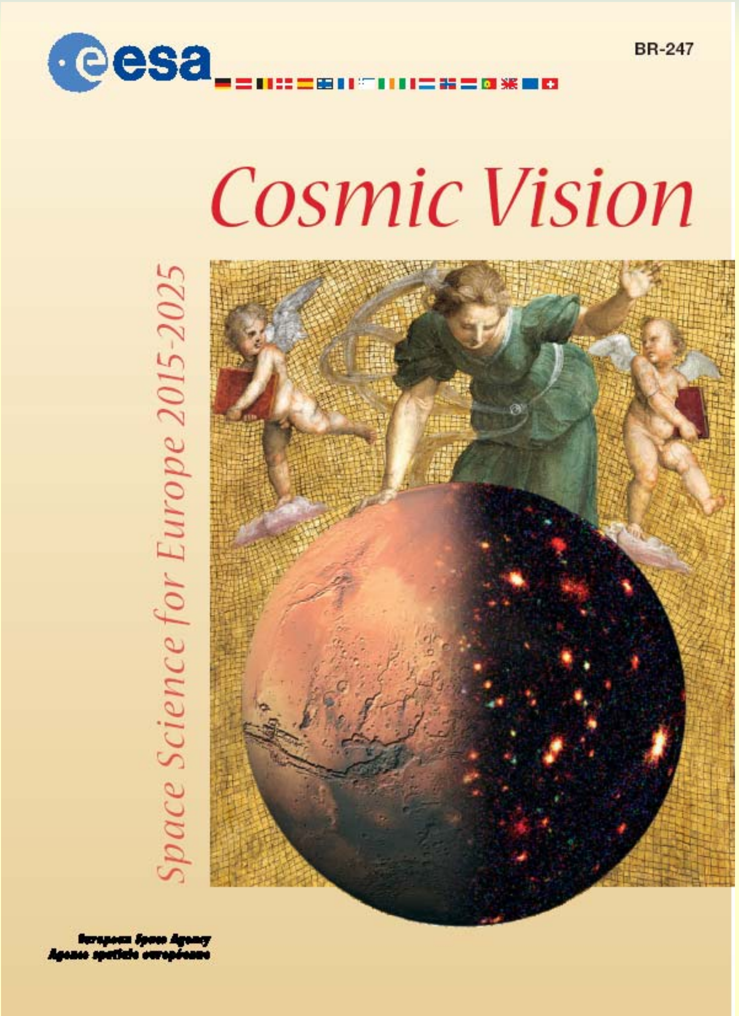
DARWIN: Search for extrasolar planets

Principles
&
Technologies

The new science program



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?**

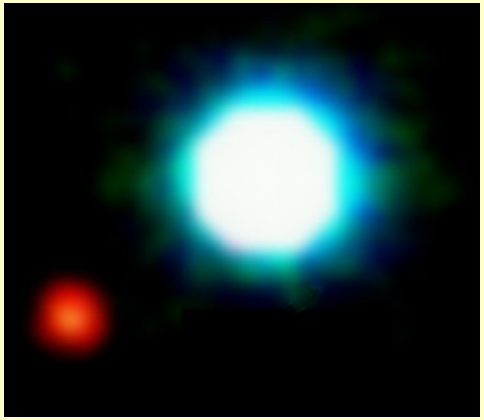
The search for extra-terrestrial life

Anybody out there?

- No clear signs of life in the solar system
- We know little about other planetary systems

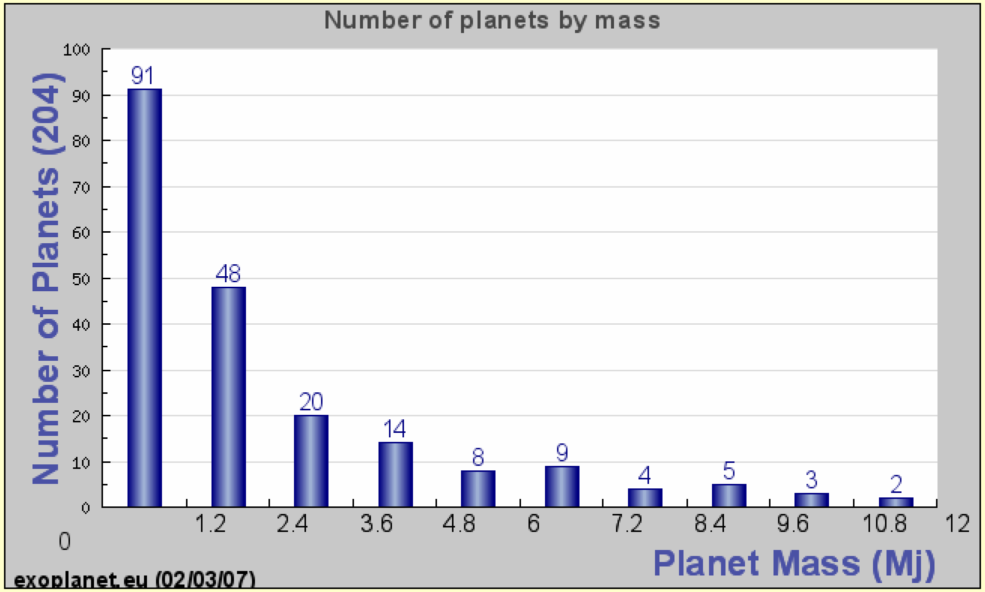
BUT

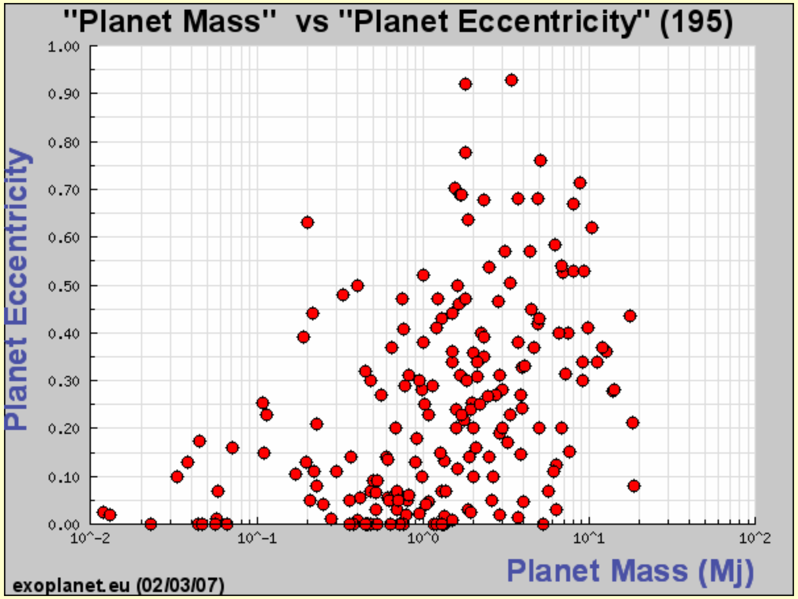
- 209 extrasolar planets are known:
- large, massive objects like our *giants*
- orbiting close to their parent star
- in eccentric orbits
- mostly detected by Doppler shift



First direct image of an exoplanet? The composite shows brown dwarf 2M1207A (center) with its fainter companion. (April 2004 - ESO) 2-5 Jupiter masses, 40 AU from brown dwarf, 1500 yrs orbit CR: 100

Current planet census





($M_J = 318 M_{\oplus}$)

<u>DARWIN mission objectives:</u>

- Detection and characterisation of *exo-earths*
- High resolution general astro-physics

Earthlike planets

			
0.8 $M_\oplus$	1 $M_\oplus$	0.1 $M_\oplus$	$<$ 10 – 15 $M_\oplus$
0.7 AU	1 AU	1.5 AU	HZ 0.7-1.5 AU (CHZ 0.9 - 1.1 AU)
737 K (464 °C)	287 K (14 °C)	248 K (-25 °C)	273 – 373 K (0 – 100 °C)

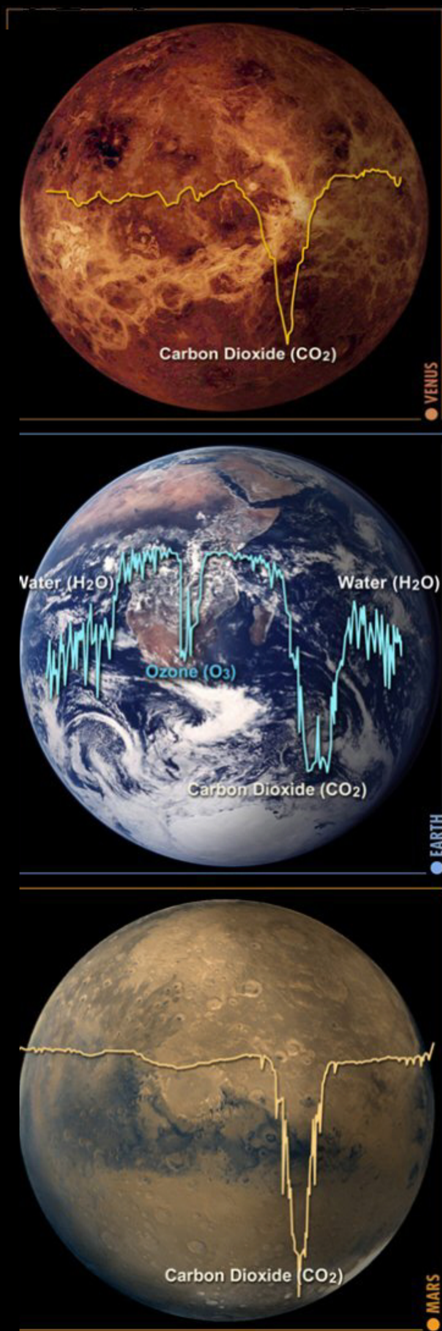
Spectroscopy

	Central wavelength in µm	FWHM in µm
H2O	6.5	1.39
CH4	7.5	1
Continuum	Range [8-9]	-
O3	9.6	0.47
Continuum	Range [10-13]	-
CO2	15	2.92
H2O	28.6	12.2

Mission phase	Science goal	λ of interest
Detection	Detect planet	Whole band
Spectro	Detect atmosphere	CO2
		H2O
	Detect evidence of life	O3
		CH4

Detection of Water, Carbon dioxide

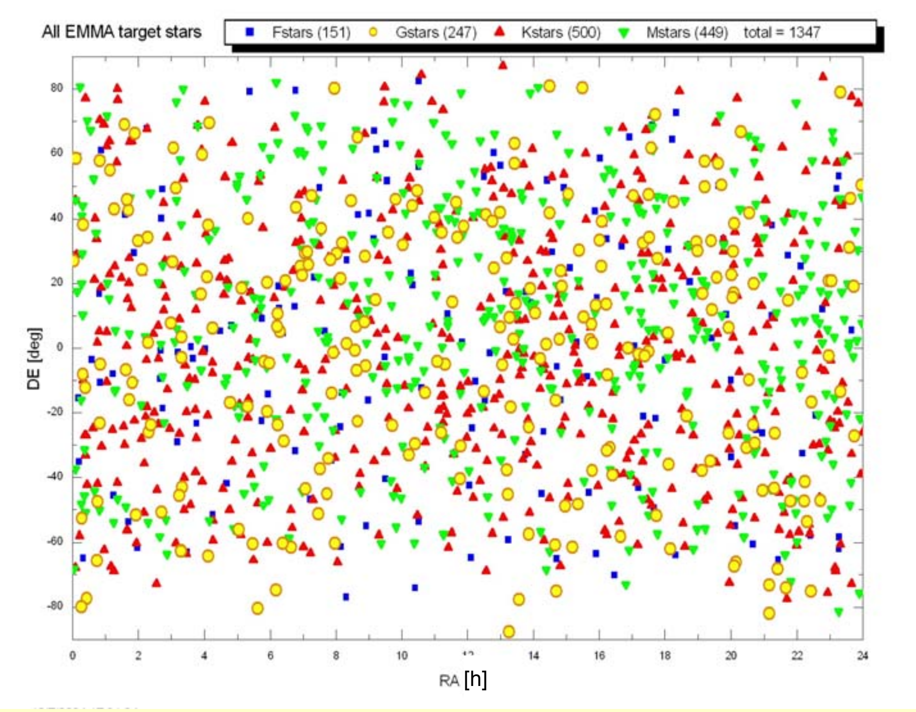
and Oxygen (Ozone) implies earth-like life.



Where ?

Single stars out to 25 pc:

Spec. Type	Number
F	43
G	100
K	244 (incomplete)
M	241 (incomplete)
Total:	608



1" = 1 AU/1 pc
⇒ Search ≥ 25 mas


Stars are a billion times brighter…

...than the planet
...hidden
in the glare.


Like this firefly.

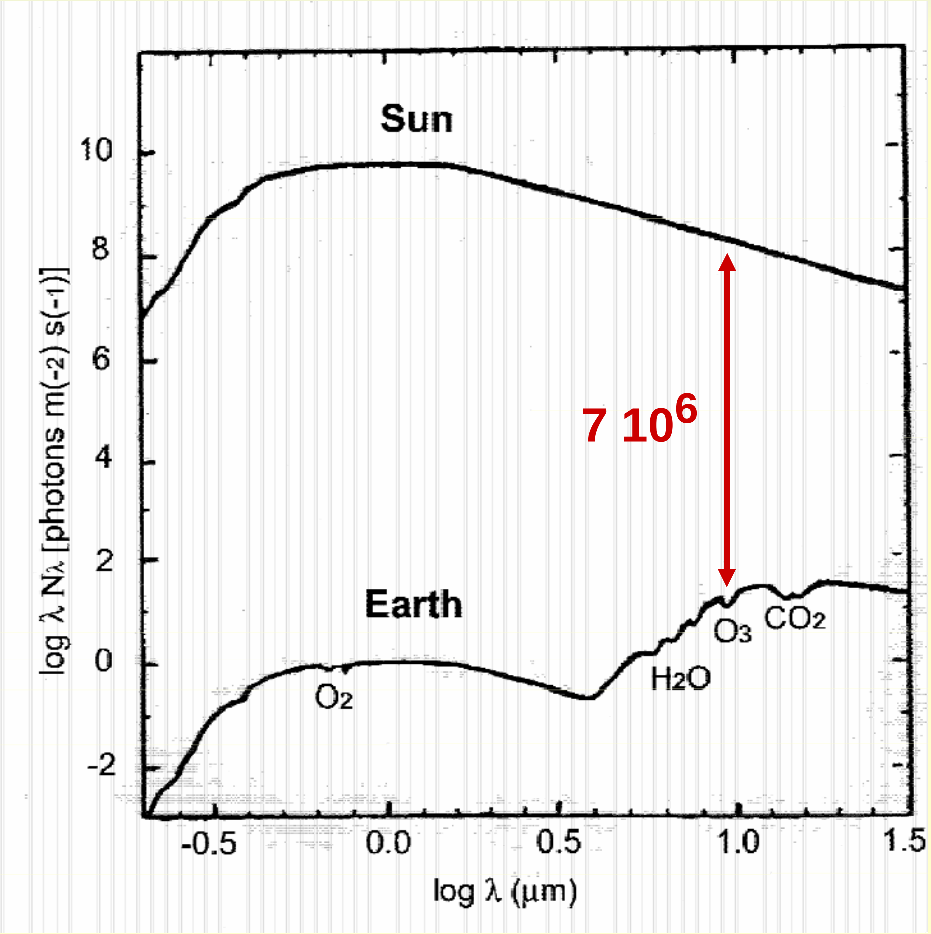
Planet & Star Intensity Ratio

Wien's law:

$\lambda_{max} \cdot T = 3000\ \mu m \cdot K$

$T_{Earth} = 300\ K$

$\rightarrow \lambda_{max} = 10\ \mu m$



→ Darwin shall operate in the infrared

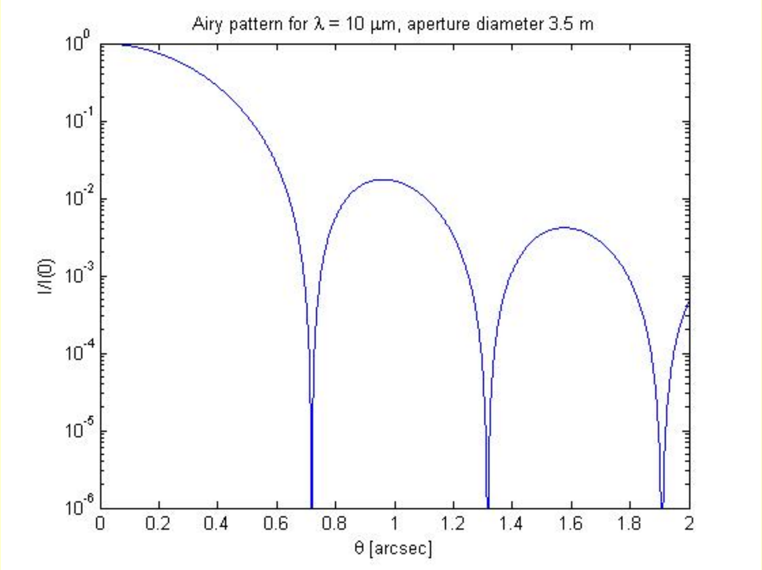
Diffraction's law:

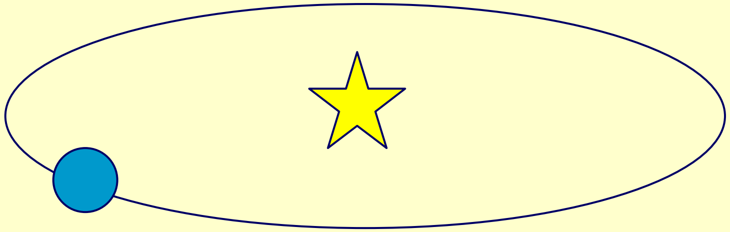
$\theta = \lambda / D$

$\theta_{\text{Earth-like}} < 1\ \text{AU} / 10\ \text{pcs} = 0.1''$

and $\lambda = 10\ \mu m$

→ D >> 20 m





→ Darwin shall operate as an interferometer

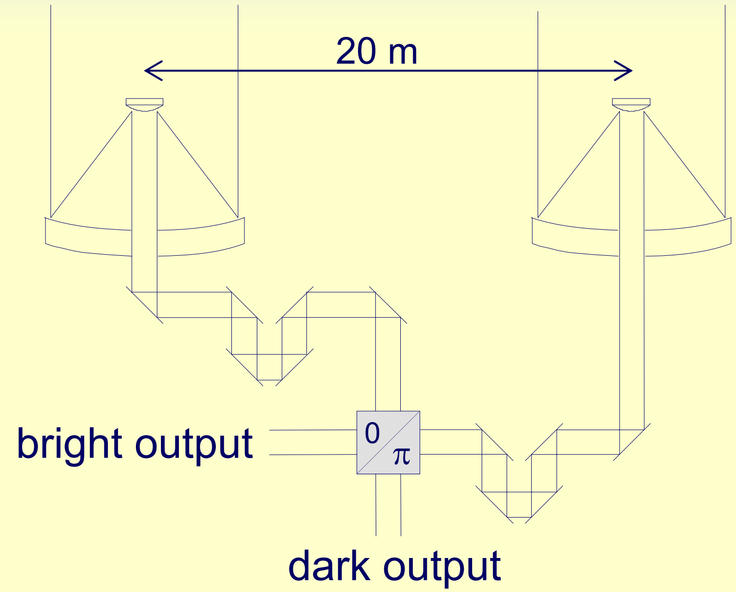
Nulling Interferometry

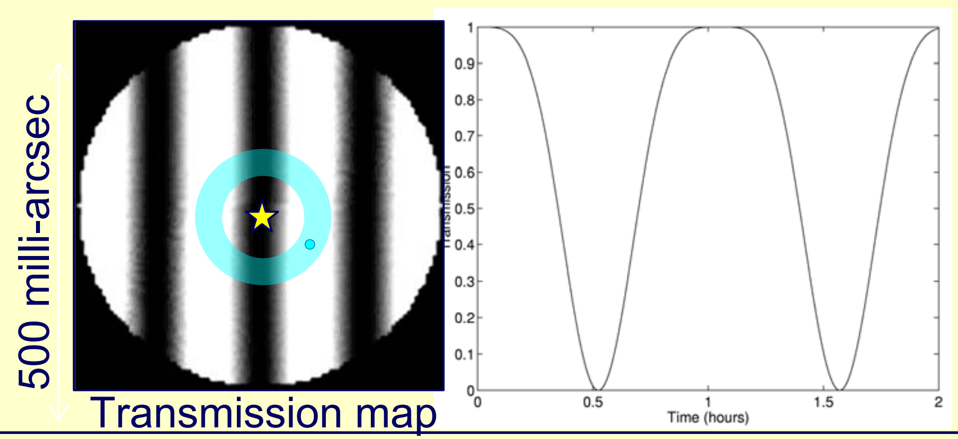
Nulling interferometry allows us to see a faint object close to a bright star.

Stellar light is cancelled by destructive interference, while planet light interferes constructively.

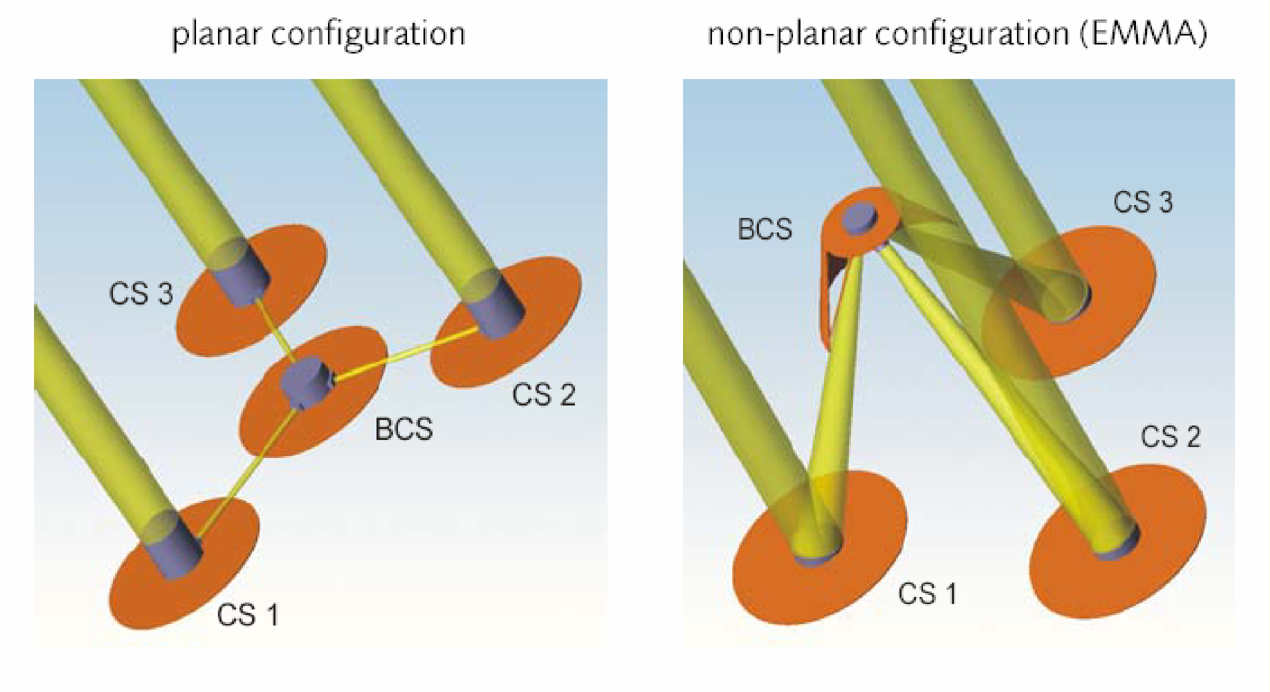
More collectors required for:

- High stellar rejection
- Internal modulation
- Result: 3-4 collectors



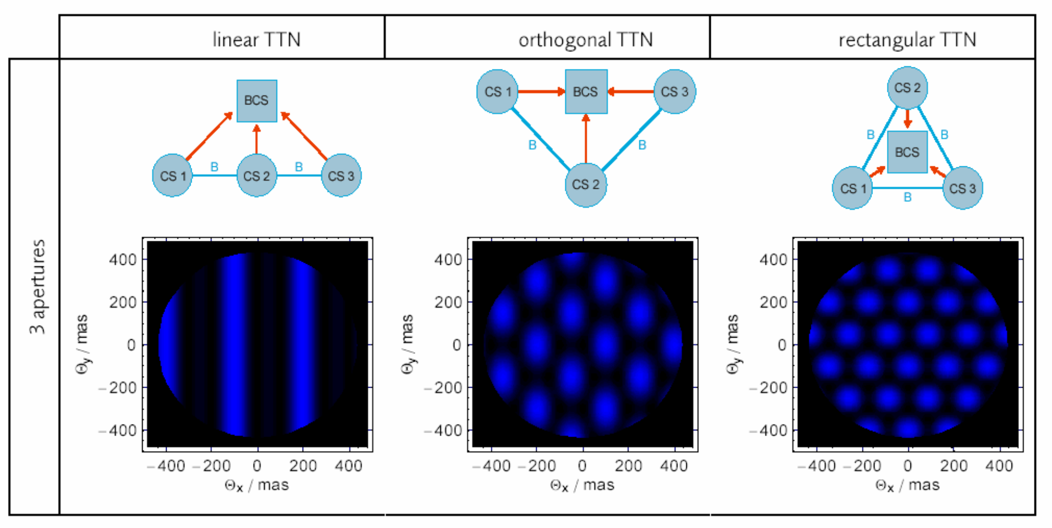


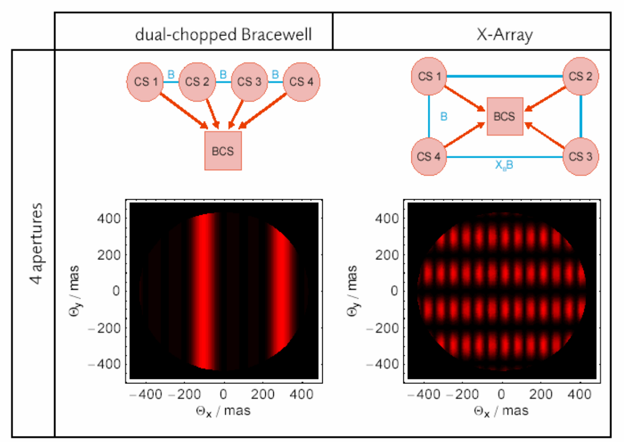
Candidate architectures



Any candidate configuration can be implemented in a planar or non-planar version

Candidate configurations





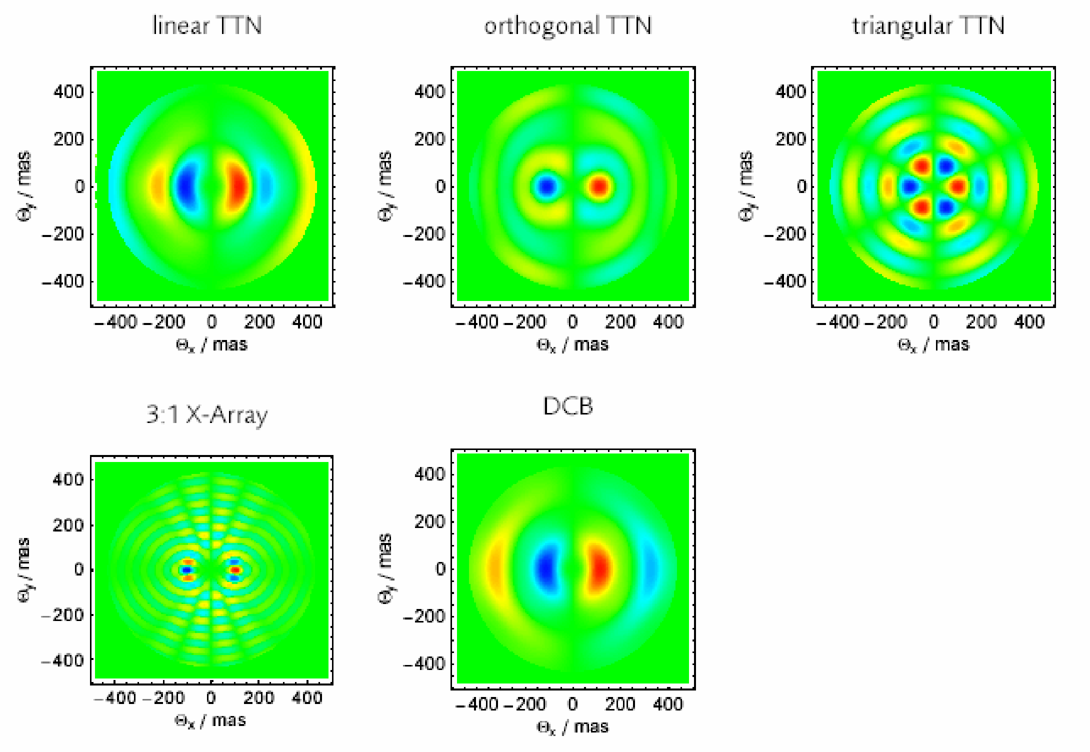
For exo-planet detection, nulling configuration shall provide:

- Θ^2 extinction (maximum planet detection efficiency)

- Internal modulation/phase chopping (exo-zodiacal dust signal rejection)

→ Darwin configuration shall contain at least 3 telescopes

Candidate configurations



Correlation maps assuming a single planet at θx =100 mas (Θy =0) from the central star.

The orthogonal TTN and the X-array show the narrowest correlation peaks (86 mas and 21 mas, respectively).

The orthogonal TTN (with non-planar configuration) is studied by Alcatel-Alenia Space under ESA contract.

The X-array (planar configuration) is studied by EADS Astrium under ESA contract.

The challenges

Contrast ratio star : planet is 1.000.000 : 1

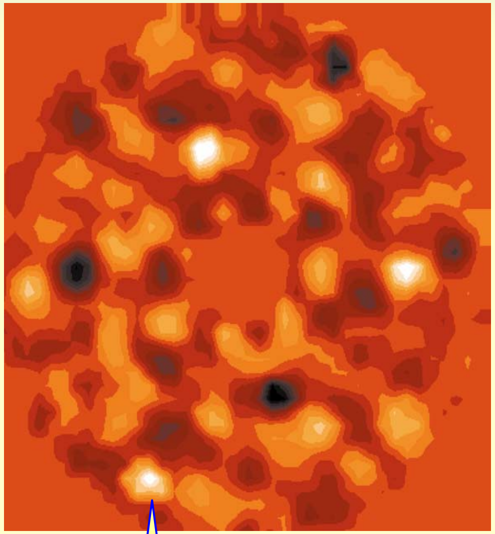
- ➔ Nulling ratio: 10^{-6}
  - ➔ Optical path length control < 1 nm
  - ➔ Beam intensity matching < 0.2%
  - ➔ Polarisation < 2 mrad
  - ➔ Beam tip/tilt < 3.6 µrad
  - ➔ Pupil shift < 0.35 %

Separation planet and star 20 – 200 mas

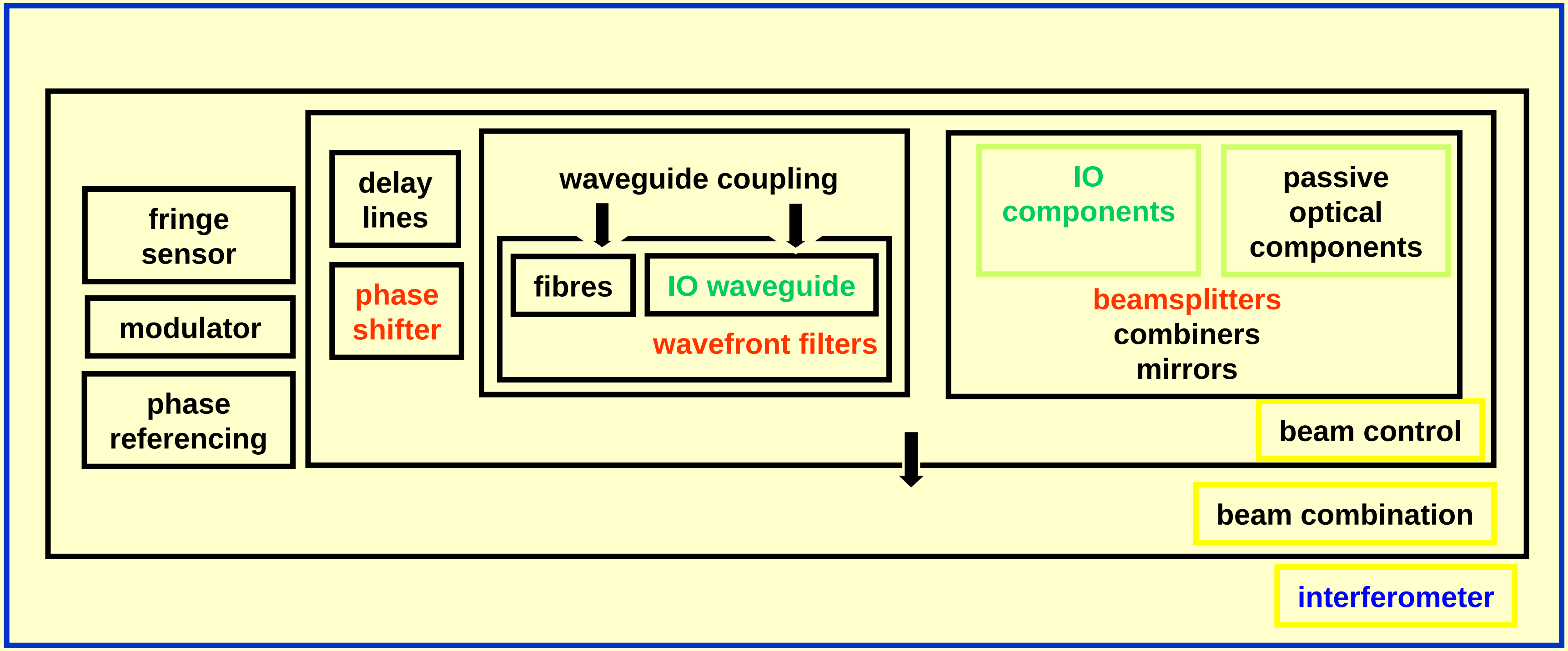
- ➔ Interferometric baselines 15 – 150 m
  - ➔ 4-5 spacecrafts in close formation
  - ➔ Correction of relative displacement and attitude

Spectral range 6 – 20 µm

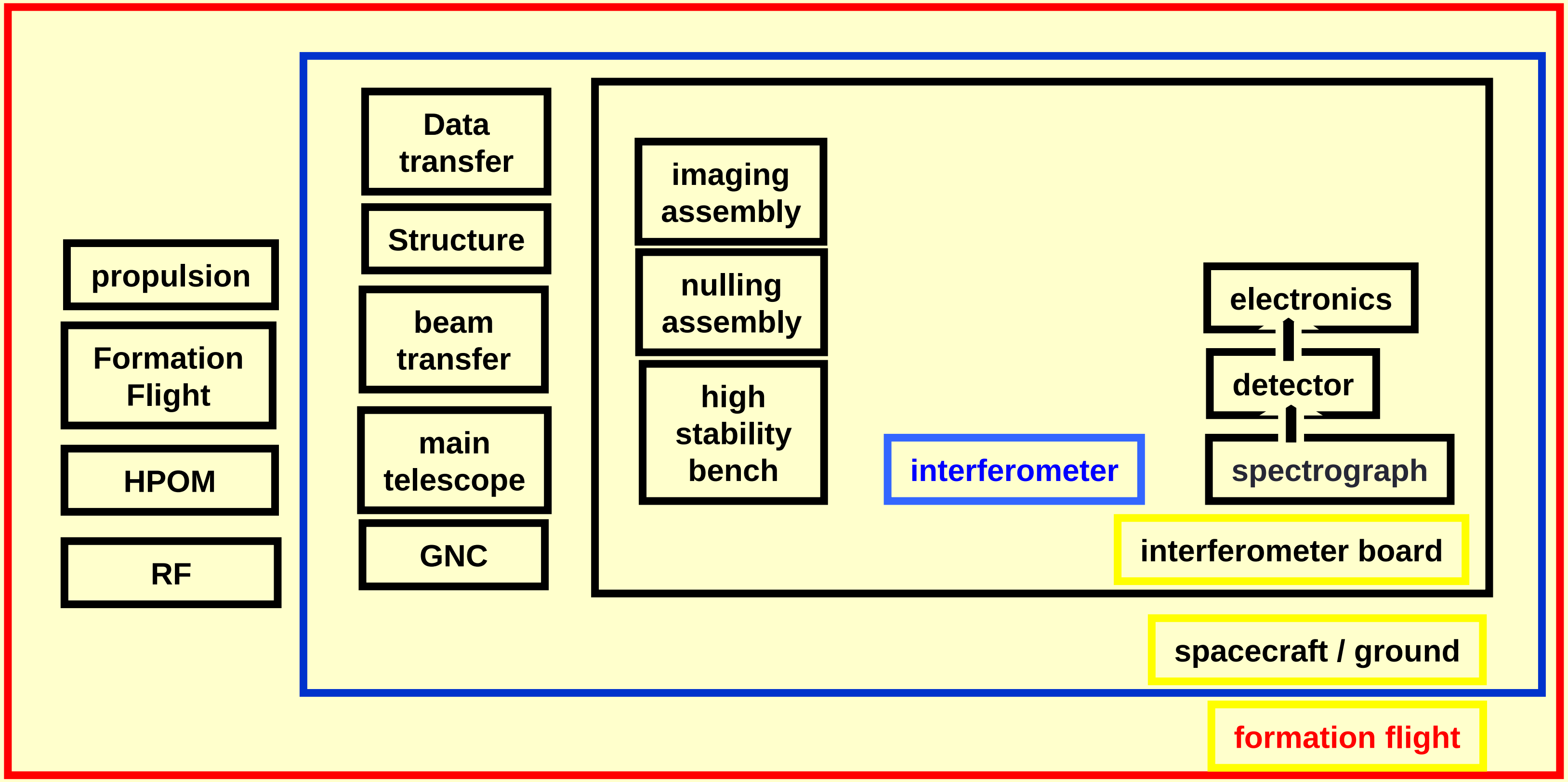
- ➔ Payload temperature: < 40 K
- ➔ Detector temperature: < 8 K



Interferometer subsystems



Top level: optical bench, s/c + FF



Mission Drivers: Example Wavefront Filters

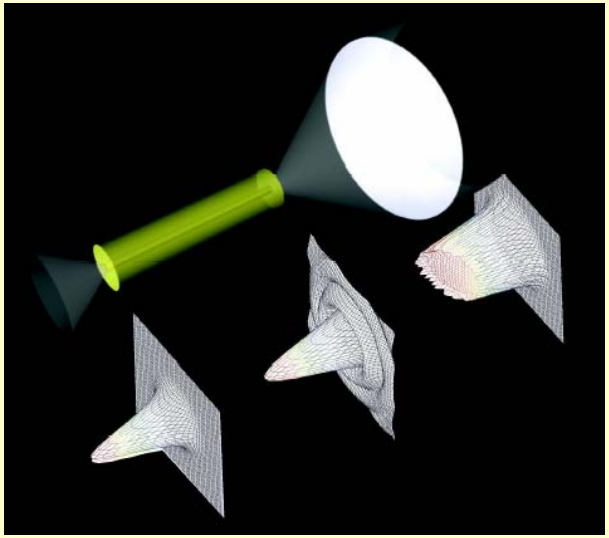
Single Mode Fibers substantially relax requirements on optical elements (making the system realistic)

The required wavelength range is not used industrially

New technology is required

Options:

- Integrated Optics
  - hollow metallic
  - dielectrics
- Chalcogenide (3 - 11 µm)
- Silverhalides (5.8 – 20 µm)
- Tellurium (4 – 20 µm)
- Photonic Crystals (Holey)



Parameter	Requirement
Spectral range	6 - 20 µm
High-order mode suppression ratio	10^6
Total insertion loss	< 1.5 dB (71% throughput)

Single-mode mid-IR optical fibers

Goal: *identify materials, design concepts, and develop manufacturing processes for the production of optical single mode fibers for the thermal infrared.*

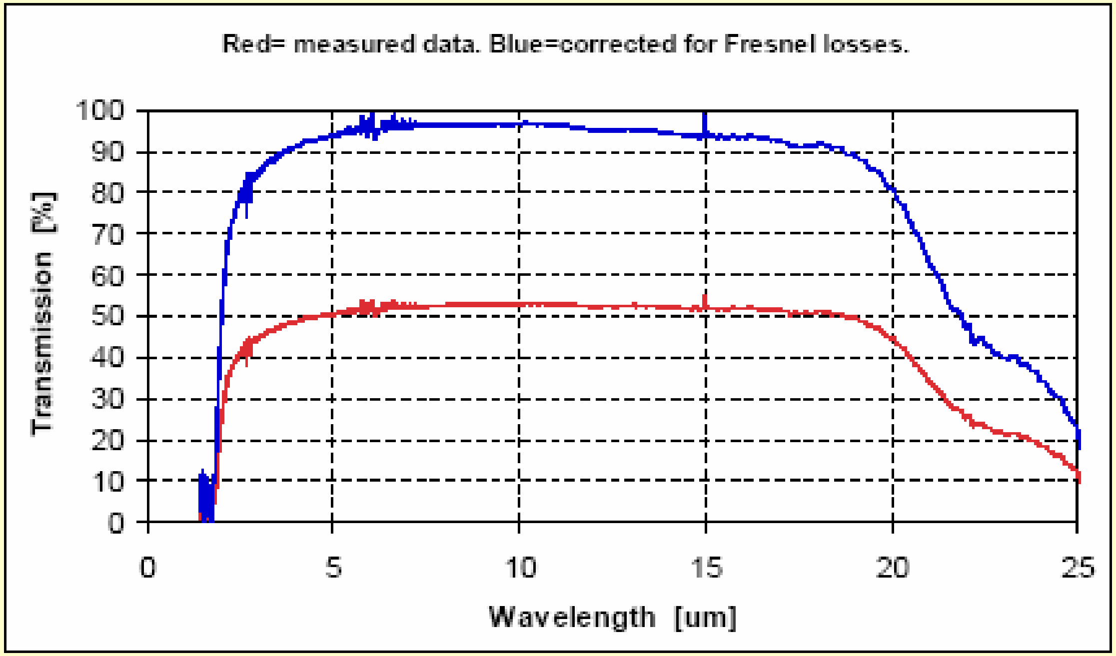
EADS Astrium (D)
GaAsSeTe (5-10 μm)
AgBrCl (up to 20 μm)

TPD-TNO (NL)
TeAsSe(4-12 μm)

SM operation at 10 μm demonstrated for selected samples
Absorbing coating and >20 cm length to damp leaky modes

TGGI

Figure: Transmission of purified TGGI-G6 with correction for Fresnel losses (1.75 mm)
TNO
Universite de Rennes



First successful fibre drawing tests (ø 400µm/ø 520µm)

Parameter	Requirement
Spectral range	6 - 20 µm
Total insertion loss	< 1.5 dB (71% throughput)

Integrated optics

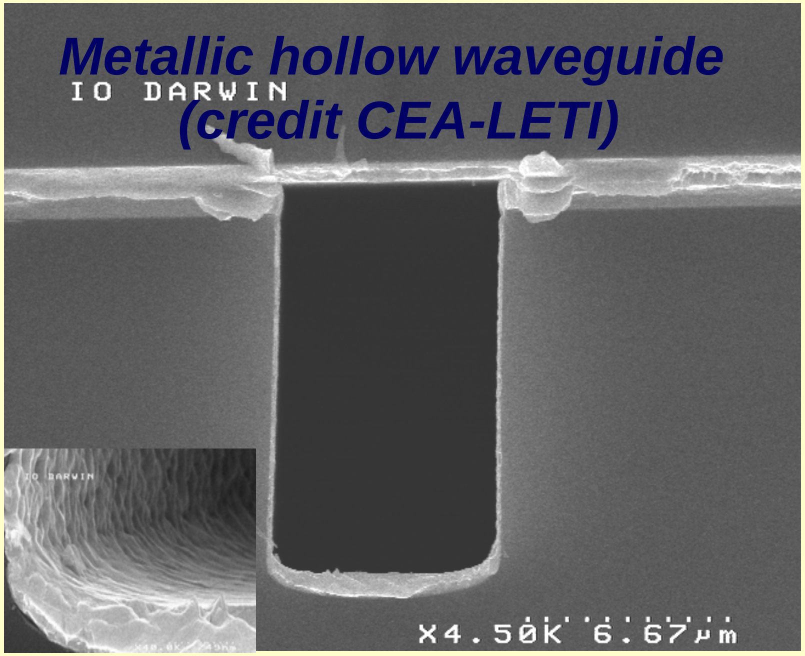
***Goals:** Identify materials and manufacturing technologies for single-mode IO components for 4-20 micron range*

- ❑ *Produce designs of optical chips performing functions relevant to DARWIN (wavefront filtering, splitting, recombination)*

- ❑ ***Team** leader: IMEP (F)*

- *Metallic hollow waveguides tested, good modal filter but high absorption (1% / mm) prevents complex functions*
- *Chalcogenide waveguides: suitable glass pairs & purity still issues.*

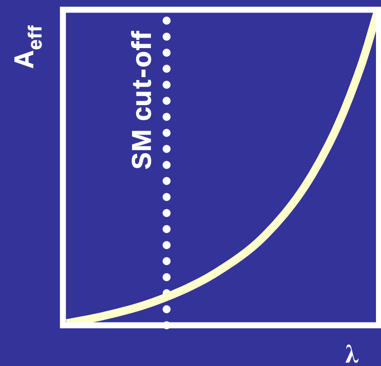
***Status:** completed 03/06*

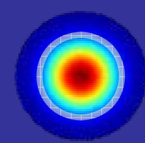


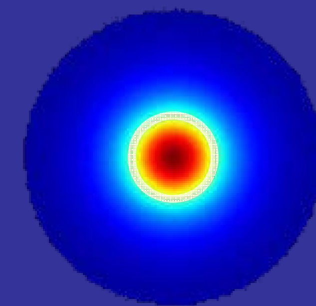
Metallic hollow waveguide (credit CEA-LETI)

Photonic crystal fibres

Step-index fibers:



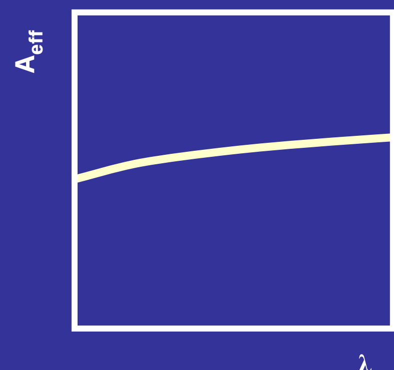


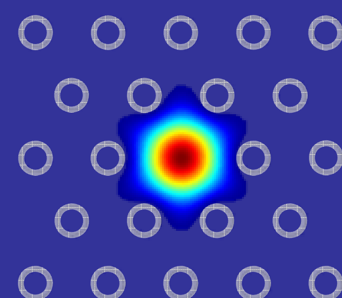


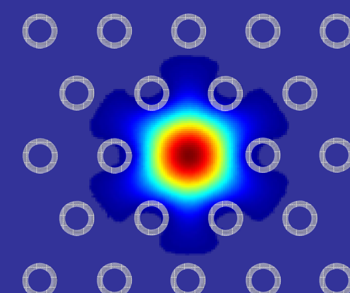
λ/a = 0.2

λ/a = 0.4

Holey fibers:







λ/Λ = 0.04

λ/Λ = 1.20

A_{eff} of HF can be much flatter as a function of λ relative to conventional designs