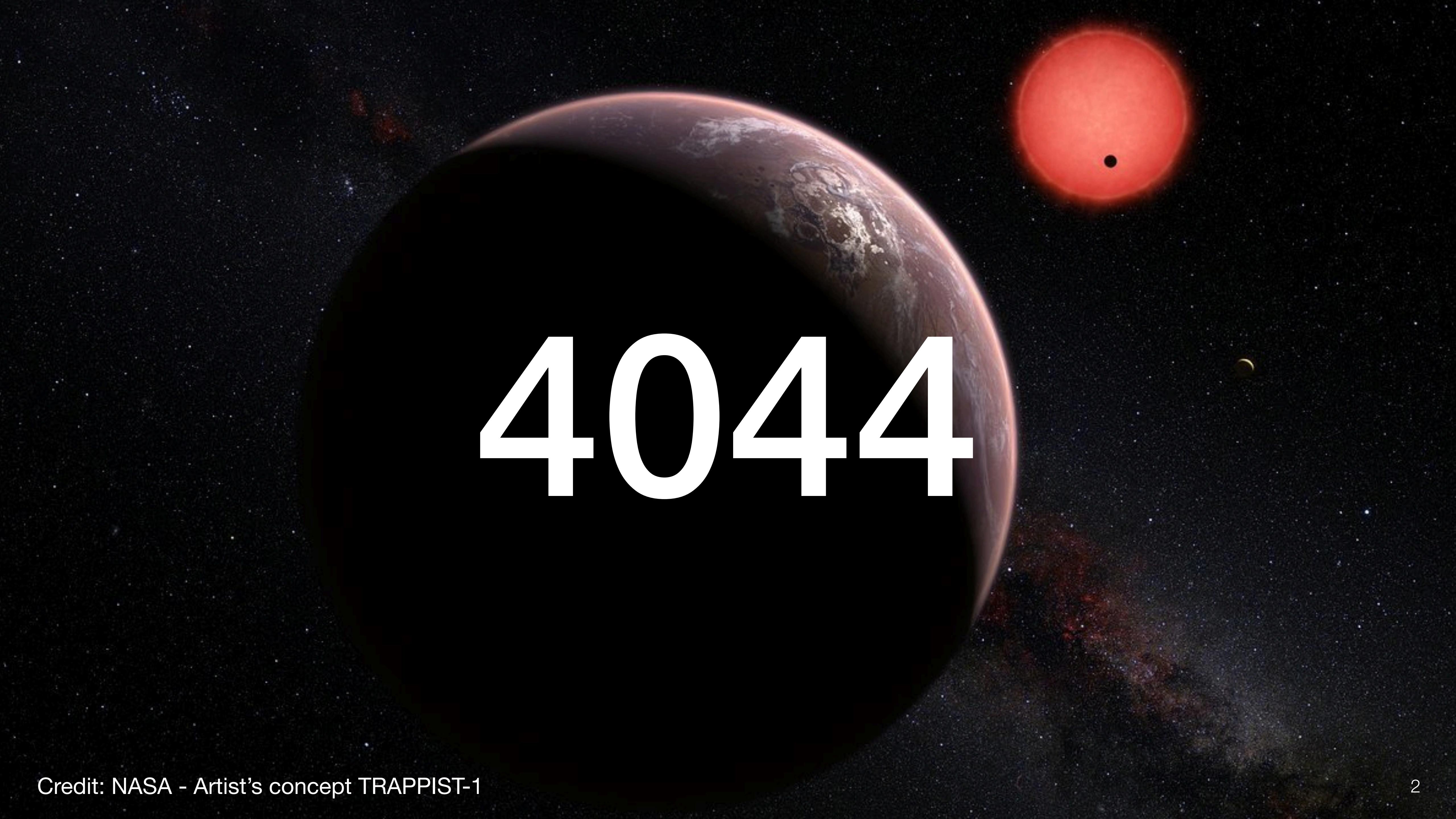


Feasibility study of an interferometric CubeSat for exoplanet science

Colin DANDUMONT

Dr. D. DEFREERE, A. BICHET, S. DIBARTOLOMEO and Prof. J. LOICQ

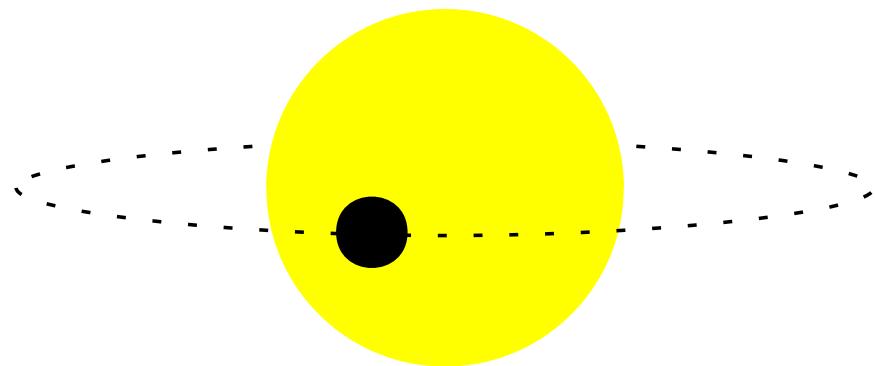


An artist's concept of the TRAPPIST-1 star system. In the center is a small, reddish-orange star with a prominent solar flare on its upper left. Seven Earth-sized planets are shown orbiting it in a circular path. The planets are various shades of brown and tan, with some showing signs of atmospheric activity or surface features. The background is a dark, star-filled space.

4044

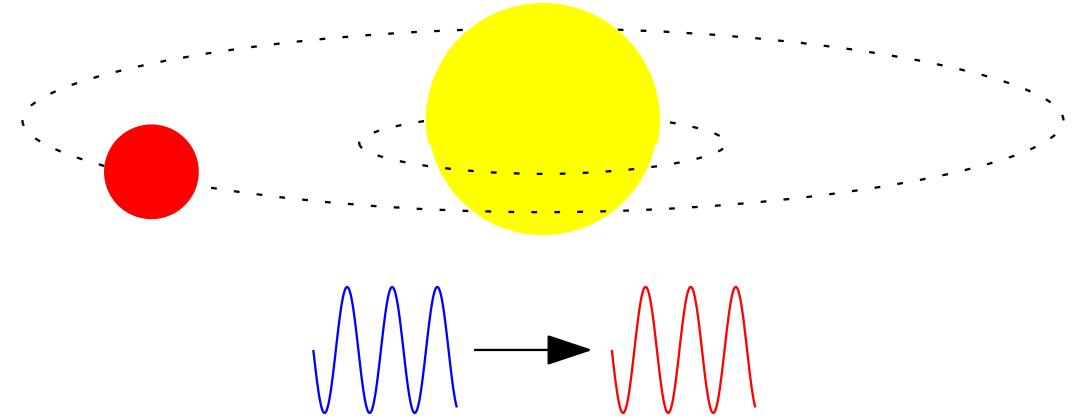
4044

Transit



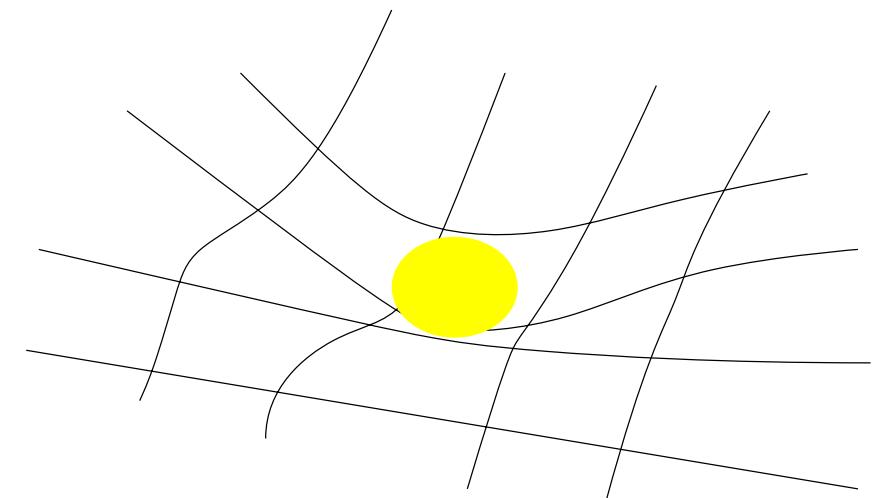
77.0%

Radial velocity



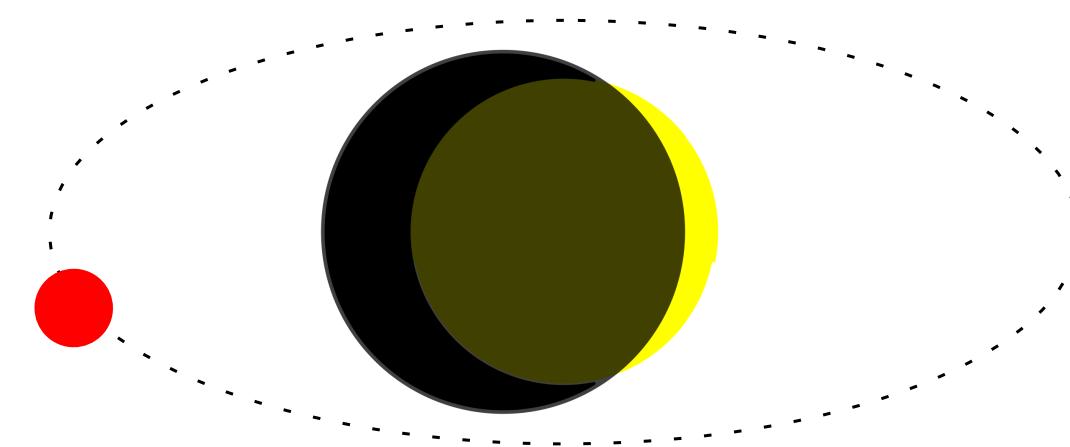
18.9%

Microlensing



1.9%

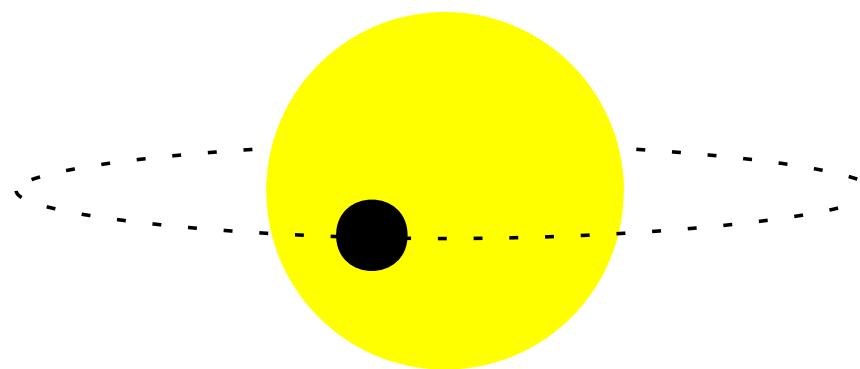
Imaging



1.2%

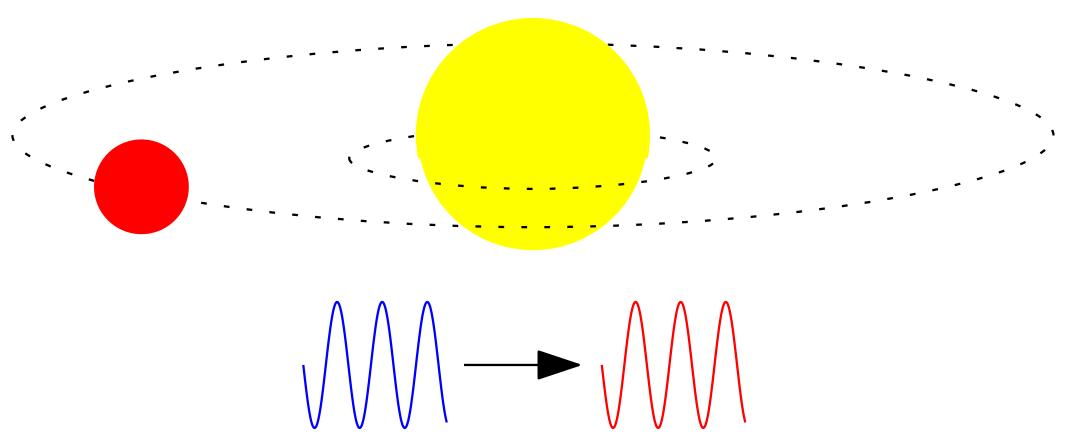
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Transit



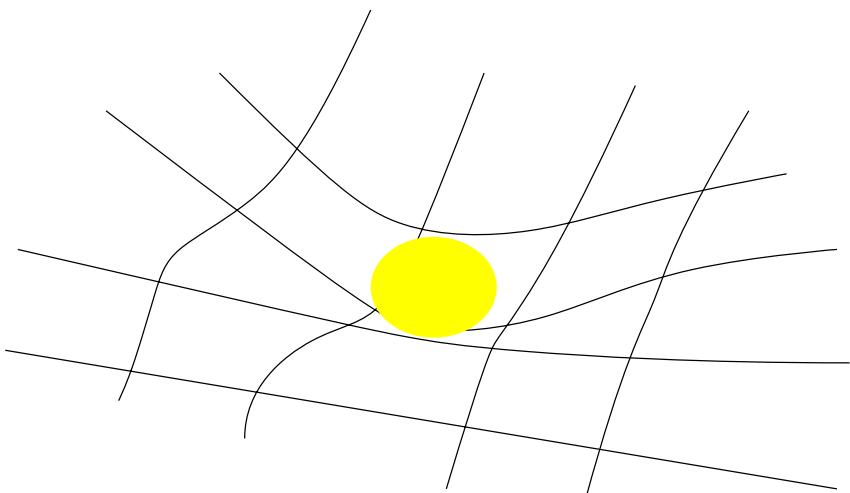
77.0%

Radial velocity



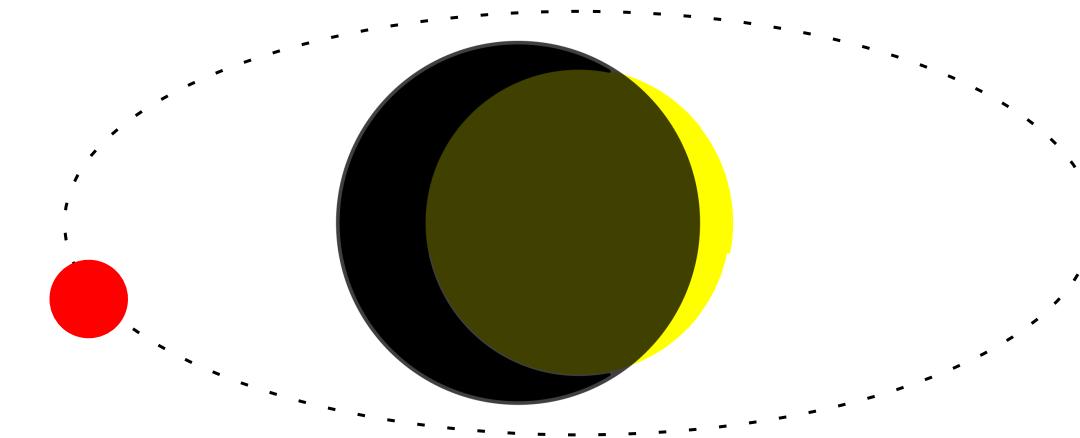
18.9%

Microlensing



1.9%

Imaging

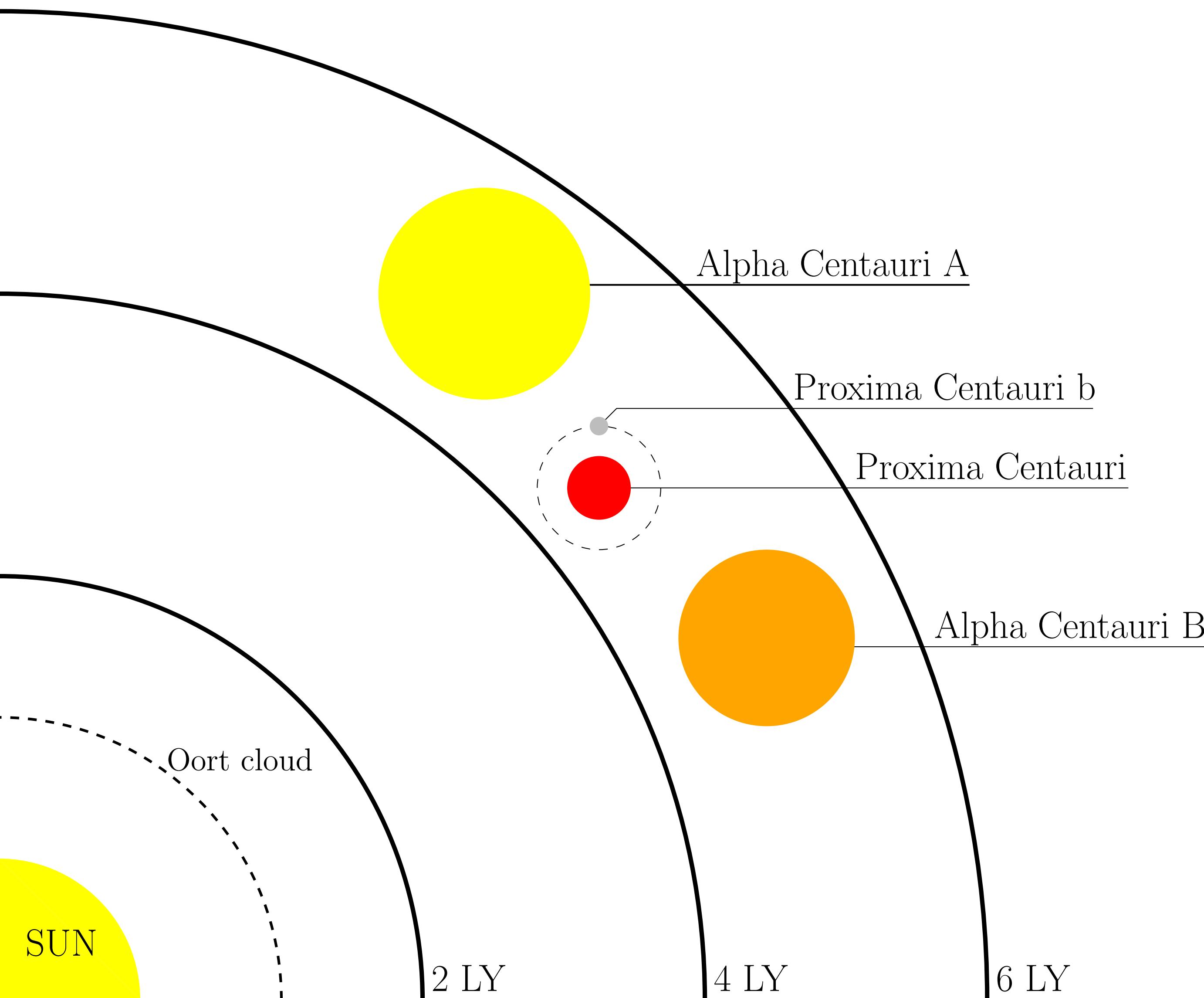


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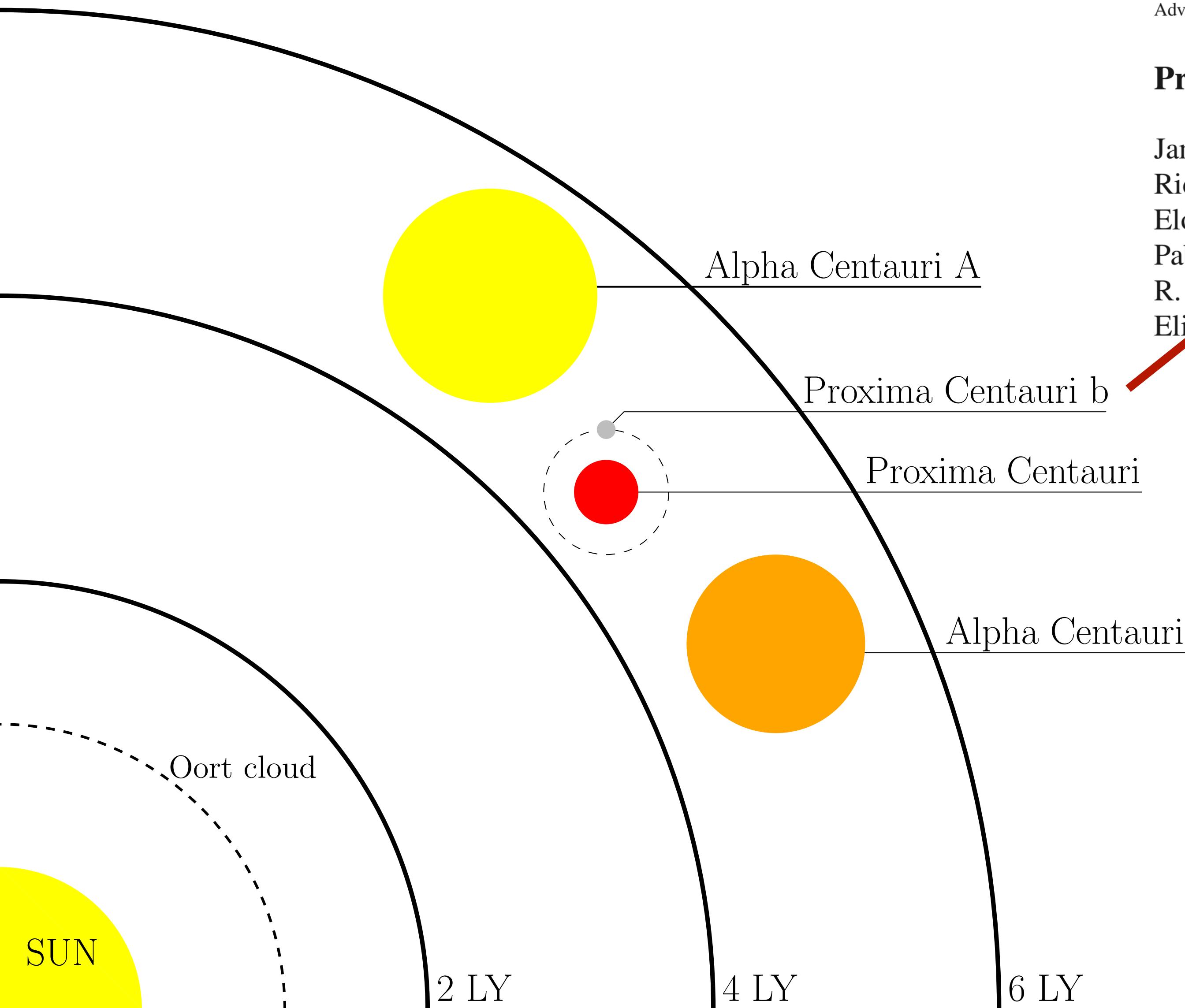
> 98% = indirect methods!

**Direct
methods!**

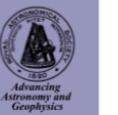
Proxima Centauri b?



Proxima Centauri b?



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of the
ROYAL ASTRONOMICAL SOCIETY



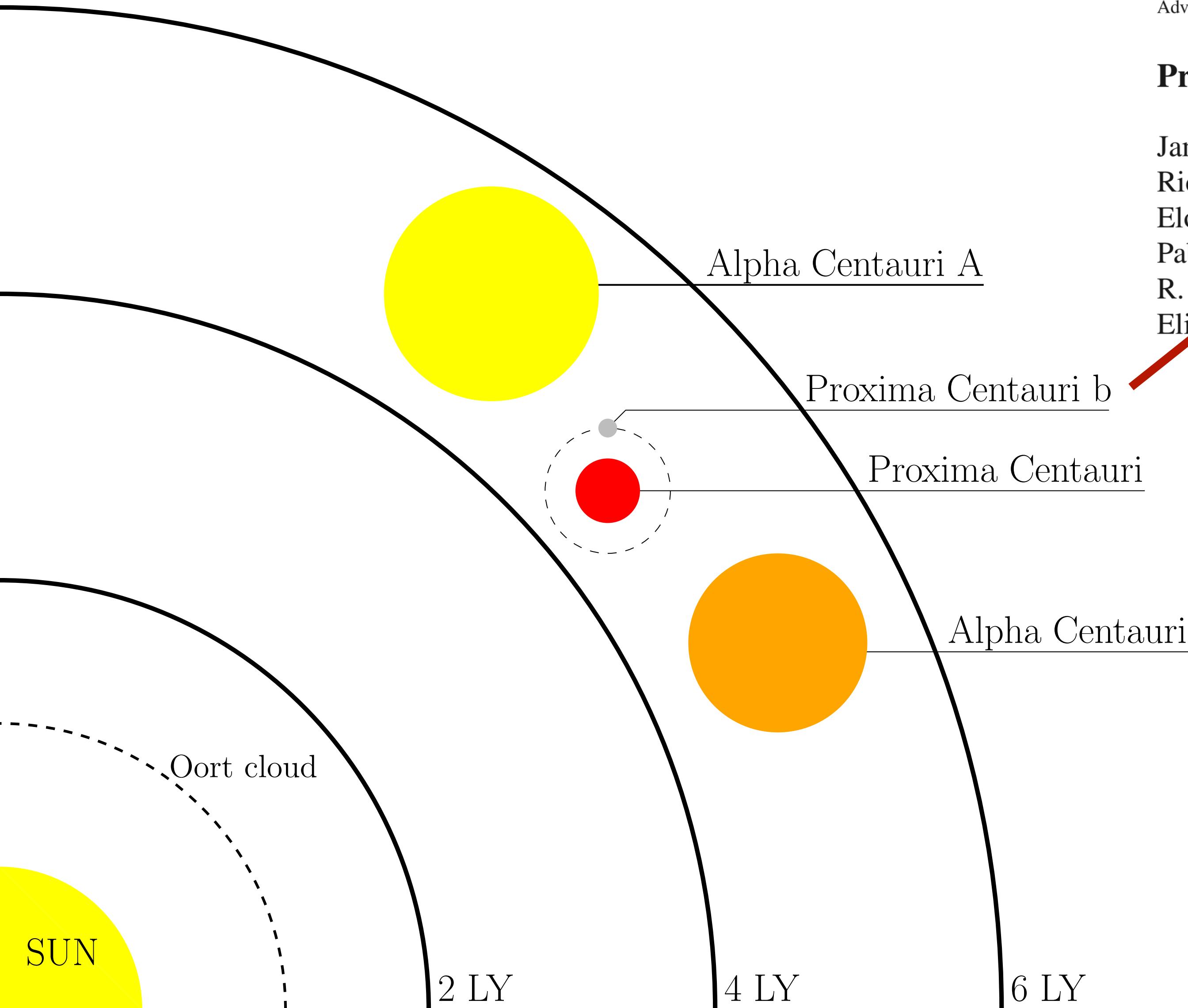
MNRAS **487**, 268–274 (2019)
Advance Access publication 2019 May 11

doi:10.1093/mnras/stz1268

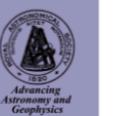
Proxima Centauri b is not a transiting exoplanet

James S. Jenkins,^{1,2*} Joseph Harrington,³ Ryan C. Challener,³ Nicolás T. Kurtovic,¹ Ricardo Ramirez⁴, Jose Peña⁵, Kathleen J. McIntyre,³ Michael D. Himes,³ Eloy Rodríguez,⁶ Guillem Anglada-Escudé,⁵ Stefan Dreizler,⁶ Aviv Ofir,⁷ Pablo A. Peña Rojas,¹ Ignasi Ribas,^{8,9} Patricio Rojo,¹ David Kipping,¹⁰ R. Paul Butler,¹¹ Pedro J. Amado,⁴ Cristina Rodríguez-López,⁴ Eliza M.-R. Kempton,^{12,13} Enric Palle^{14,15} and Felipe Murgas^{14,15}

Proxima Centauri b?



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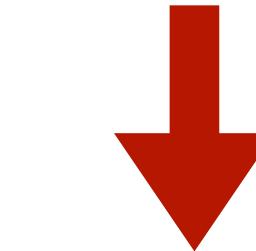


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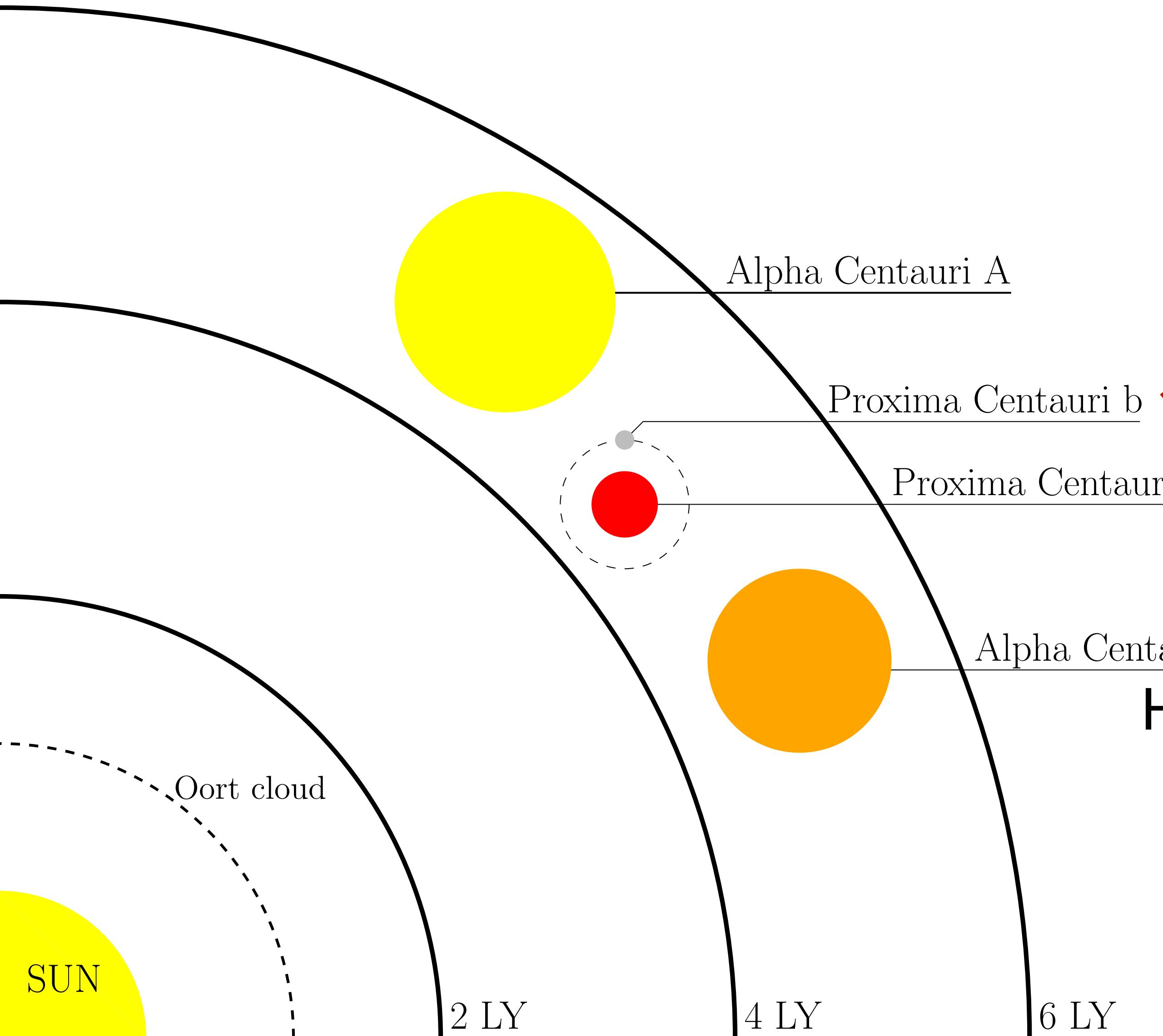
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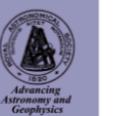


Direct imaging

Proxima Centauri b?



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ROYAL ASTRONOMICAL SOCIETY

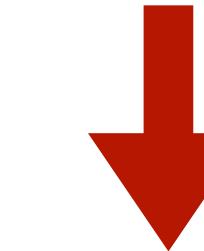


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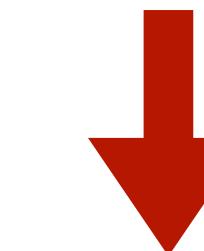
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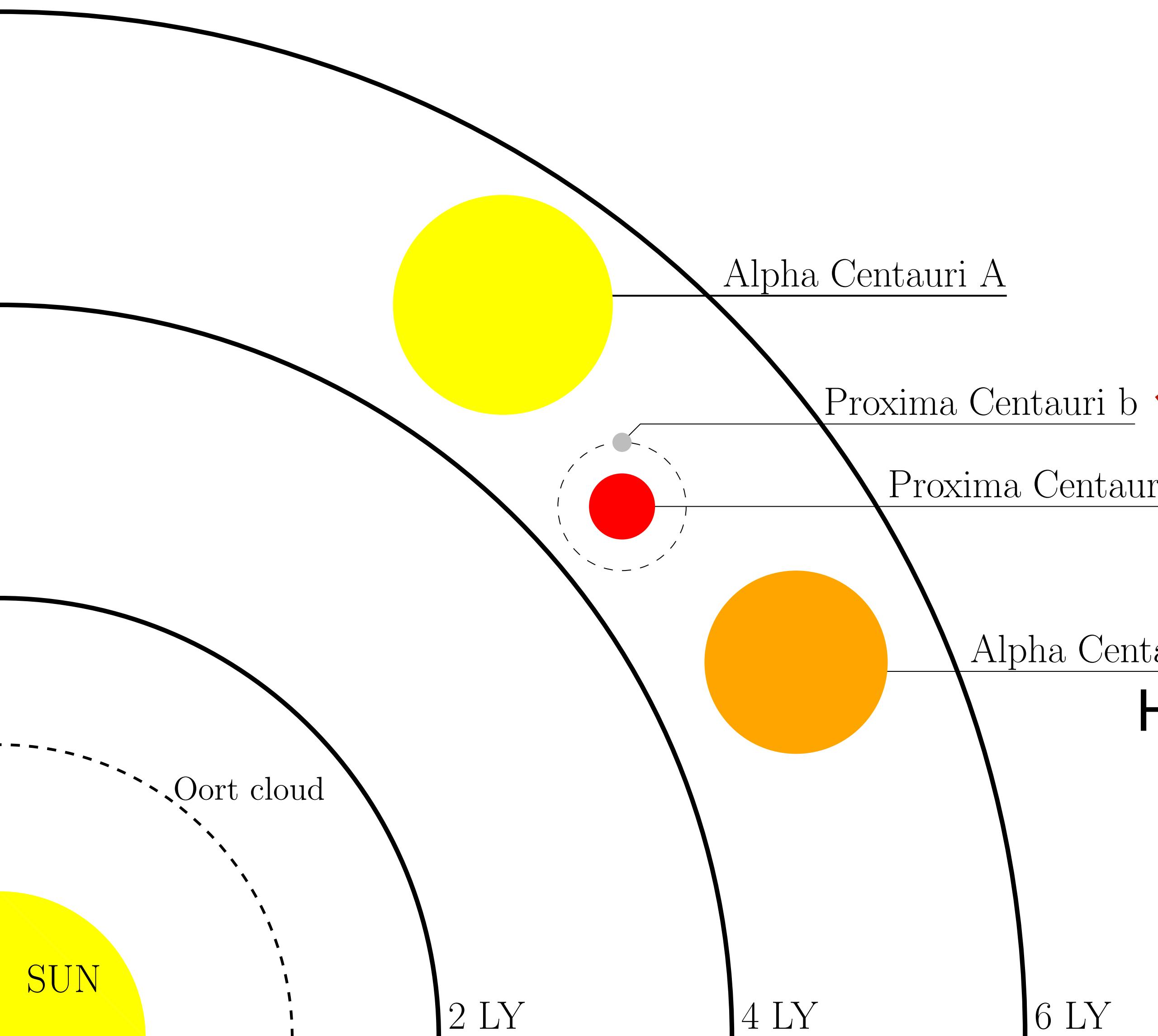


Direct imaging



**How can we resolve the planetary system?
i.e. 38 mas**

Proxima Centauri b?



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Direct imaging

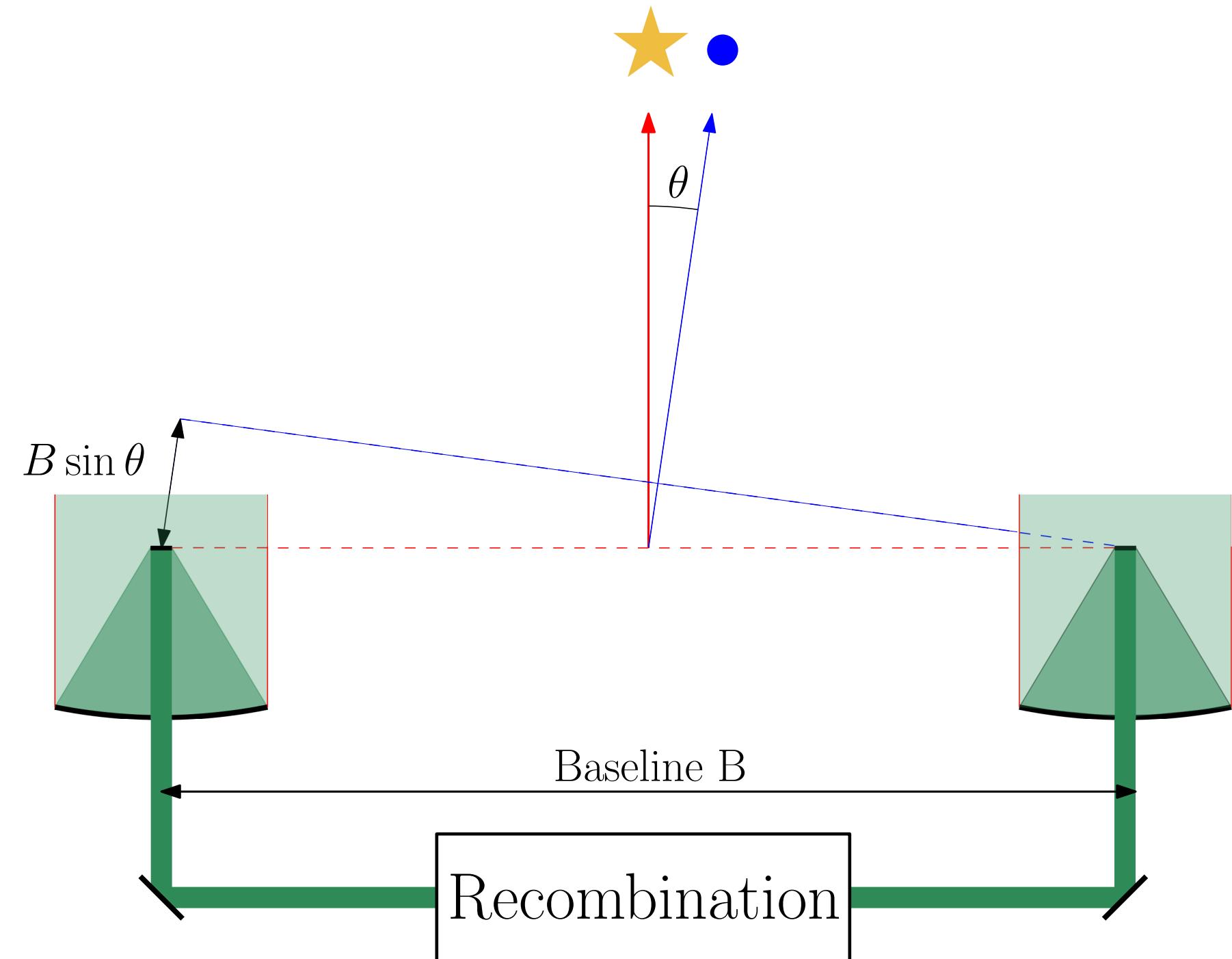
How can we **resolve** the planetary system?

i.e. 38 mas

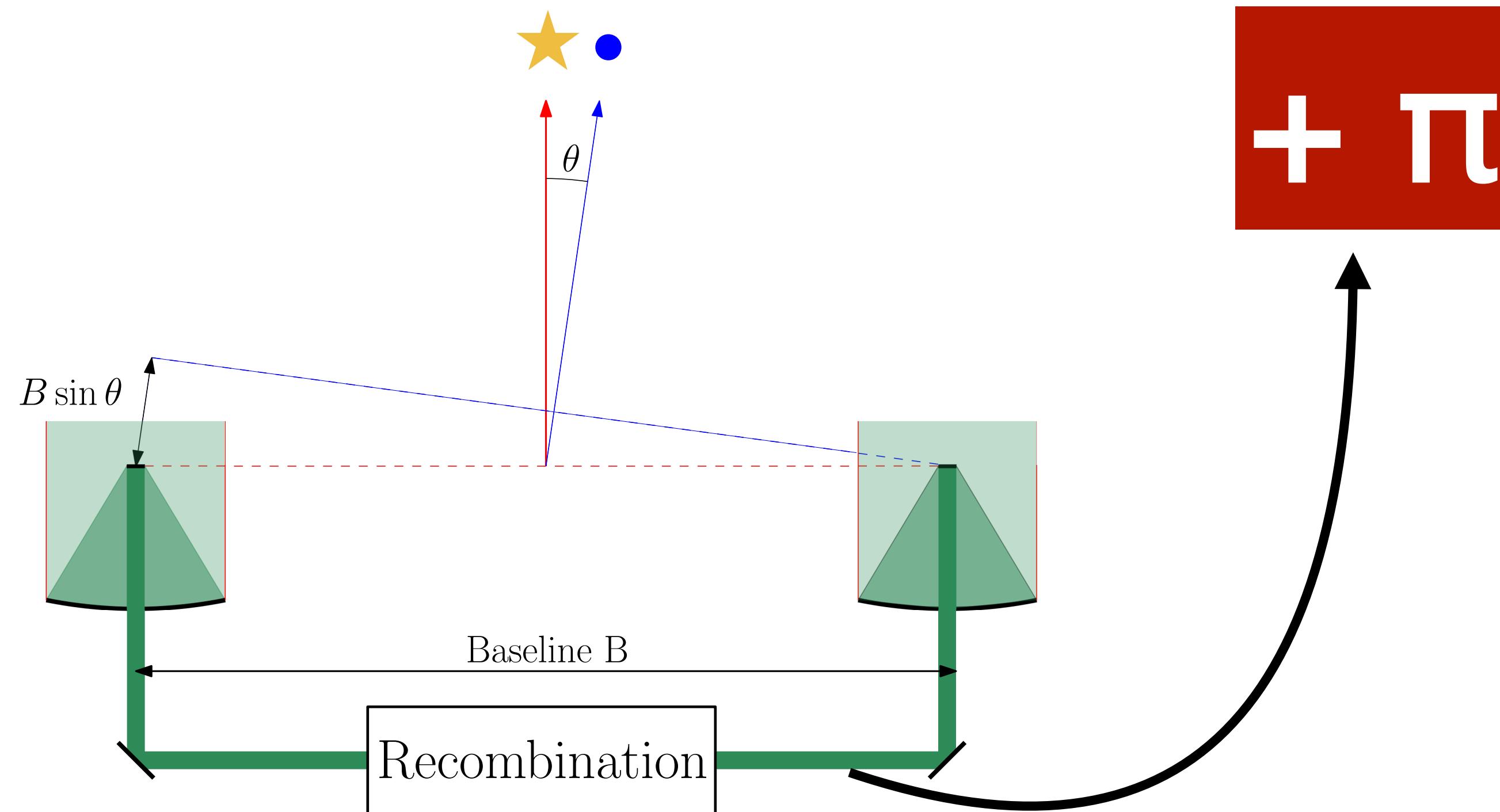
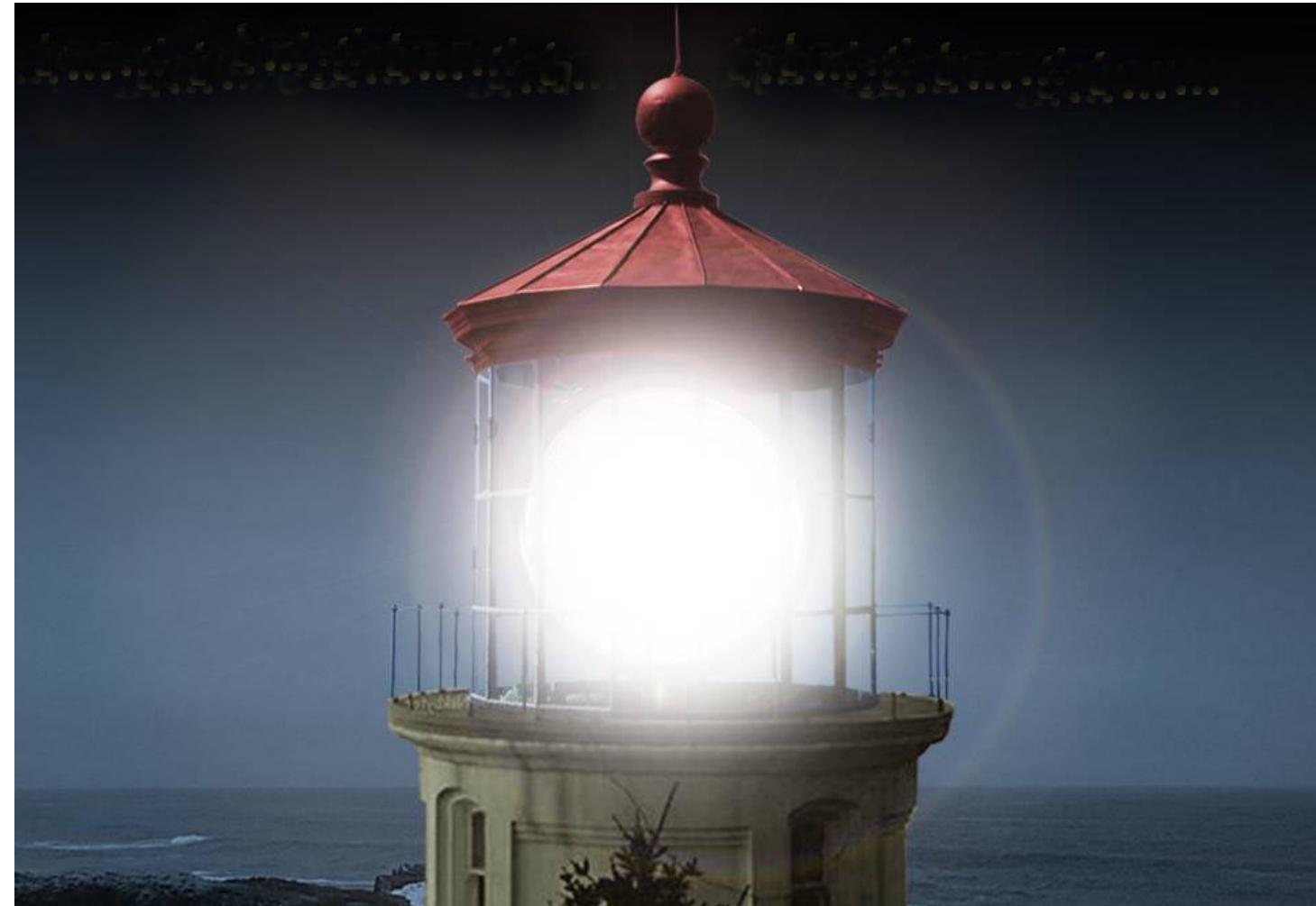


Nulling interferometry

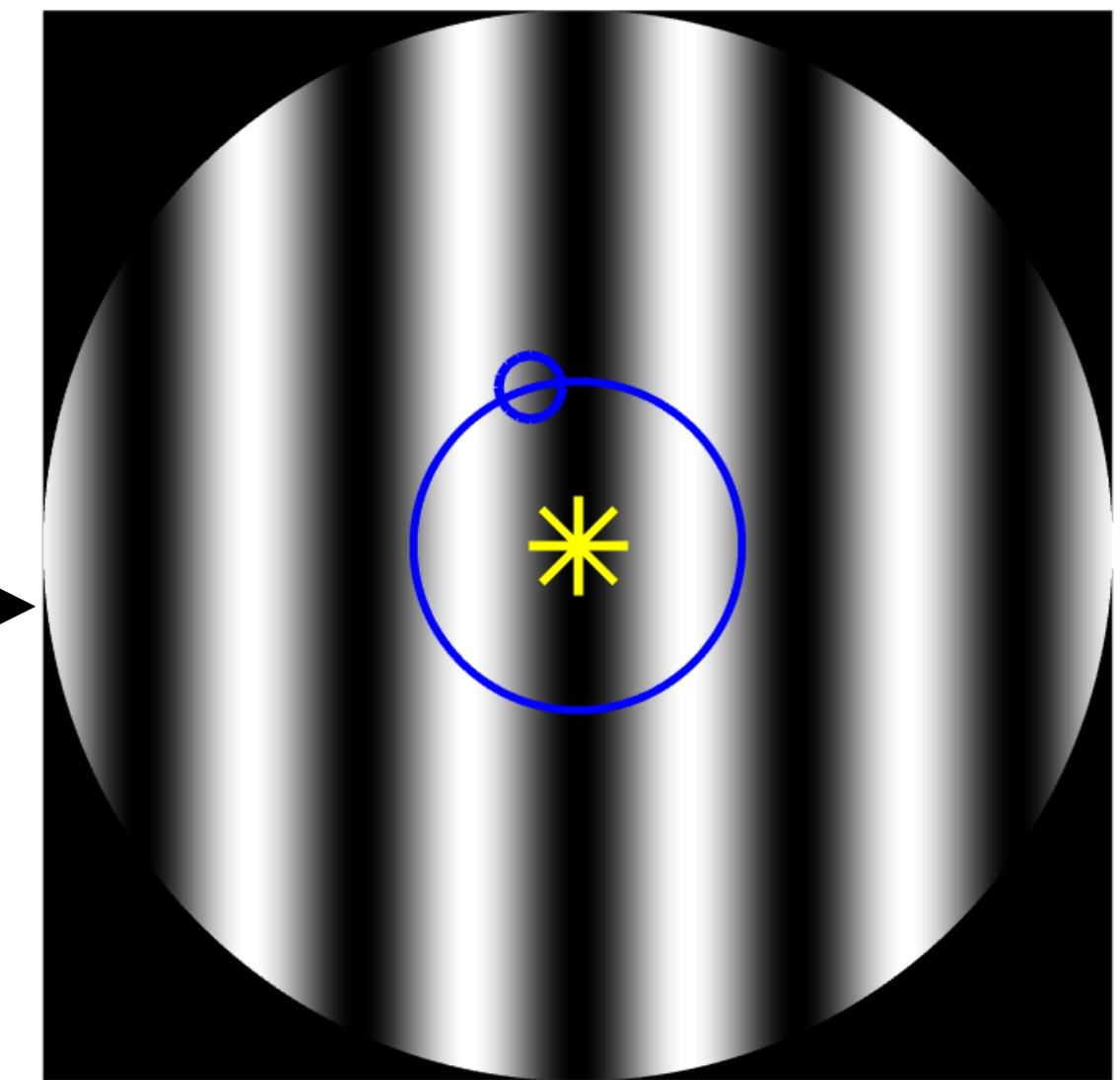
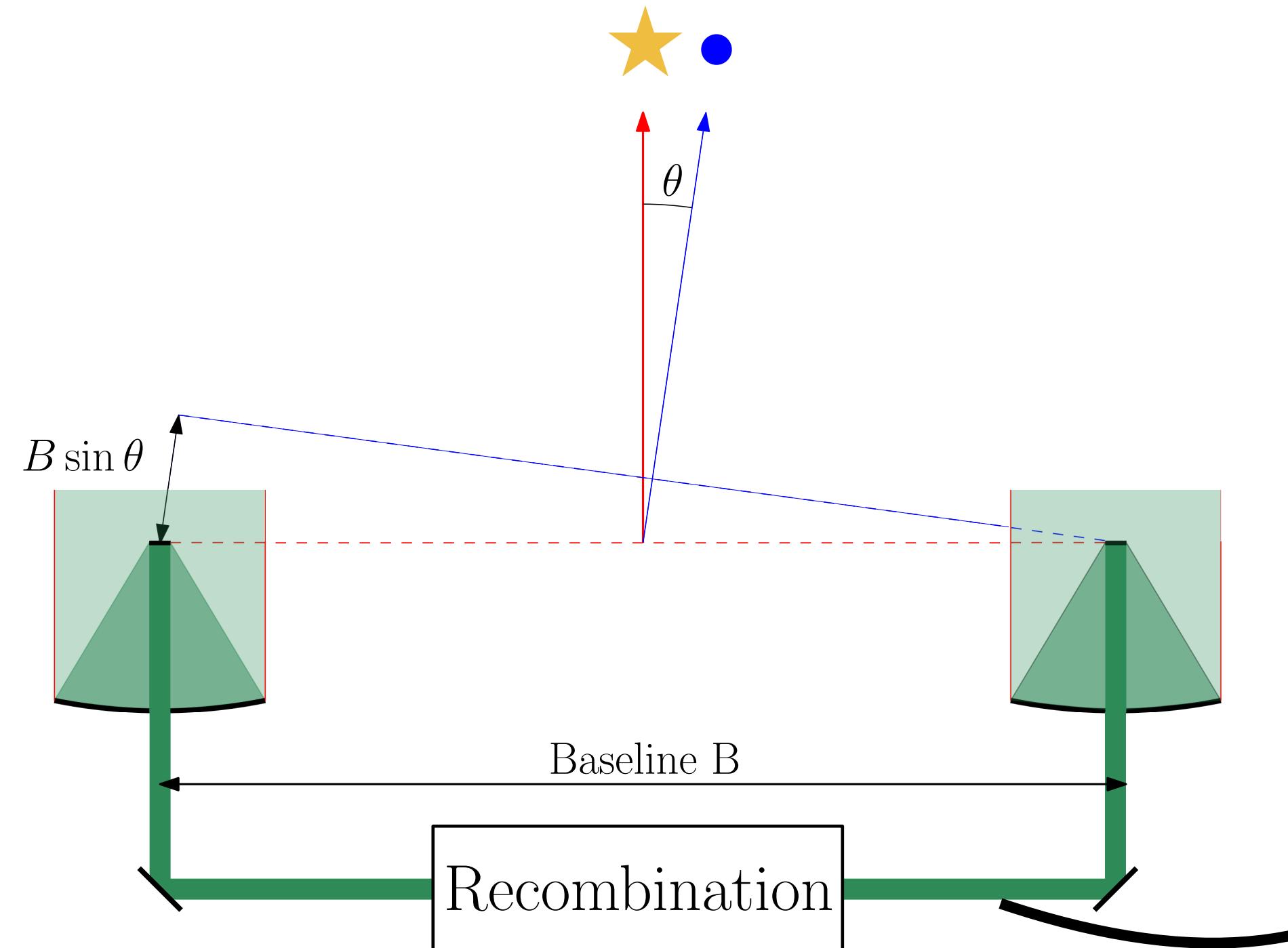
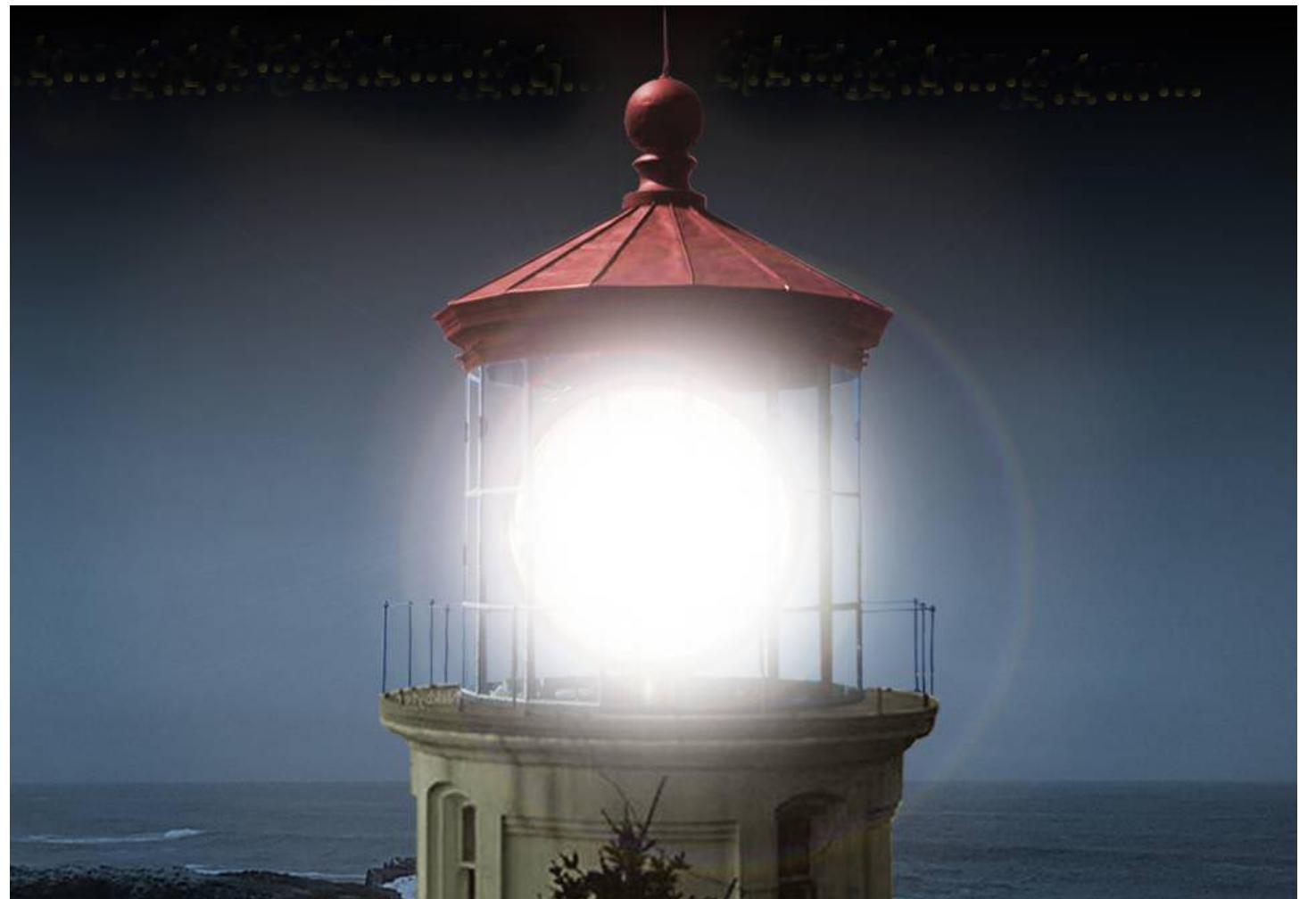
Nulling interferometry



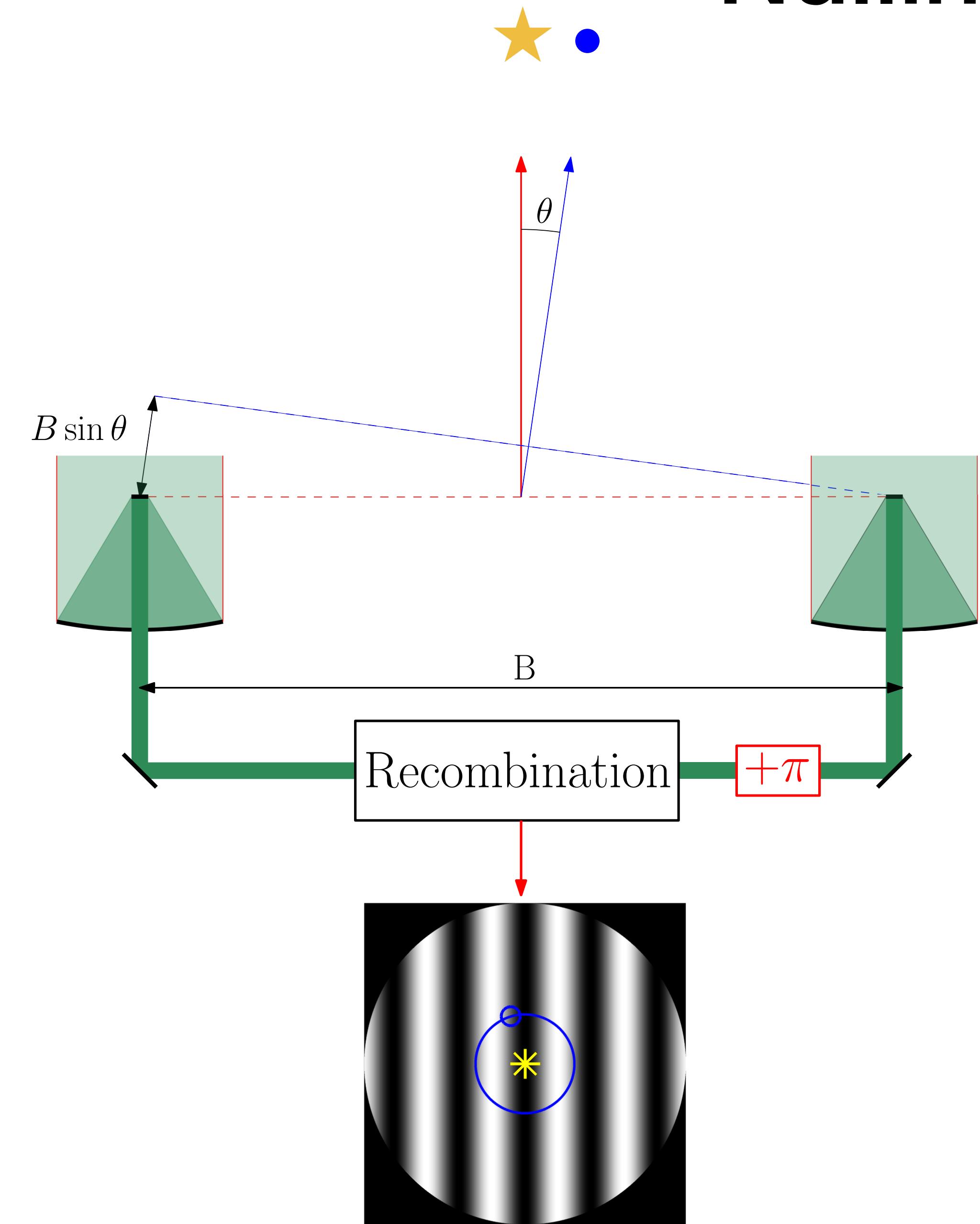
Nulling interferometry



Nulling interferometry



Nulling interferometry



High angular resolution ($D = B$)

+

Mitigation of the starlight

=

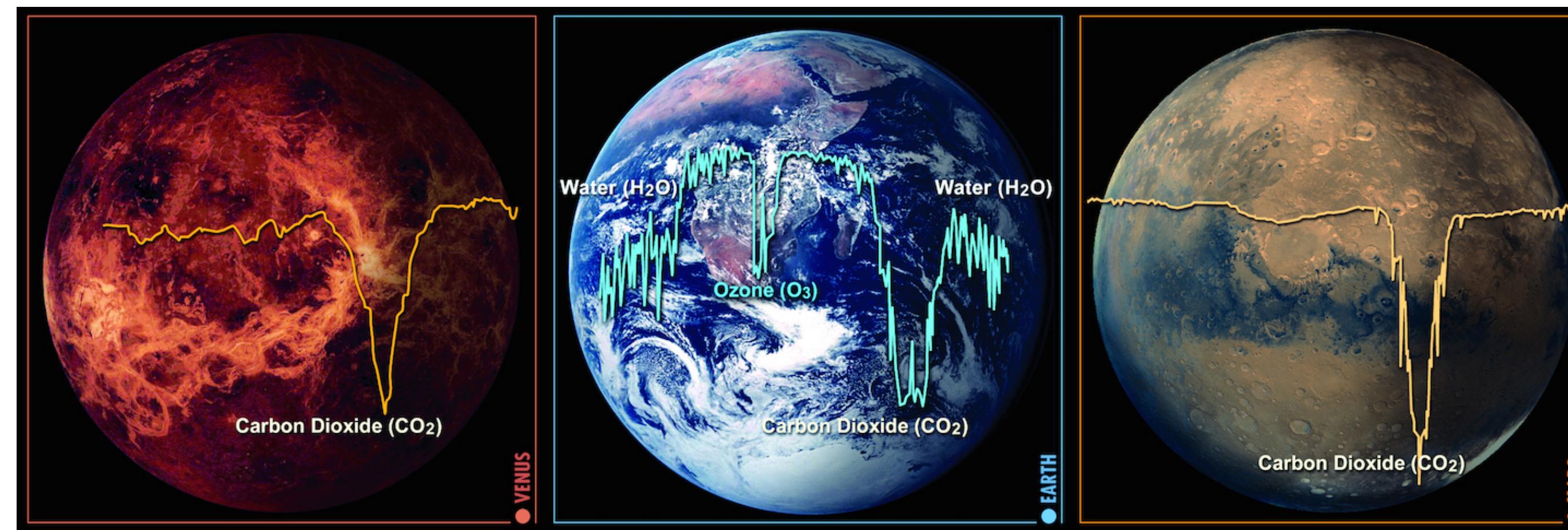
- ▶ Direct method
- ▶ Habitable zone
- ▶ Terrestrial planets
- ▶ Spectroscopy
- ▶ Bio-signatures



LIFE space mission

Large Interferometer For Exoplanets

"A space mission designed to
characterize terrestrial exoplanet atmospheres"



Quanz, Sascha P. et al. 2019. « **Atmospheric characterization of terrestrial exoplanets in the mid-infrared: biosignatures, habitability & diversity** ». arXiv:1908.01316 [astro-ph], août. <http://arxiv.org/abs/1908.01316>.

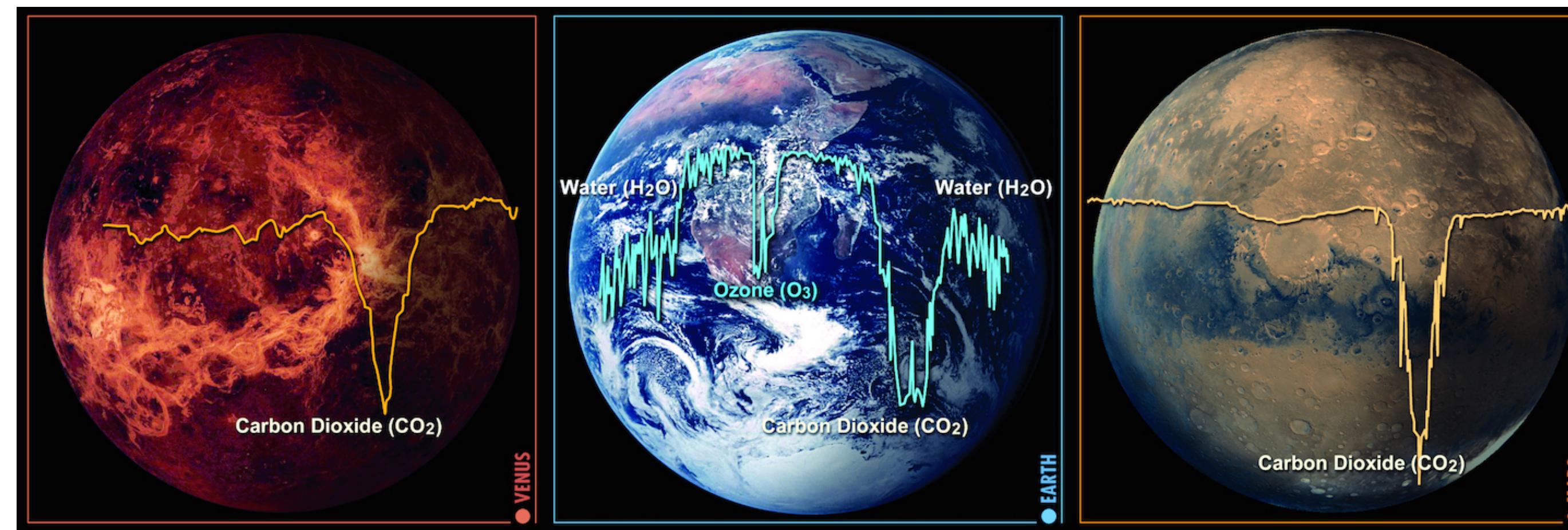
Voyage 2050 (2035-2050) - White Paper ESA



LIFE space mission

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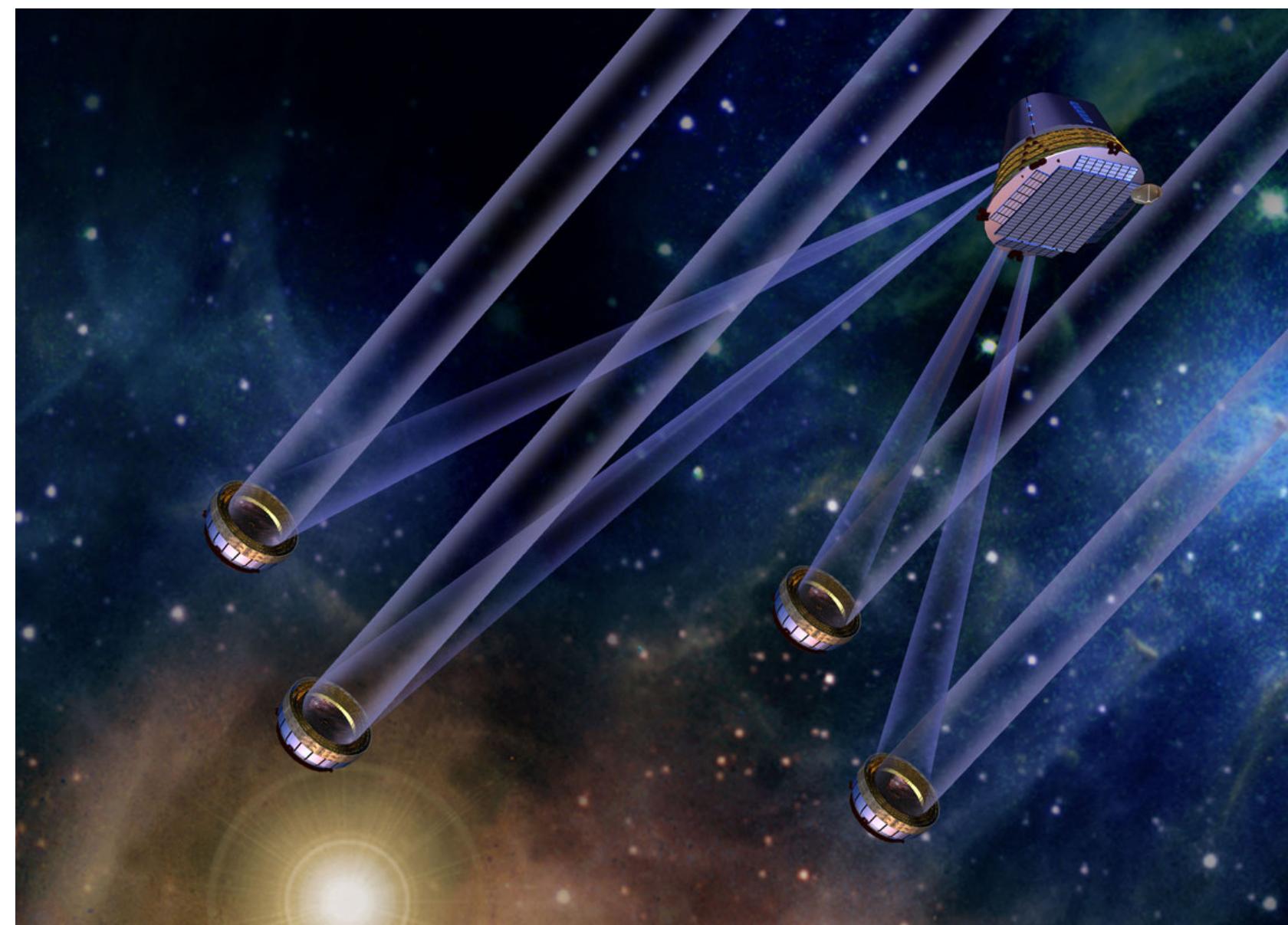
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Voyage 2050 (2035-2050) - White Paper ESA

→ CubeSat demonstrator

CubeSat demonstrator

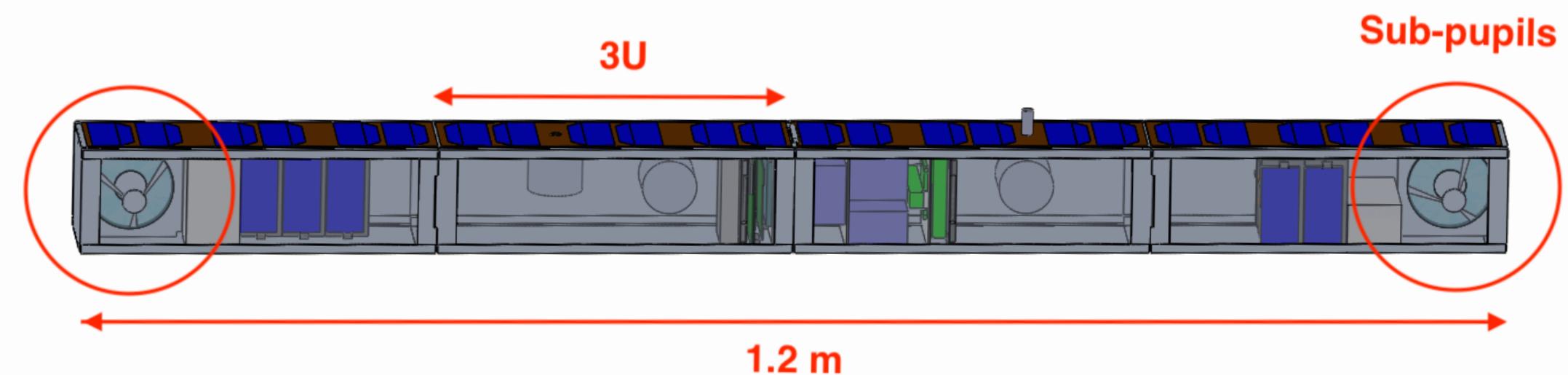
Large Formation
Flying Interferometer



Credit: ESA/Darwin

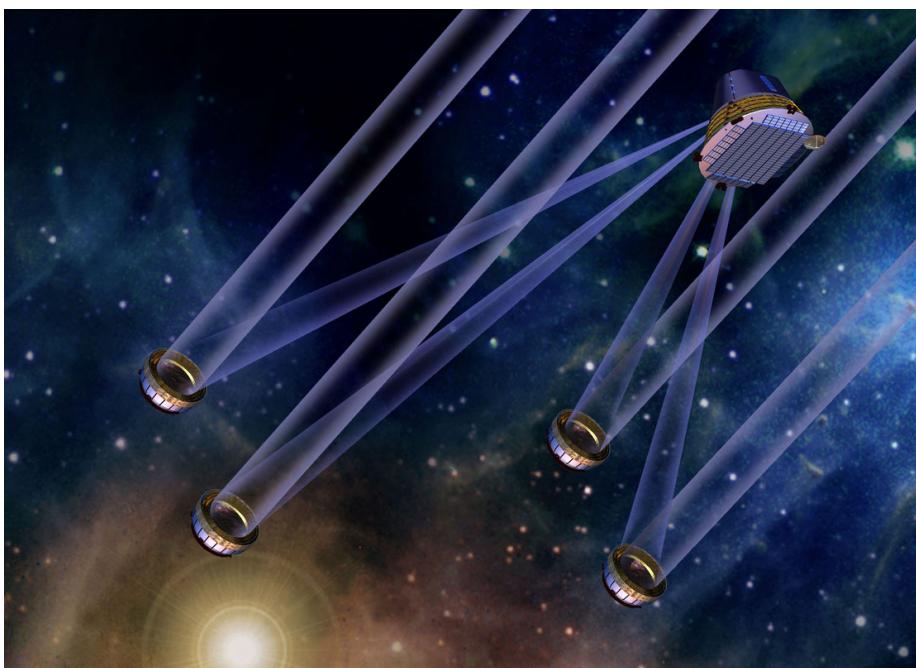
CubeSat concept

Why? A large red arrow points from the left side of the slide towards the right, indicating a transition or comparison between the two concepts.

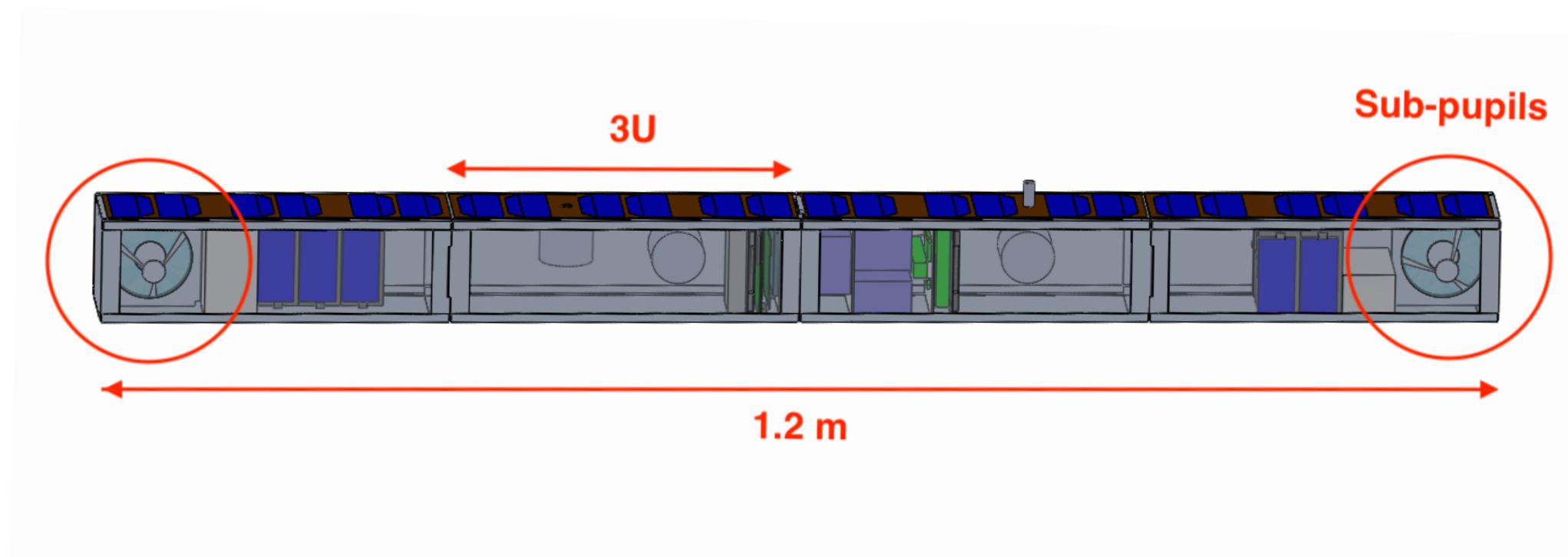


Credit: CSL/A. Bichet

CubeSat demonstrator



Why?
→



Darwin (ESA) 2007

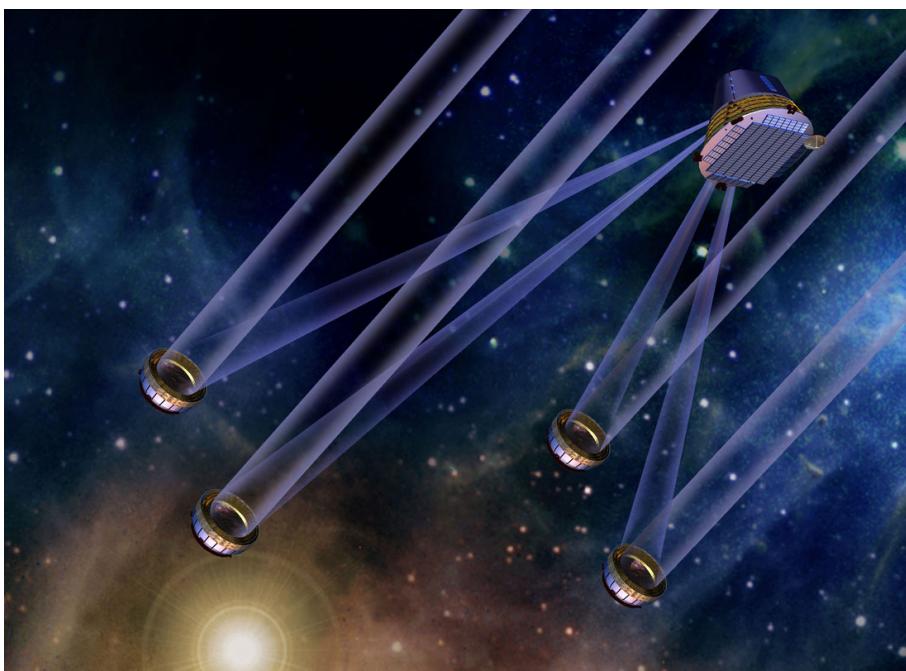
TPF-I (NASA) 2007

SPIRIT (NASA) 2007

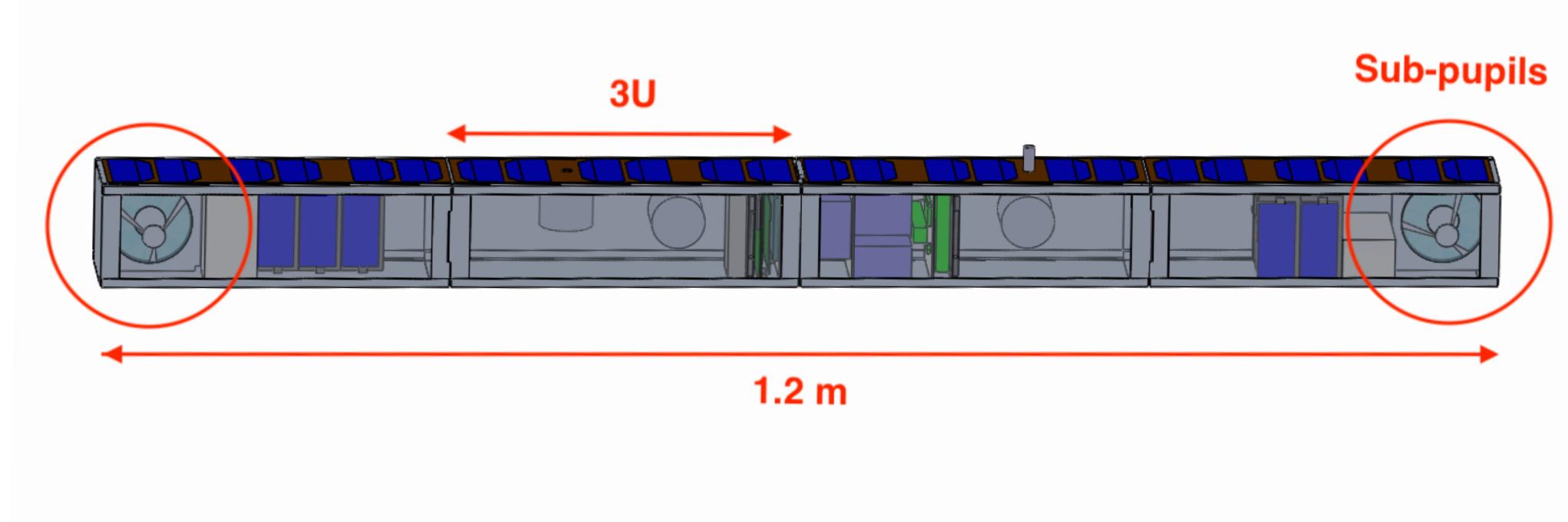
PEGASE (CNES) 2005

FKSI (Goddard) 2007

CubeSat demonstrator



Why?
→

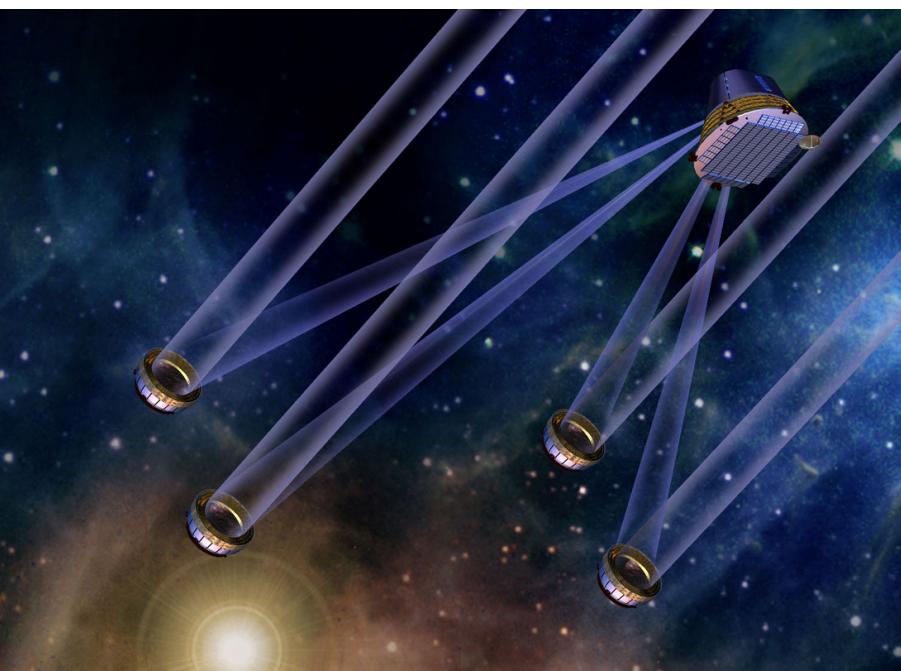


**Technological
maturity**

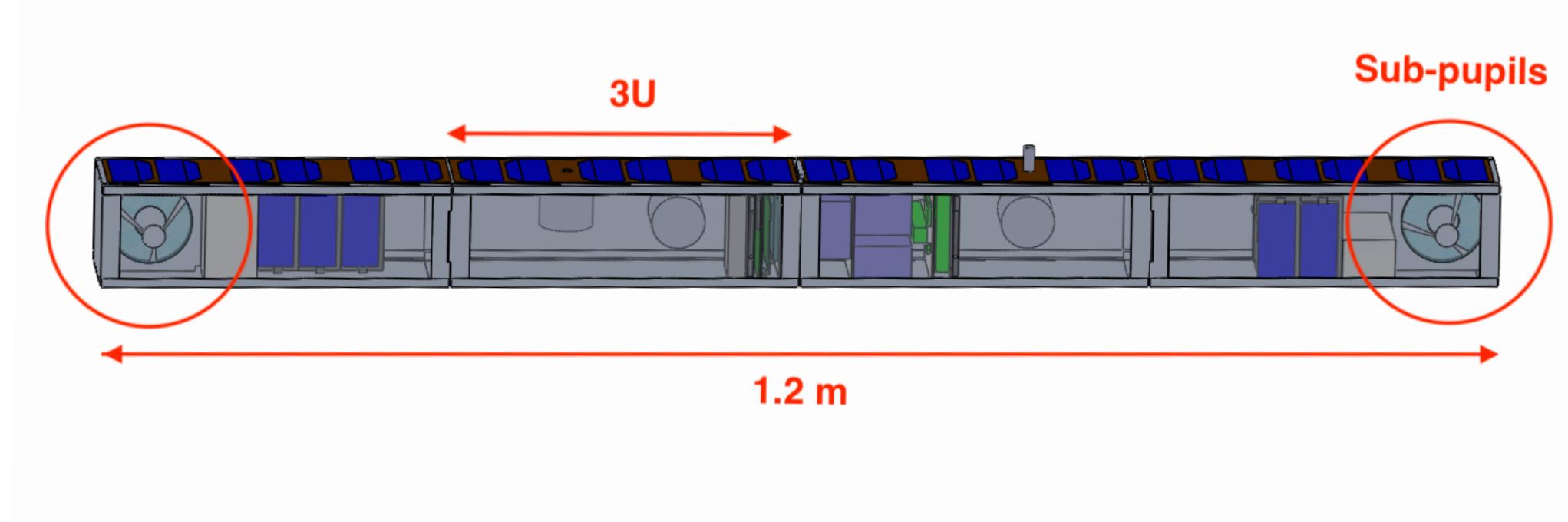
Cost

Risk

CubeSat demonstrator



Why?
→



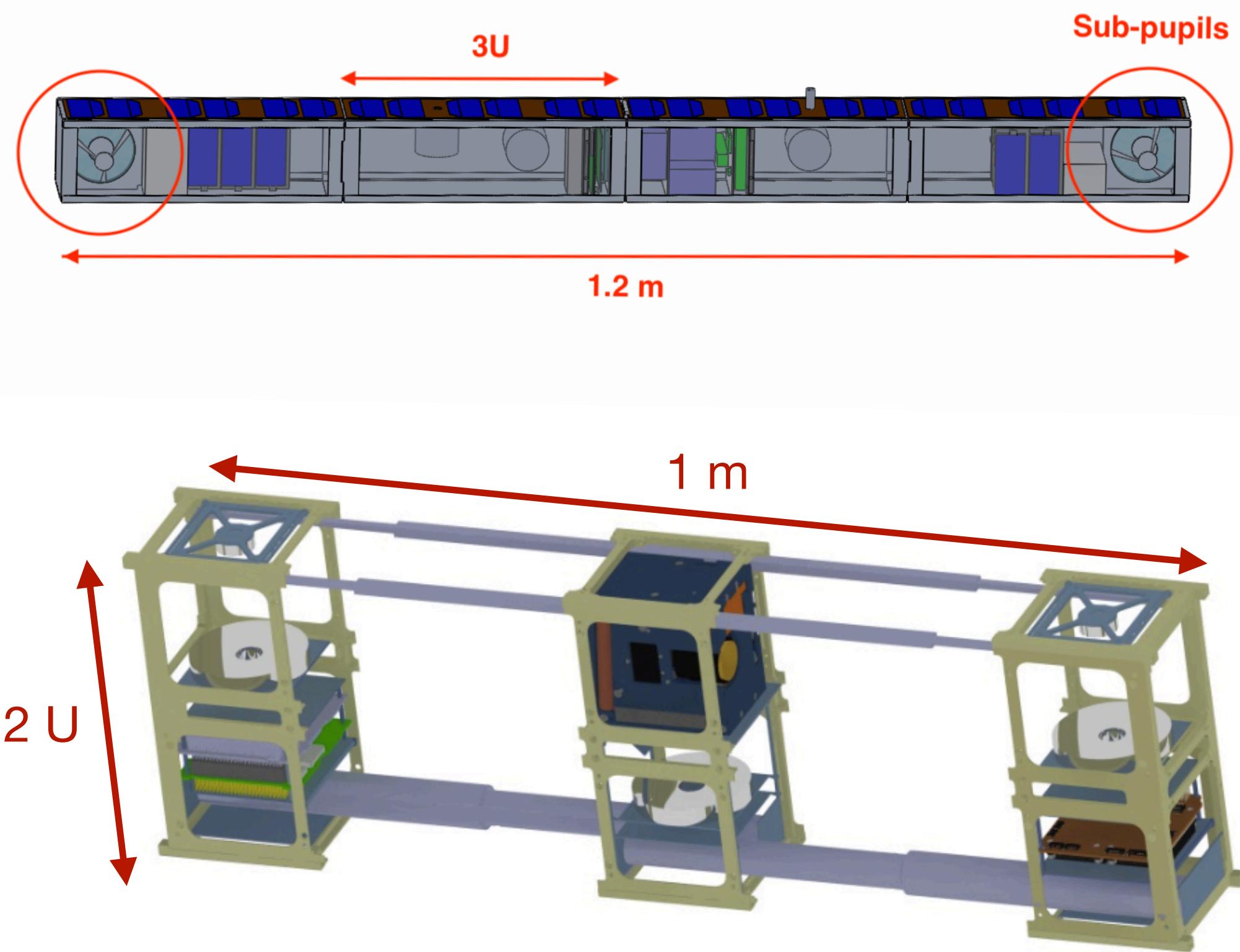
**Technological
maturity**

Cost

Risk

CubeSat demonstrator

- Main goal: **demonstrate interferometry in space**
- 2 sub-pupils = Bracewell configuration
- **No free flying**
- Modal filtering thanks to optical fibers
- Several concepts studied (master thesis)
- Lower scientific expectations
(hot Jupiter, exozodi, ...)



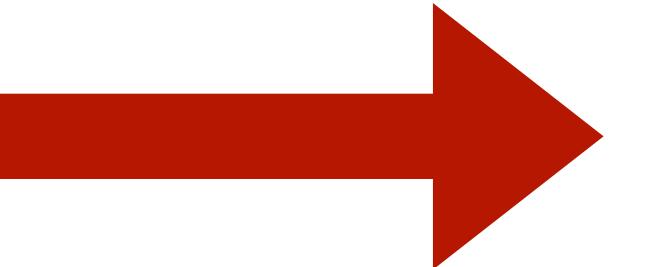
Credits: CSL/A. Bichet & S. Duijsens

CubeSat science

- Science will be done with this satellite!
- What can be detected, characterized?
- Where to look?

CubeSat science

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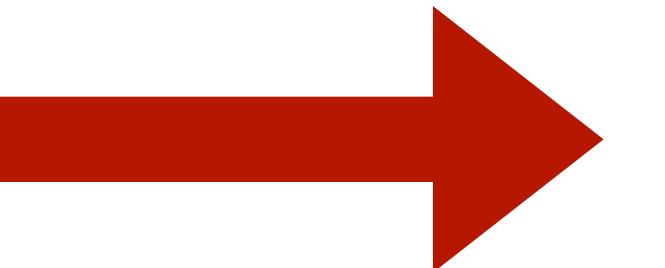


Foundation of the science case

- ▶ Fluxes
- ▶ Noises
- ▶ Signal-to-Noise ratio
- ▶ Detection yields

CubeSat science

- Science will be done with this satellite!
- What can be detected, characterized?
- Where to look?



Foundation of the science case

- ▶ Fluxes
- ▶ Noises
- ▶ Signal-to-Noise ratio
- ▶ Detection yields

Dandumont et al., 2019.

"Exoplanet detection yield of a space-based Bracewell interferometer, from nano- to small-satellites"

In preparation

CubeSat science

Science case

- ▶ Fluxes
- ▶ Noises
- ▶ Signal-to-Noise ratio
- ▶ Detection yields

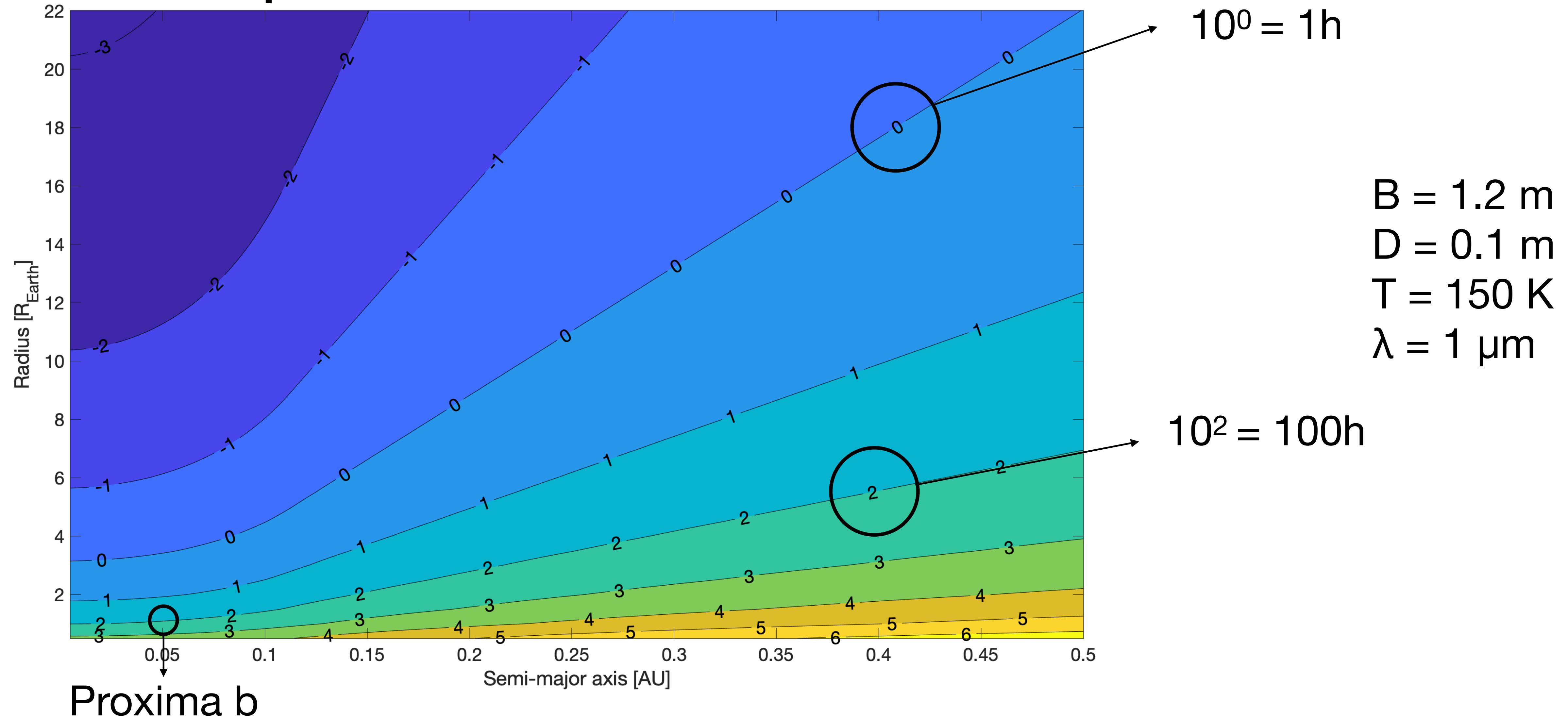


Architecture

- ▶ Diameter of sub-pupils
- ▶ Baseline length
- ▶ Temperature
- ▶ Bandwidth
- ▶ ...

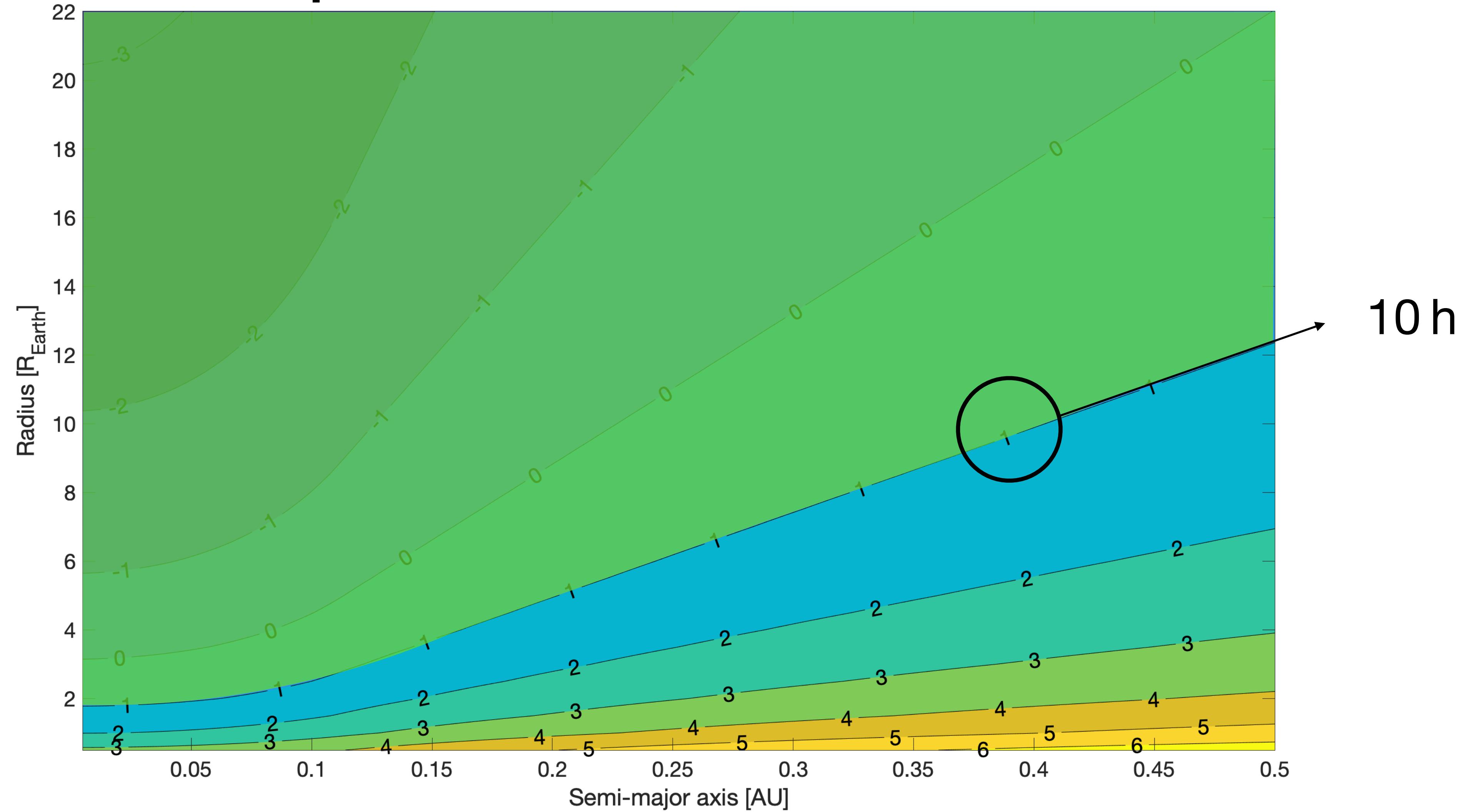
CubeSat science

Exoplanets around Proxima Centauri



CubeSat science

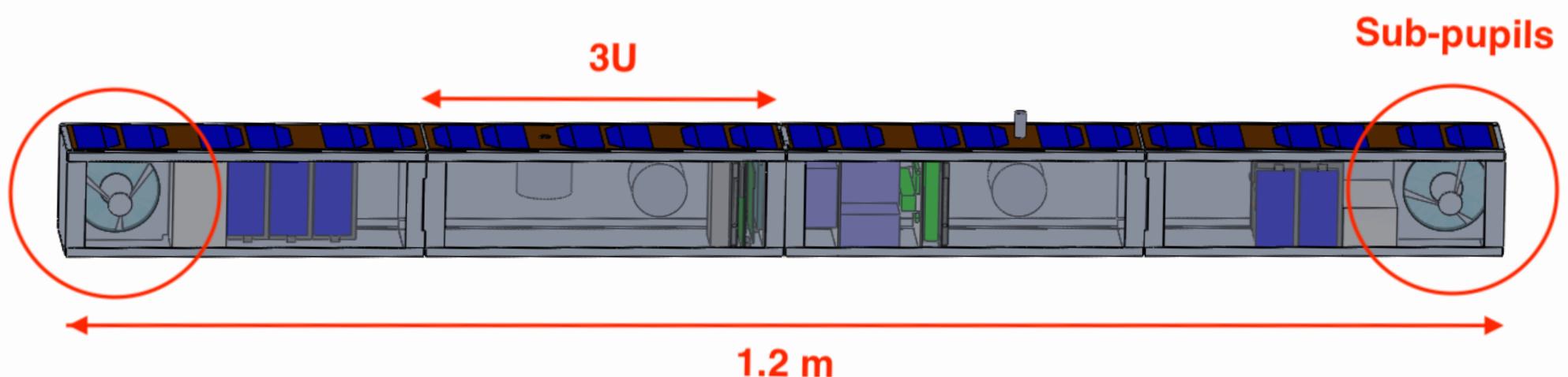
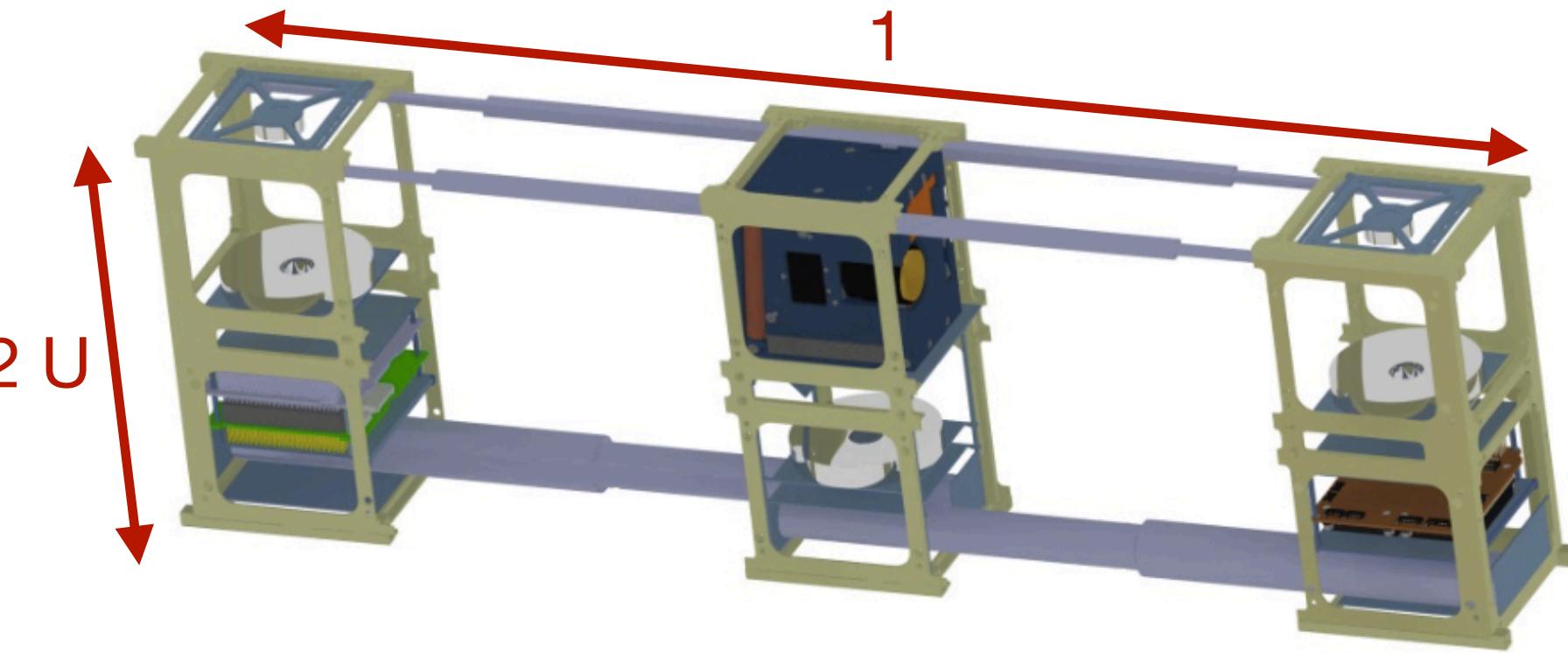
Exoplanets around Proxima Centauri

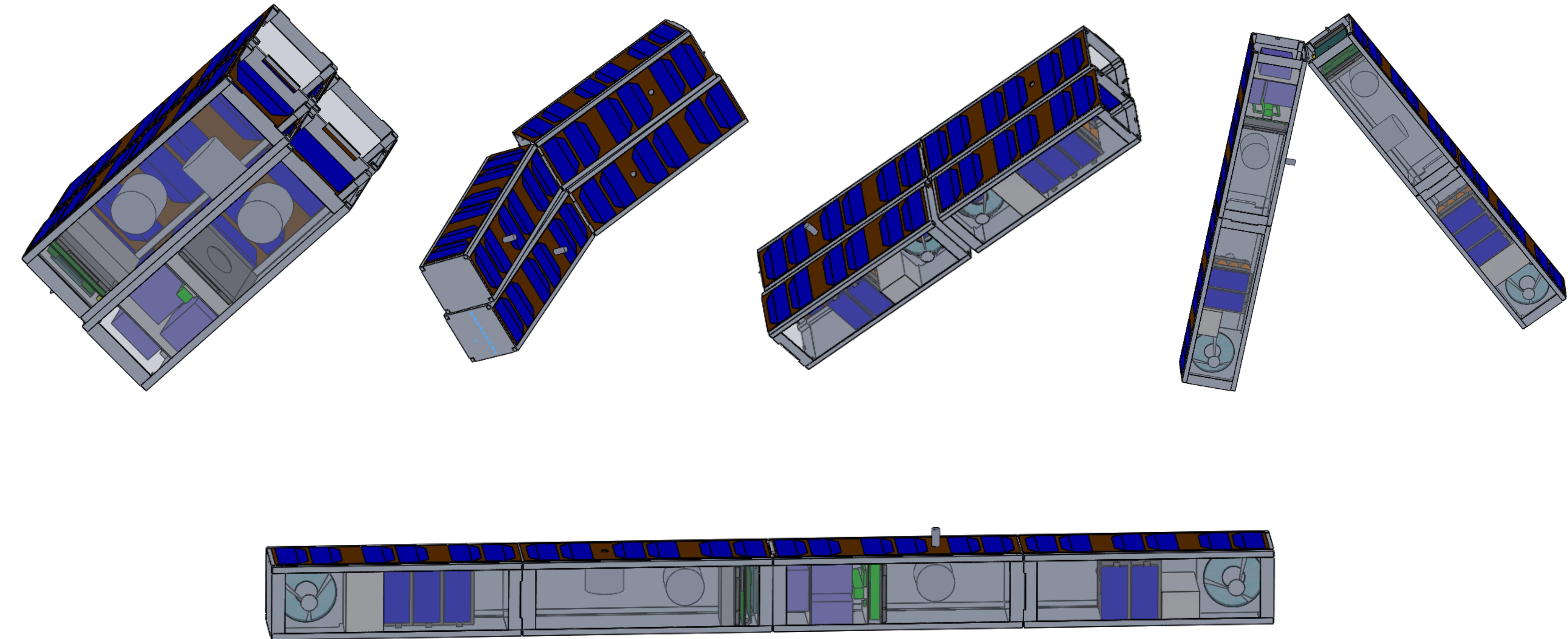


$B = 1.2 \text{ m}$
 $D = 0.1 \text{ m}$
 $T = 150 \text{ K}$
 $\lambda = 1 \mu\text{m}$

CubeSat requirements

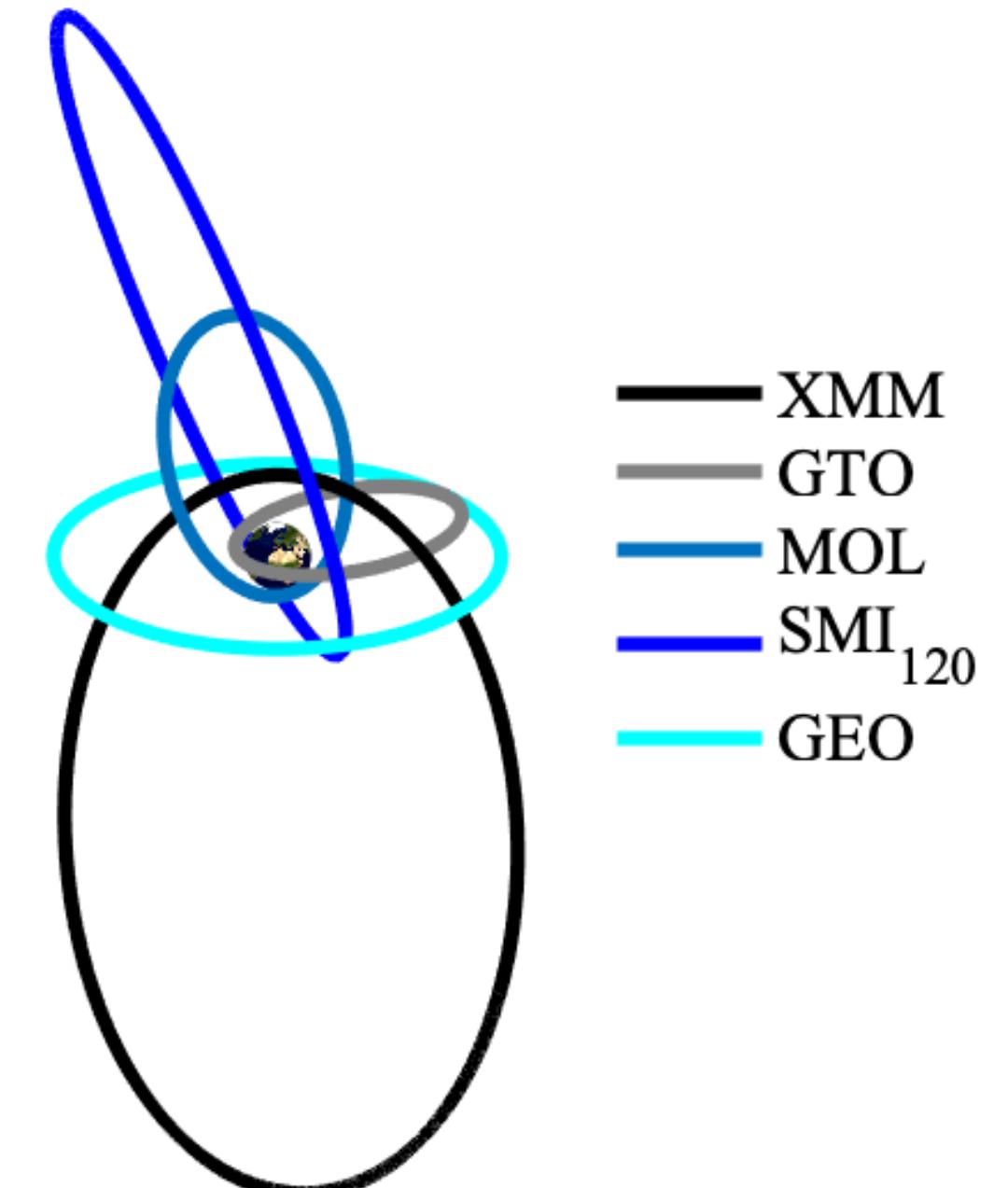
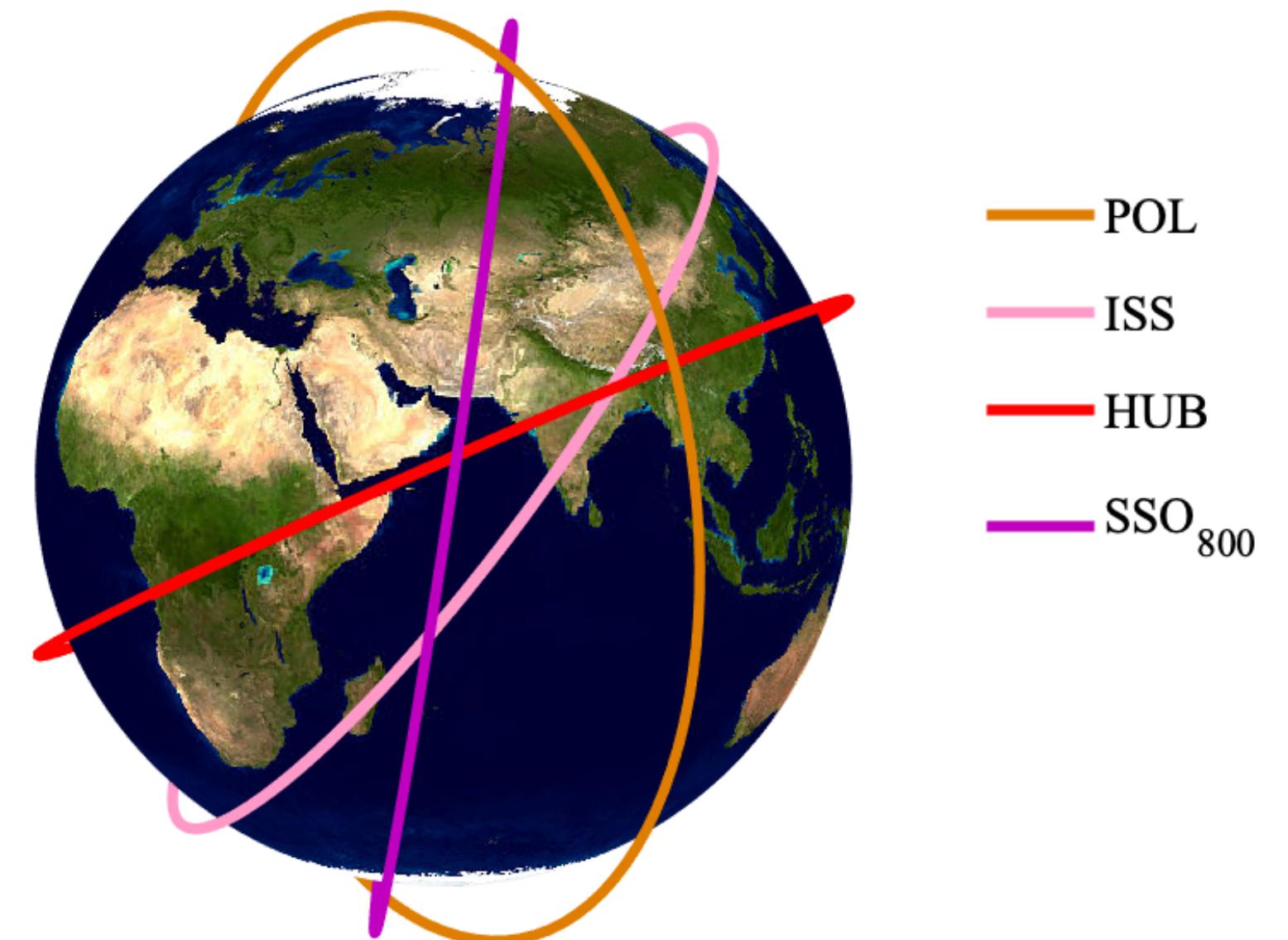
- Baseline length (~ meters)
- **Very fine pointing + stability** (~ < arcsec) - PicSat?
- Delay line sensors and actuators (~ nm)
- Precise rotation around the line of sight
- Fiber injection
- Achromatic phase shift
- Thermal control and cooling of payload (150/200 K)
- Long integration time (~ 15/20 h)
- ...





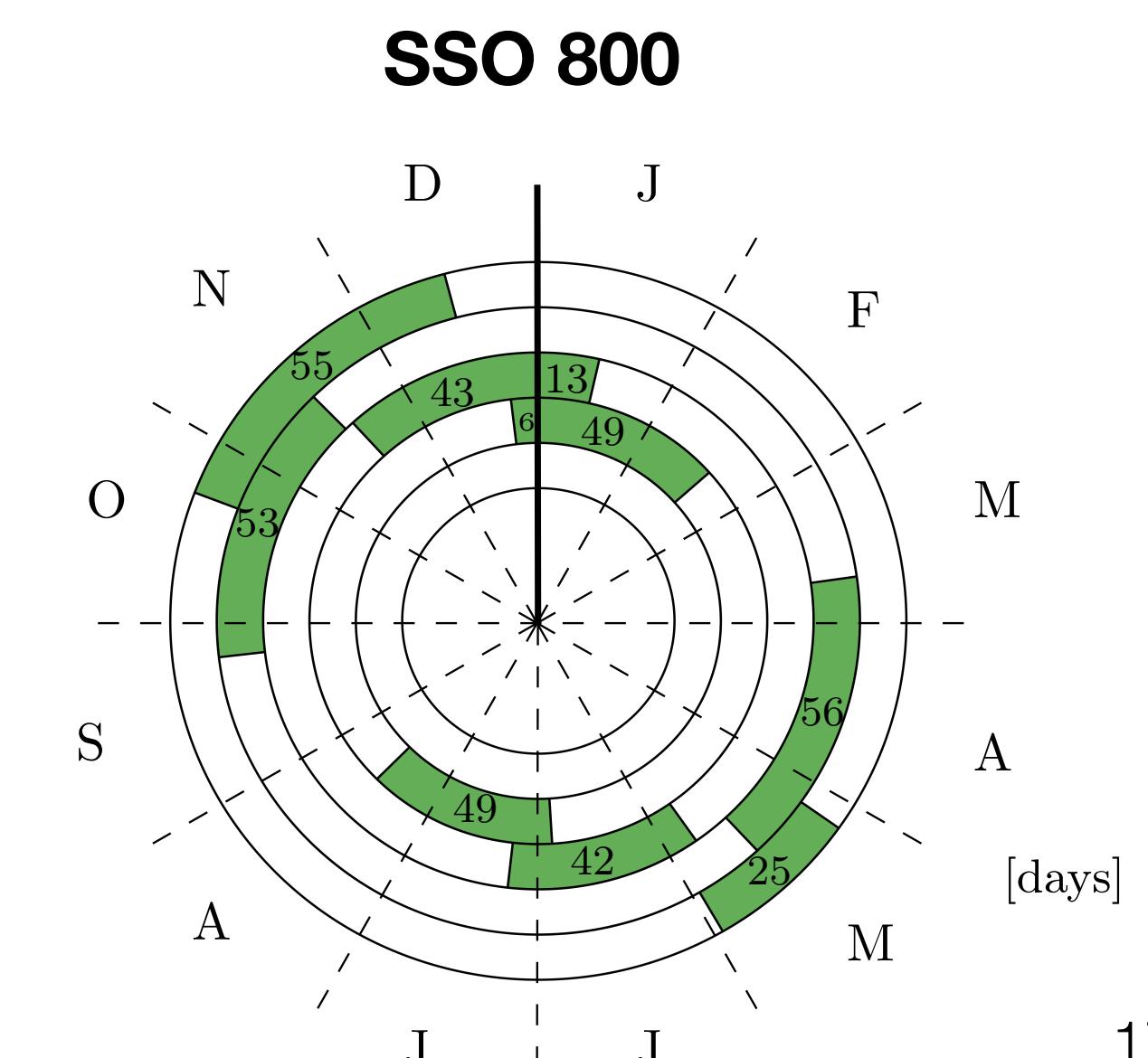
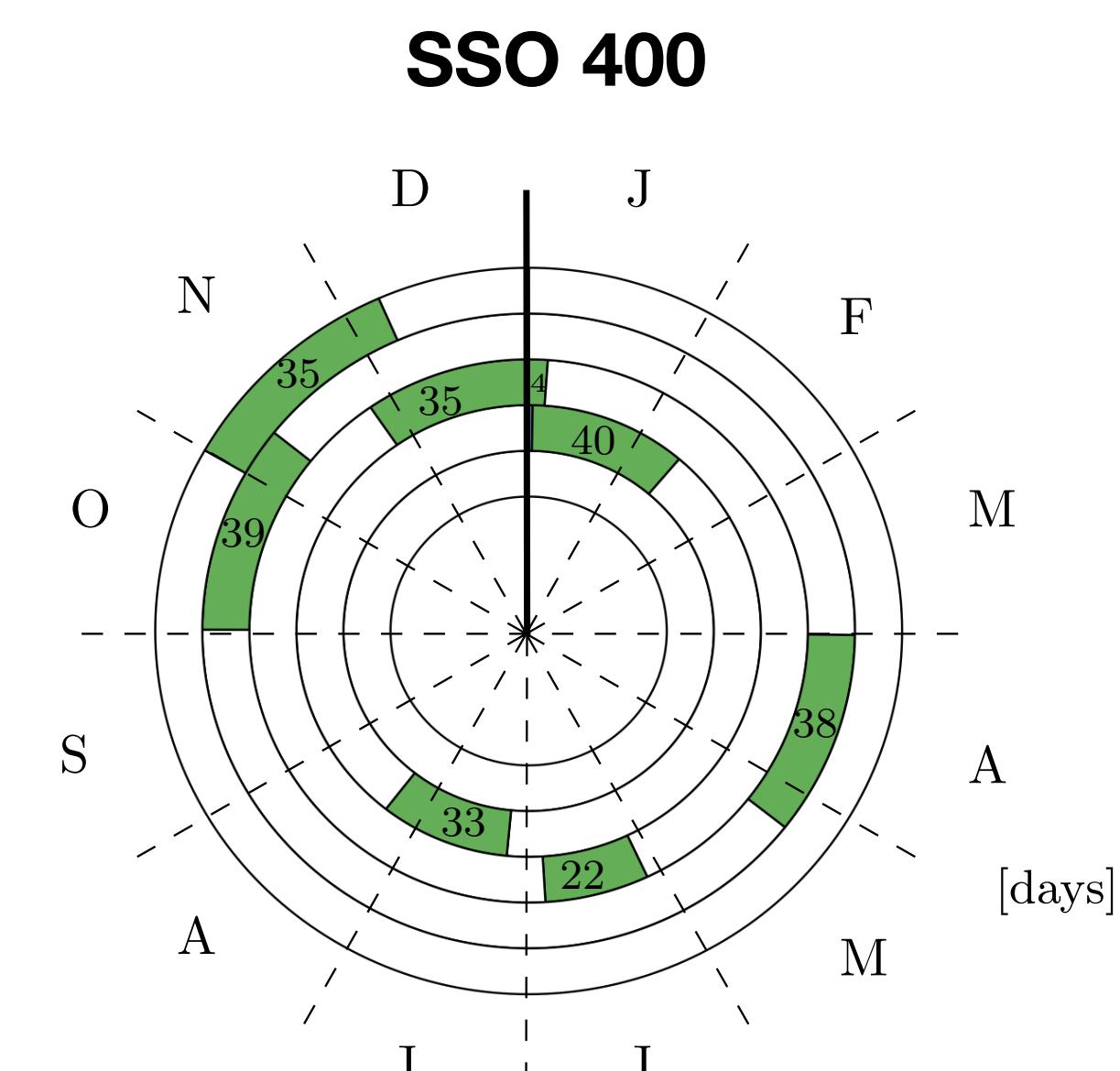
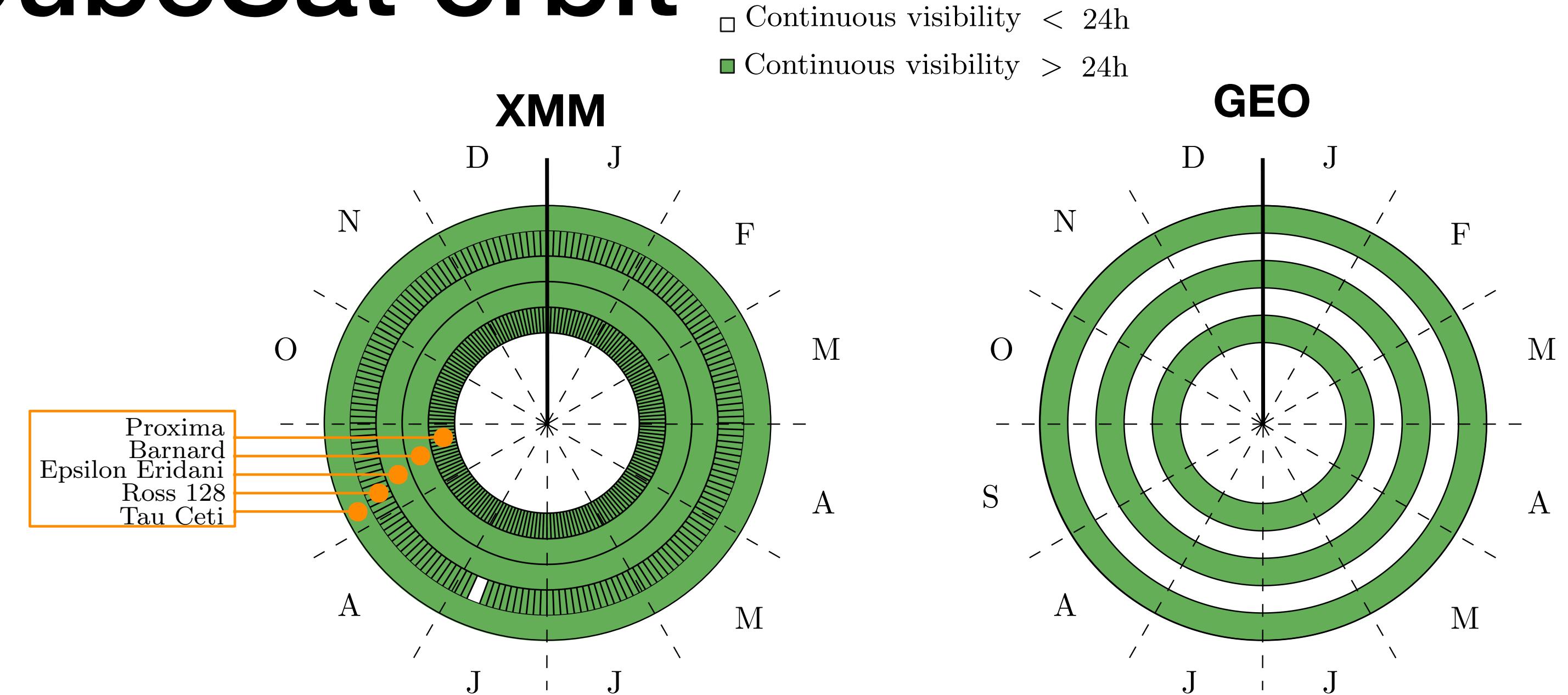
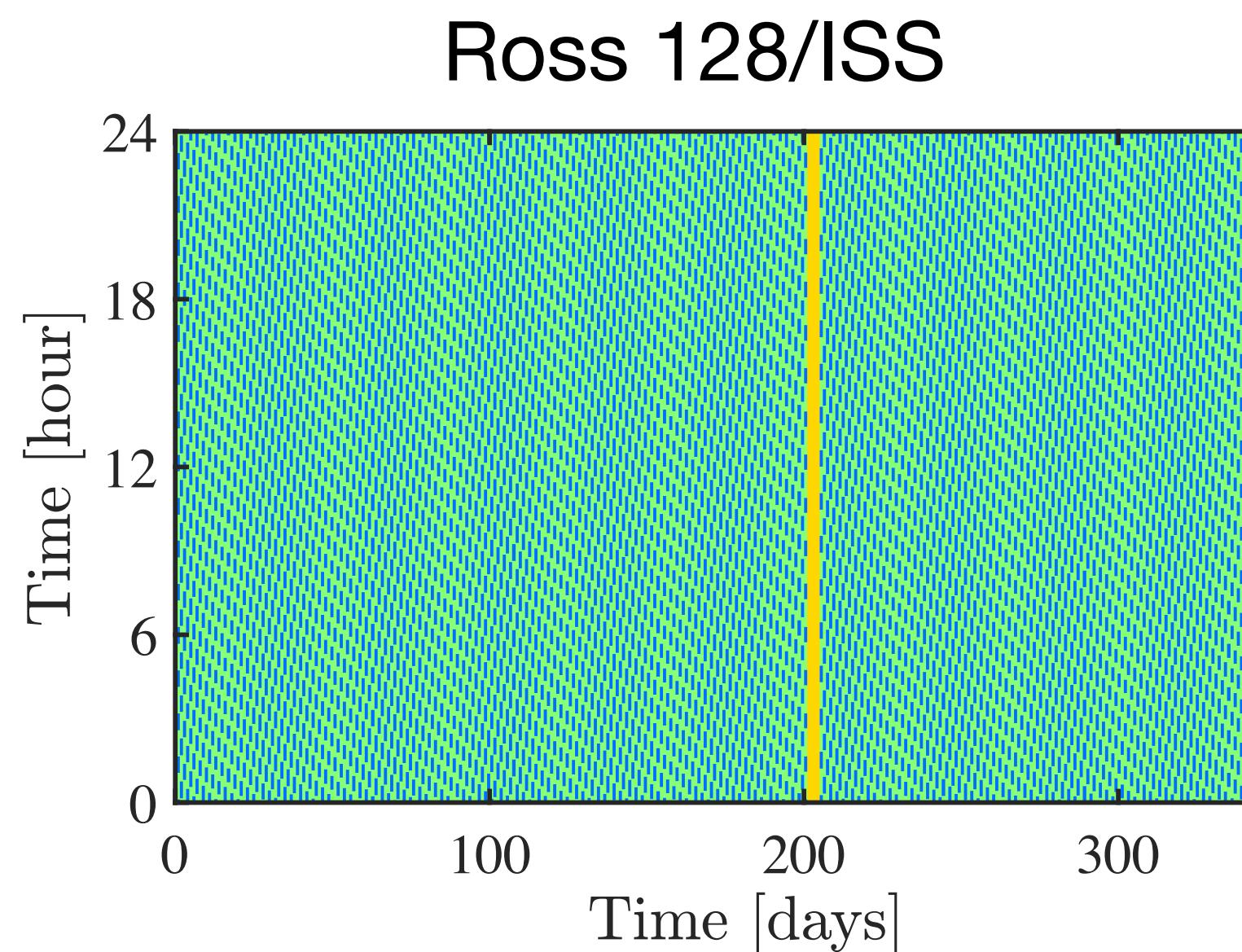
CubeSat orbit

- 5 closest stars with exoplanets considered
 - ▶ Proxima Centauri
 - ▶ Barnard's Star
 - ▶ Epsilon Eridani
 - ▶ Ross 128
 - ▶ Tau Ceti
- Set of orbits considered
- 24h of integration time



CubeSat orbit

- Observational constraints
 - ▶ Sun
 - ▶ Earth
 - ▶ Moon

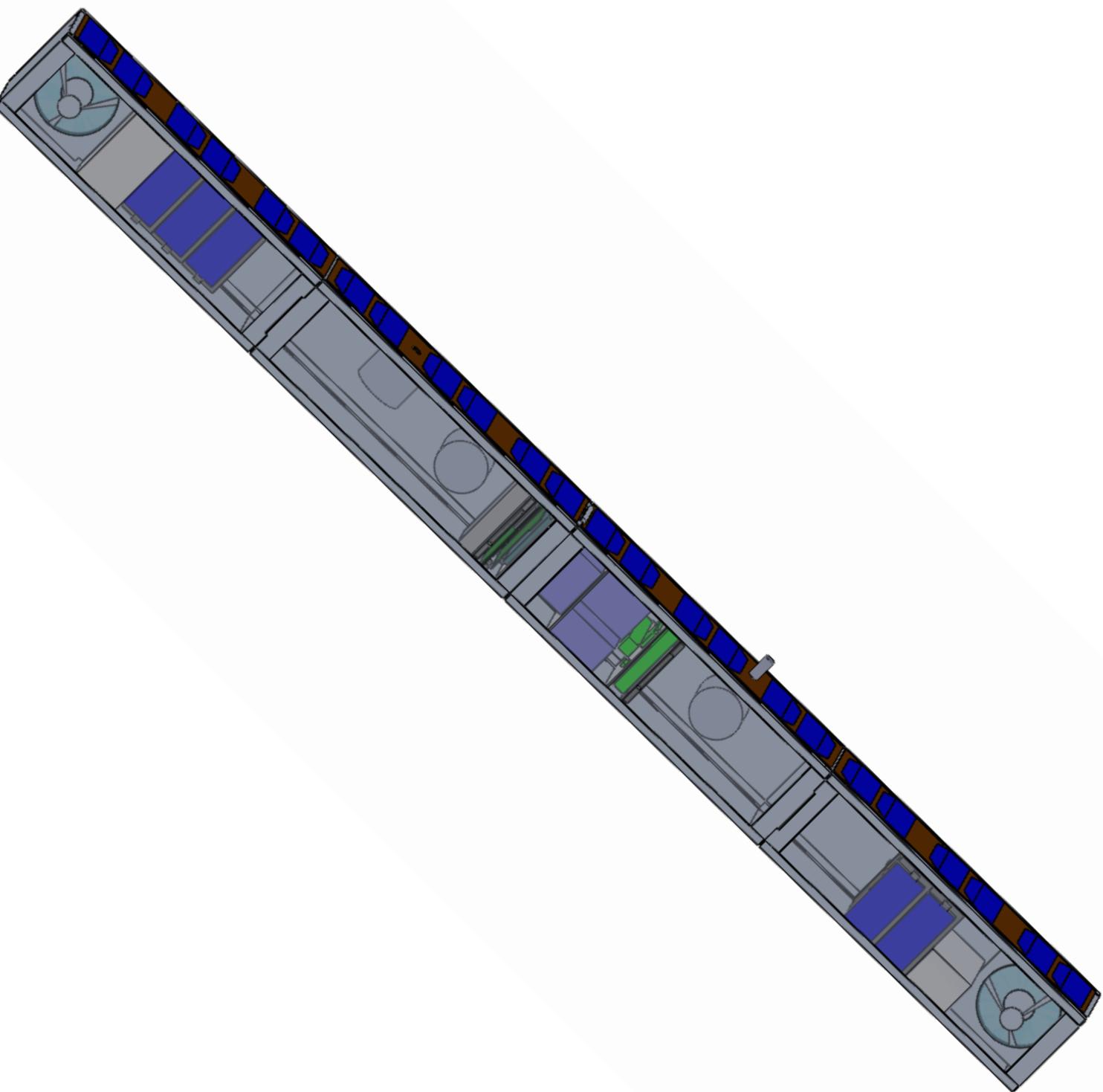


Credits: CSL/S. Dibartolomeo

Conclusion



- **Astrophysics** with a CubeSat = **Science driven**
- **Technological** demonstrator for **LIFE**
- First **stellar interferometer** in space
- Direct method = **clouds, atmosphere, etc.**
- Early design



Thanks for your attention

Acknowledgements



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- ▶ C. DANDUMONT
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- ▶ Dr. D. DEFREERE
ddefrere@uliege.be
- ▶ Prof. J. LOICQ
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Belgium
+32 (0)4 382 46 00
csl@ulg.ac.be

CubeSat science

$B = 1.2 \text{ m}$
 $D = 0.1 \text{ m}$
 $T = 150 \text{ K}$

Around Proxima Centauri
 $R = 3 R_{\text{Earth}}$
 $a = 0.82 \text{ AU}$

