OPTIMIZATION OF PHOTON-SAIL TRAJECTORIES TO ALPHA CENTAURI USING EVOLUTIONARY NEUROCONTROL

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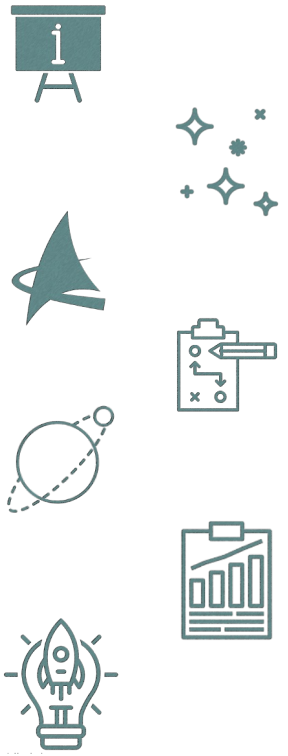

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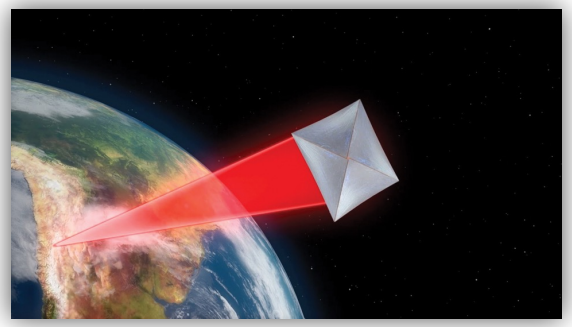
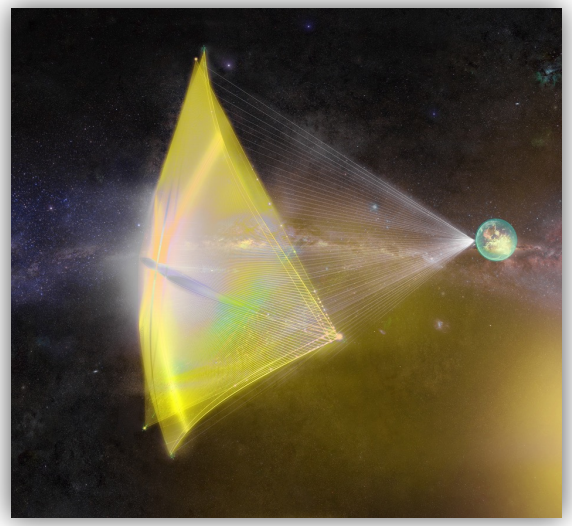
Introduction

Breakthrough Starshot

- Prove interstellar travel to Proxima Centauri
- Laser-driven sail
- 20% of speed of light → 20 years
- Fly-through mission → 1 day passage
- Goal: Pictures of exoplanet Proxima b



Source: Breakthrough Starshot



Source: Breakthrough Starshot

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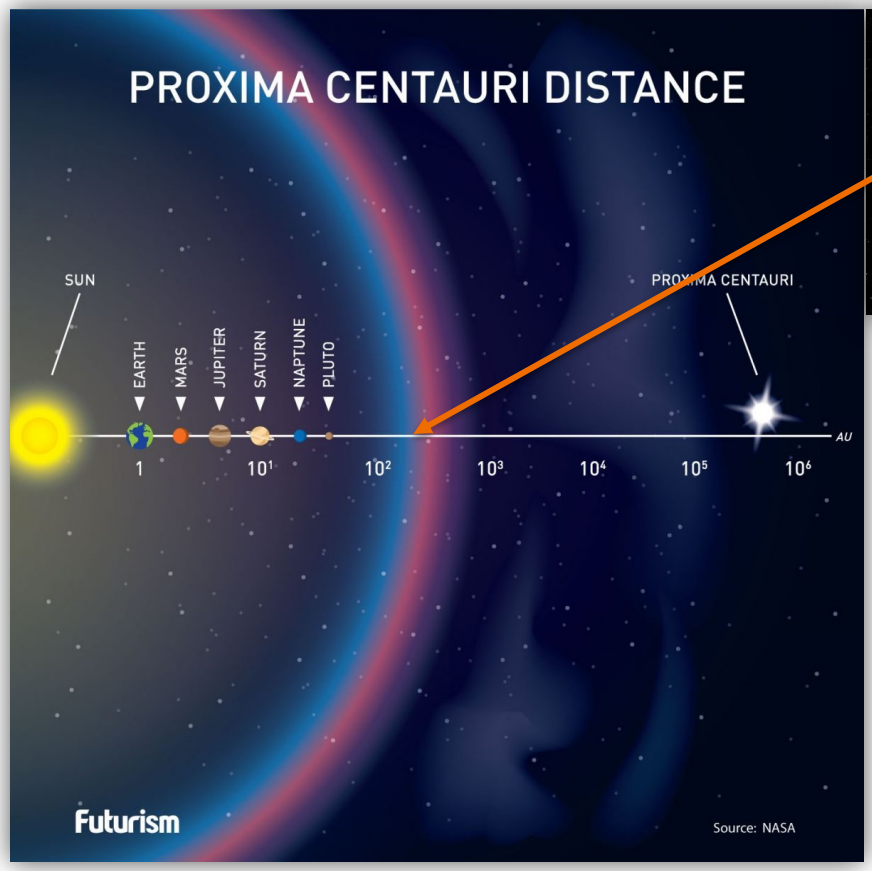
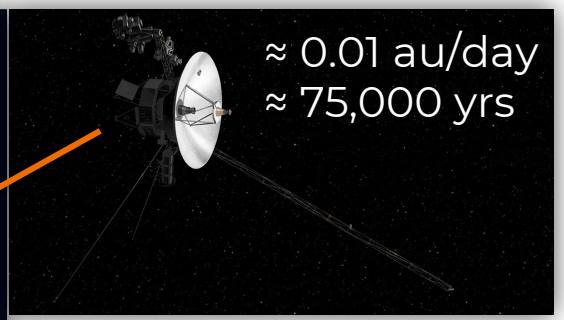
Introduction





Source: NASA

Breakthrough Starshot:

Solar system escape velocity ≈ 35 au/day

Introduction

Primary Goal

*To find the optimal steering strategy for a photonic sail to get **captured** into the Alpha-Centauri system after a minimum-time transfer from Earth*

Secondary Goal

*To investigate **transfer** trajectories between the Alpha-Centauri stars and **orbit-raising** maneuvers to explore the habitable zones of the stars*

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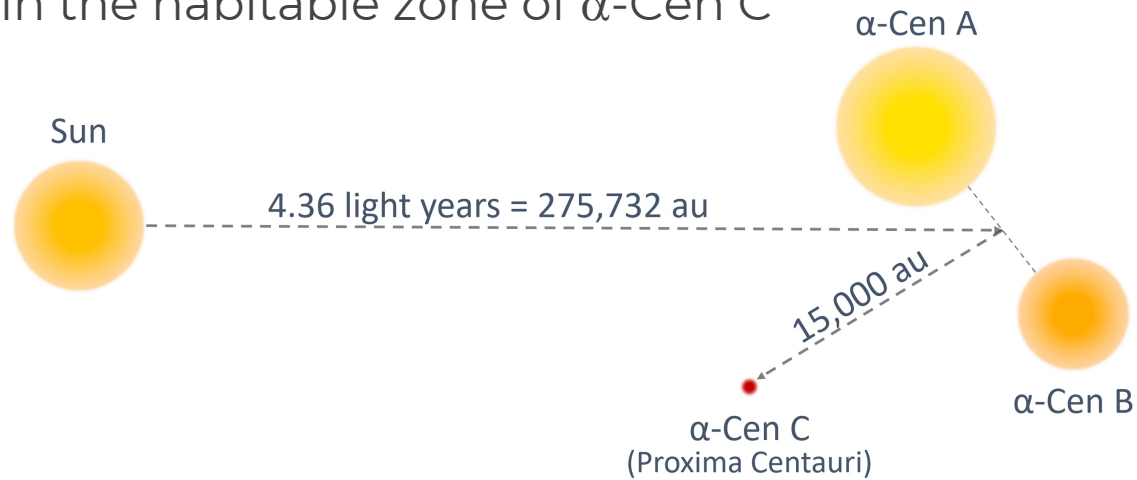
Alpha Centauri

Source: NASA/ESA/Hubble

≈ 275 000 au from the Sun

Why?

Earth-like exoplanet Proxima b
in the habitable zone of α-Cen C



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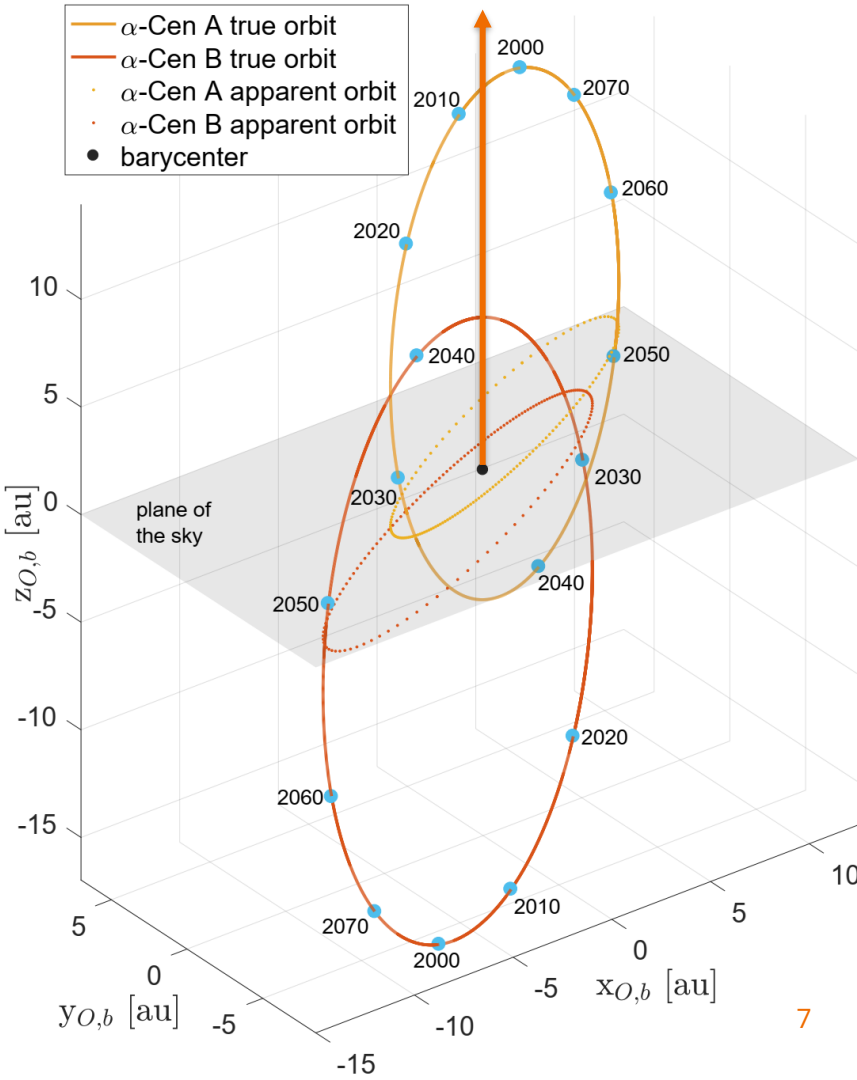
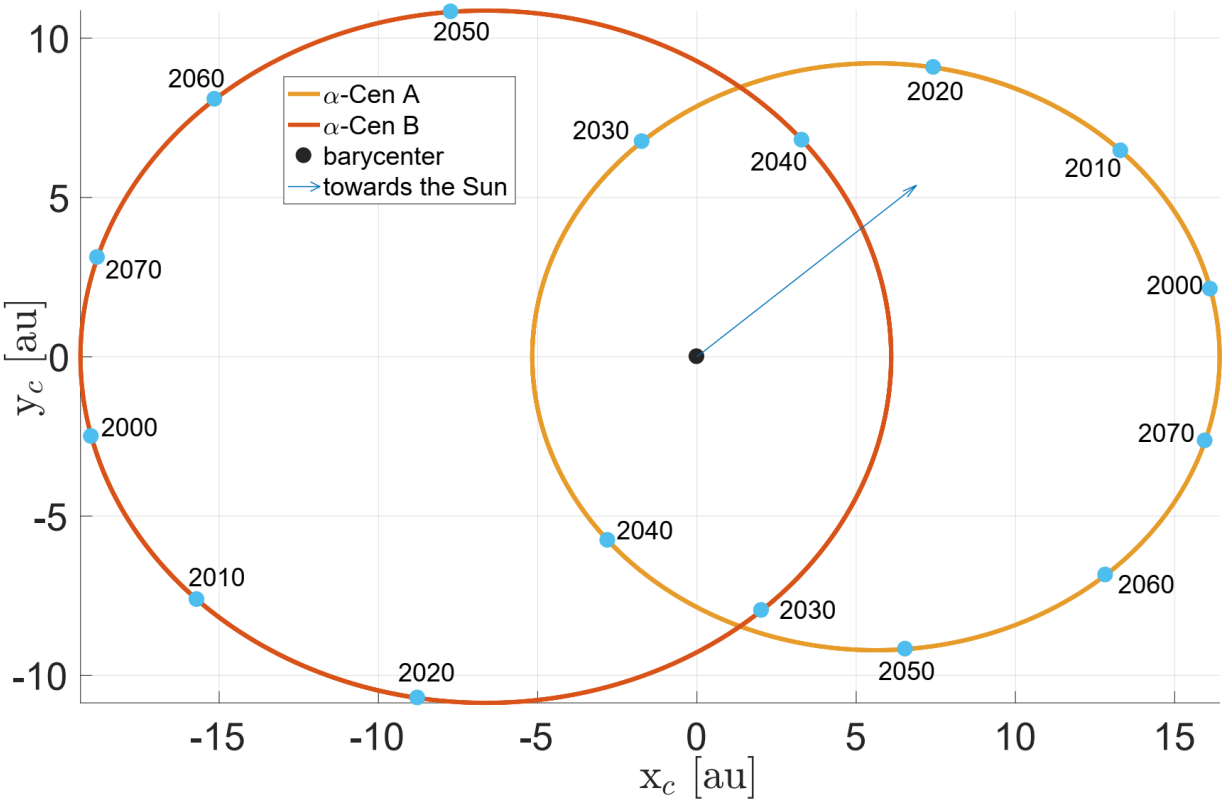
Alpha Centauri



Alpha Centauri



Photon Sail

Continuous, but small acceleration

Generate thrust without propellant

Lightness number β = performance parameter:

$$\frac{\text{SRP}-\text{acceleration}}{\text{Gravitational acceleration}}$$

Lightness number	Sun	α-Cen A	α-Cen B
β	1.0	1.374	0.534

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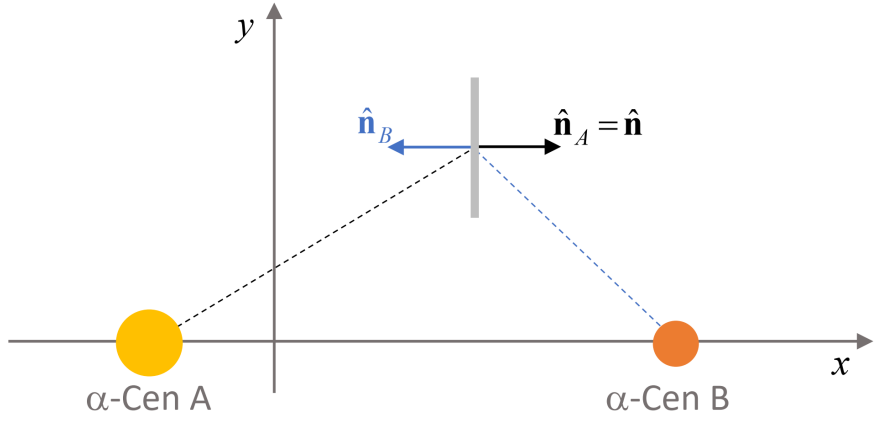
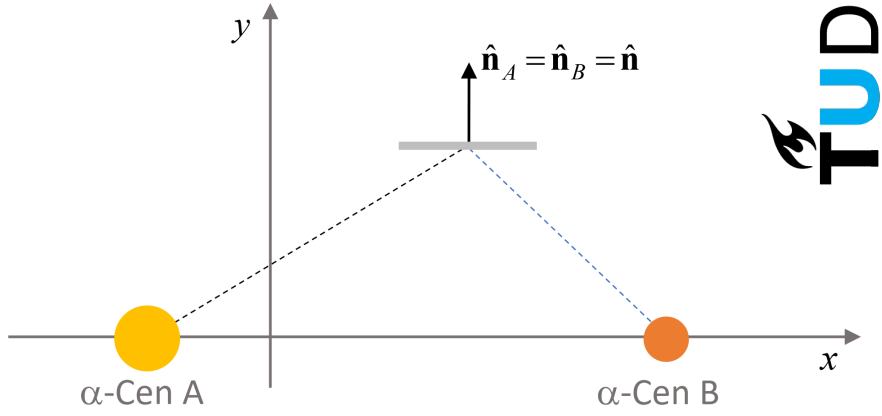
Photon Sail

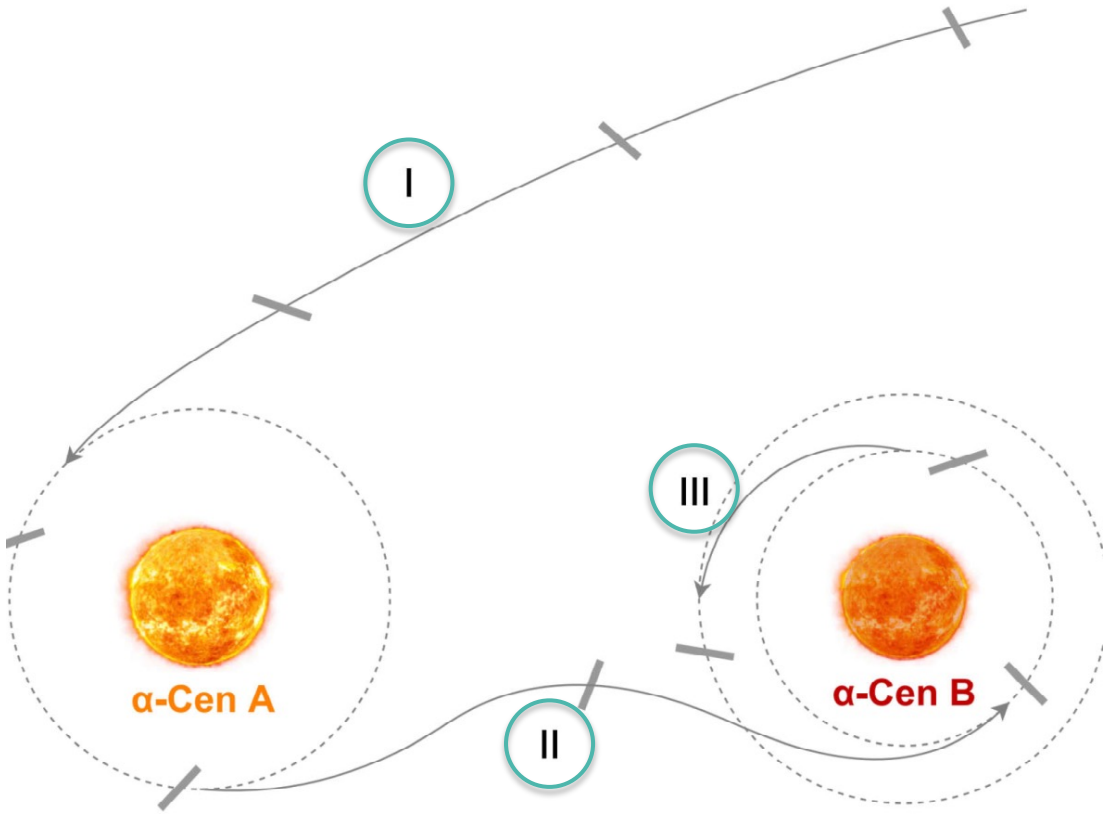
Photon-sail dynamics under effect of *two* radiative sources
(photon-pressure augmented elliptical restricted three body problem)

Acceleration depends on sail orientation and configuration





Mission Analysis



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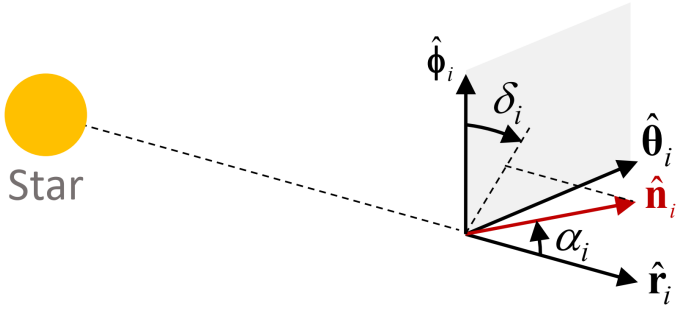
Trajectory Optimization

Find optimal steering strategy:

$$\mathbf{u}(t) = [\alpha(t),\ \delta(t)]^T$$

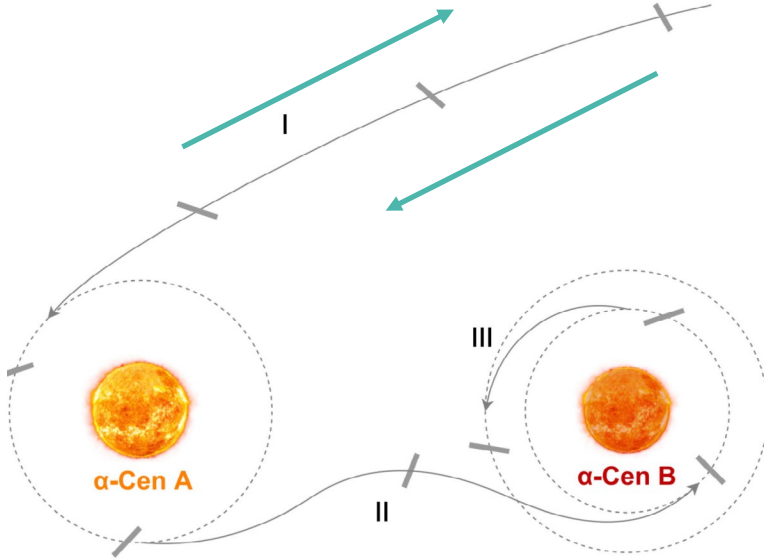


Minimise transfer time

Capture problem approached as reversed-time escape problem

- Initial condition: circular orbit about star
- Propagate forwards in time until escape conditions
- Reversing orbital motion of star system

Trajectory Optimization



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Trajectory Optimization

Optimal control solver: InTrance

Global low-thrust trajectory optimization software

Machine-learning approach combining neural networks and evolutionary algorithms

Advantages: mission description can be very broad and no initial guess is required

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Results

Sail	β	Material	Sail Loading $[g/m^2]$
A	0.040	Kapton	37
B	0.765	Gold foil	2.0
C	4.370	Composite graphene-based	0.35
D	1779	Graphene	0.00086

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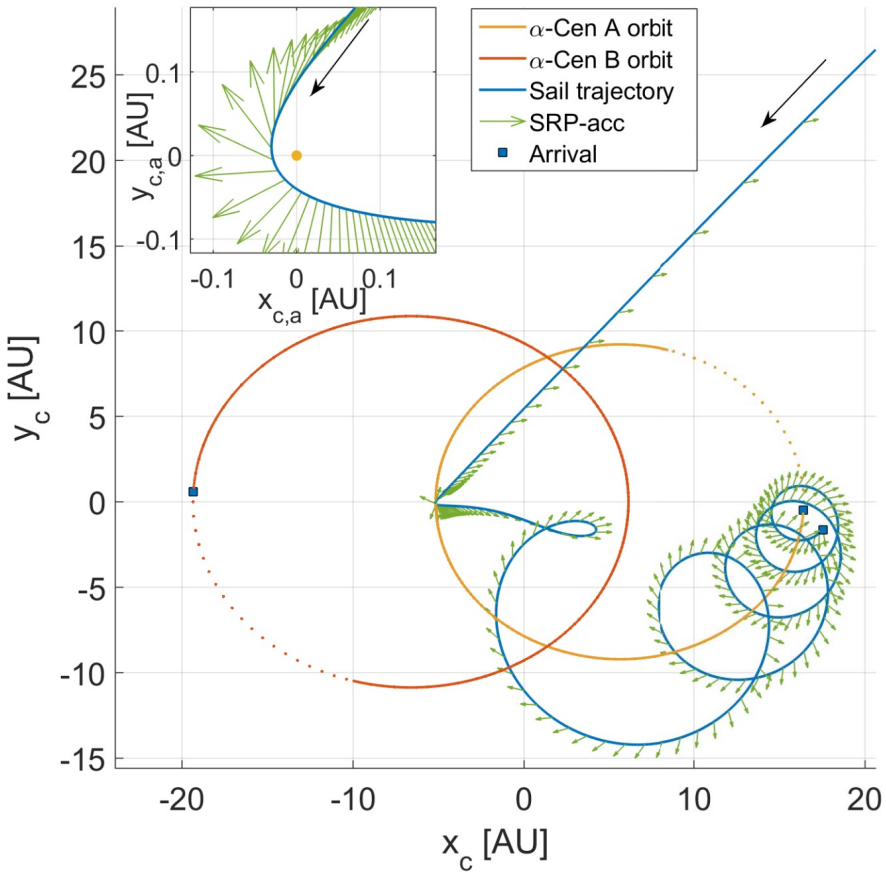
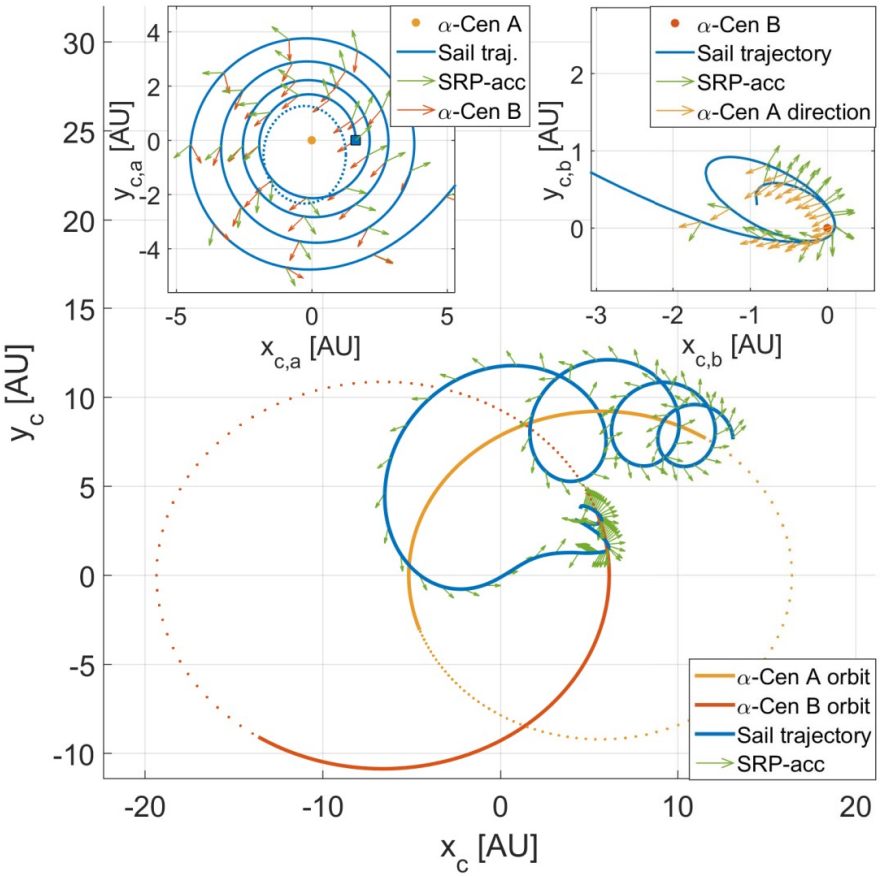
Results, Sail A



Travel time: 18,790 yrs
Injection speed: 0.023% *c*

Results, Sail A

Transfer time: 24 yrs



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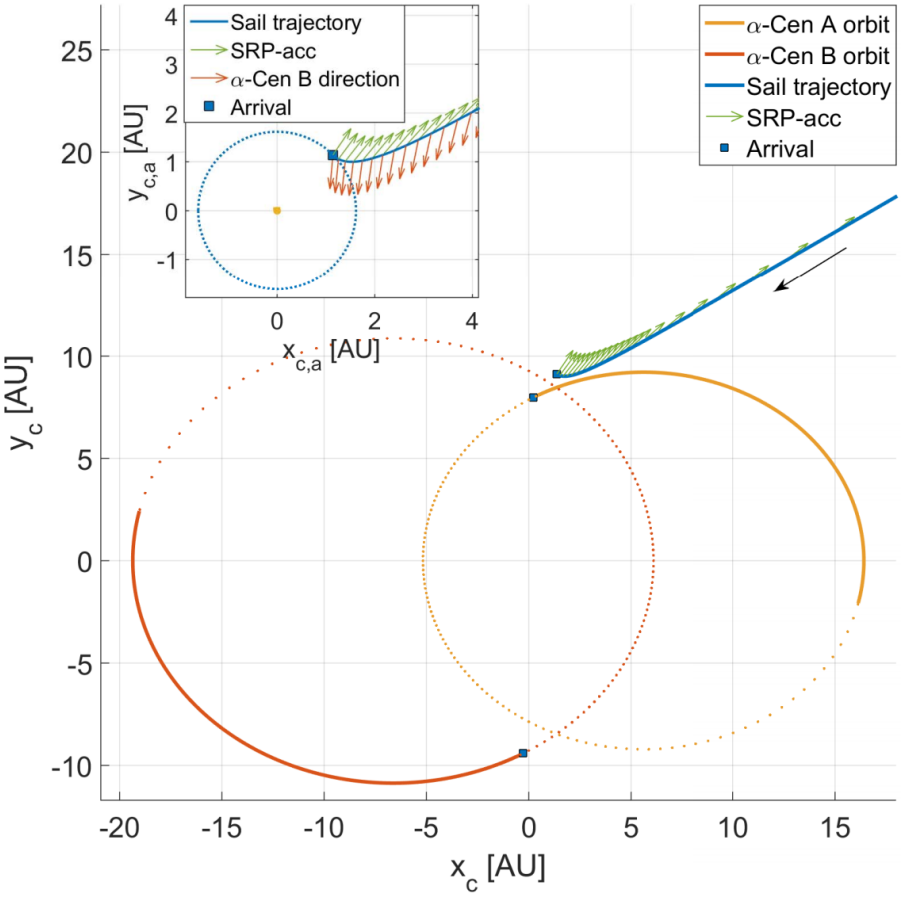
Results, Sail C



One-sided reflective sail

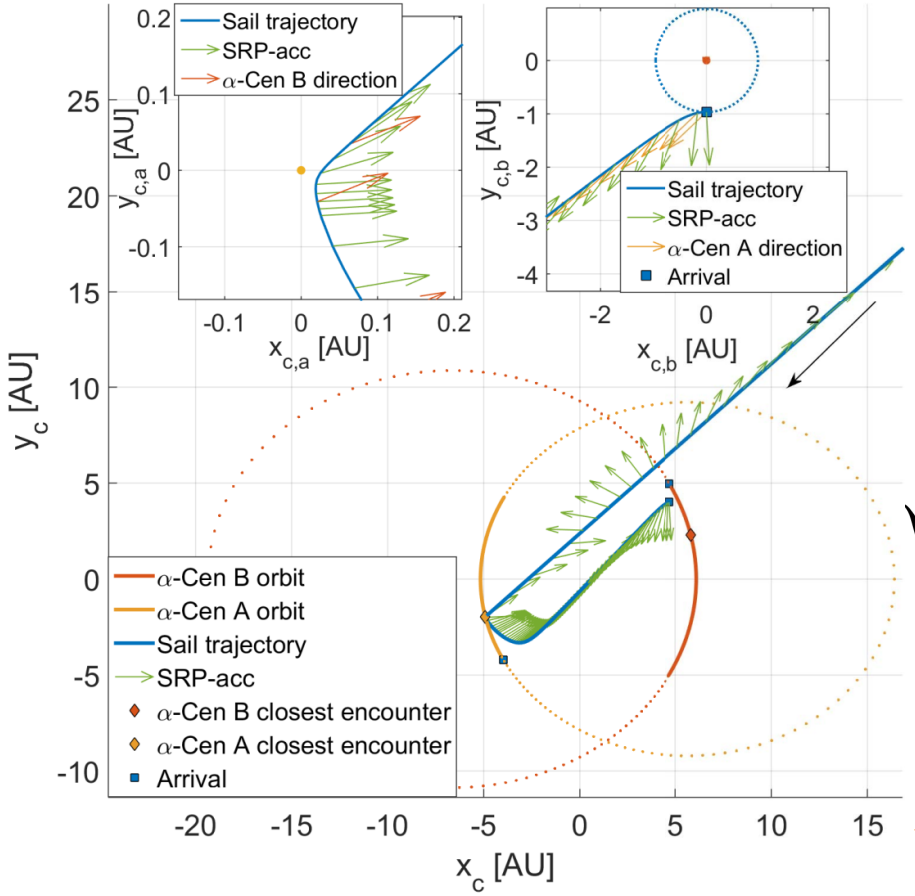
Travel time: 16,372 yrs

Injection speed: 0.026% *c*

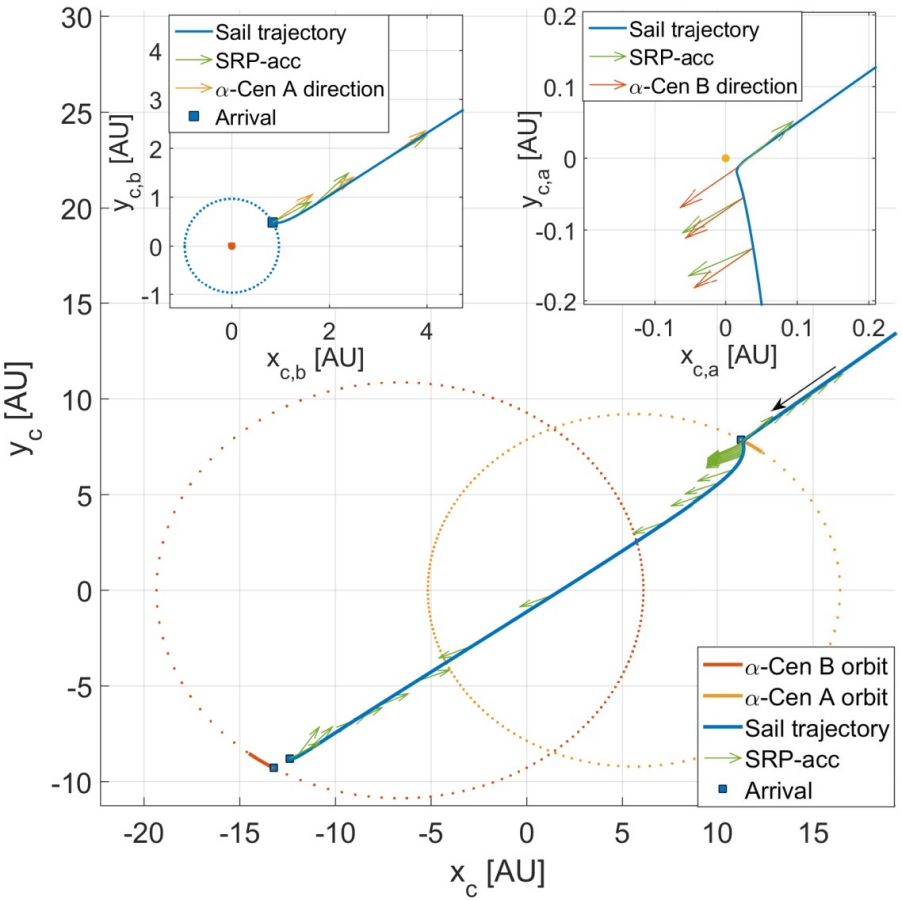
Results, Sail C

Two-sided reflective sail

Travel time: 2,000 yrs
Injection speed: 0.23% c



Results, Sail D



Circular orbit

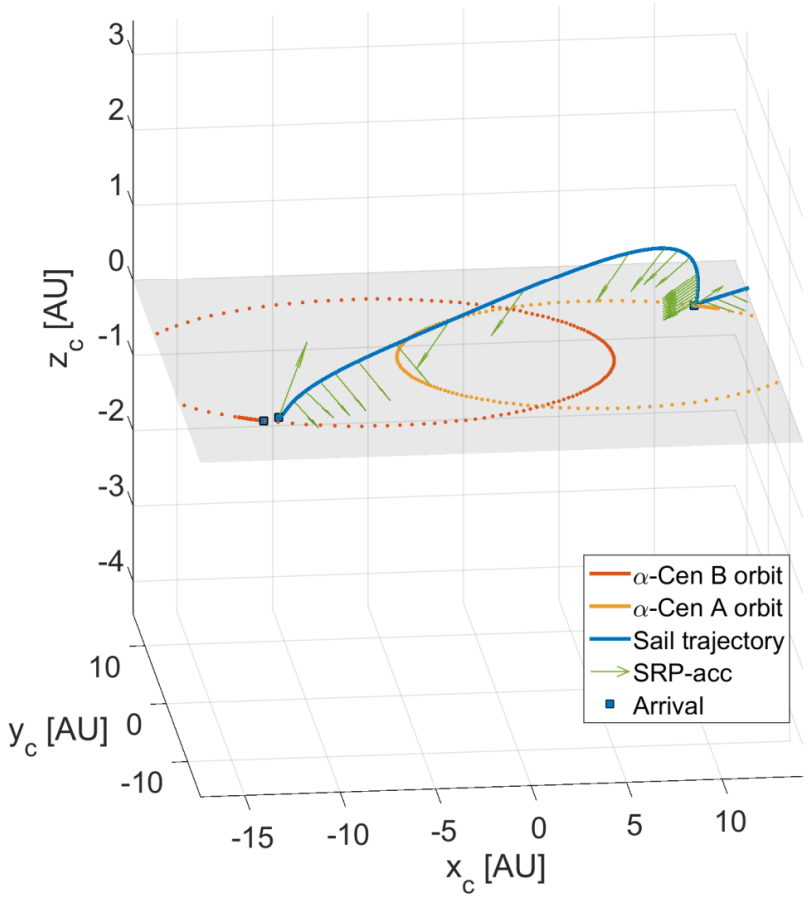
Travel time: 111 yrs

Injection speed: 3.9% *c*

Results, Sail D

Highly-eccentric orbit

Travel time: 77.6 yrs
Injection speed: 5.5% *c*



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Summary

Sail	Injection speed [% c]	Capture [yrs]	Transfer [yrs]	Orbit raising [yrs]
A	0.02	18,790	23.8	3.0
B	0.19	2,293	5.4	1.0
C (1-sided)	0.03	16,372	18.3	2.7
C (2-sided)	0.23	1,950	2.3	1.8
D	3.90	111	0.3	n.a.
D (e=0.9)	5.50	77.6	n.a.	n.a.

Average improvement of capture trajectories of 30% in terms of interstellar flight time compared to previous work

Conclusion

1. Sending a sail today vs. more advanced photonic sail in the future
2. Capturing of sail according to Breakthrough Starshot would take 2,000 years instead of 20 years
3. Futuristic ultralight sail enables capture in less than 80 years, suggesting to jettison the sail upon arrival
4. Travel time from Sun to Alpha Centauri for two-sided reflective sail is eight times shorter than one-sided reflective sail
5. Technological development required for two-sided sails
6. Fly-through mission is probably the only option for a first mission to Alpha Centauri

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Thank you for your attention

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