DECELERATION OF HIGH-VELOCITY INTERSTELLAR PHOTON SAILS INTO BOUND ORBITS AT ALPHA USING PHOTOGRAVITATIONAL ASSISTS. René Heller[1] and Michael Hippke [2], [1]Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany, heller@mps.mpg.de, [2]Luiter Straße 21b, 47506 Neukirchen-Vluyn, Germany, michael@jaekle.info

Introduction: Located at a distance of about 4.22 lightyears [1], it would take about 100,000 years for humans to visit our closest stellar neighbor Proxima Centauri (α Cen C, or Proxima) using modern chemical thrusters [2]. New technologies are now being developed that involve high-power lasers firing at 1 gram solar sails in near-Earth orbits, accelerating them to up to 20% the speed of light (c) within minutes [3,4]. Although such an interstellar probe could reach Proxima 20 years after launch, without propellant to slow it down it would traverse the system within just a few hours.

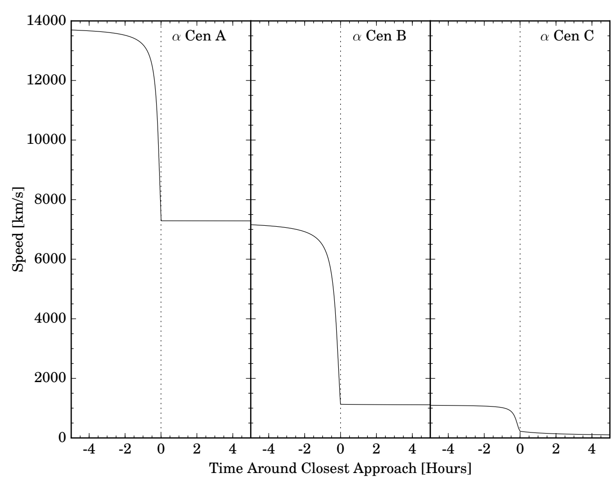
Deceleration from Interstellar Velocities: Proxima is a member of a stellar triple system, with its companions α Centauri A and B at a distance of about 12,000 astronomical units. We demonstrate how the stellar photon pressures of the stellar triple α Cen A, B, and C can be used in combination with gravity assists to decelerate incoming solar sails from Earth into bound orbits (see Figure) [5]. Sails that successfully perform the required live course corrections at α Cen could thus visit three stellar systems and an Earth-sized potentially habitable planet [6,7,8,9,10] in one shot, promising extremely high scientific yields. Photo-gravitational assists provide a novel means of interstellar fly-by exploration of the α Cen system, reducing the technological demands on the onboard high-speed imaging system substantially.

Methods: We combine the gravitational pull from the star and its repulsive photon force onto an incoming test sail and numerically integrate its trajectory. The computer experiments are done for a broad range of the sail's mass-to-surface ratio (10^{-4} g m^{-2} $\leq \sigma \leq 10^2$ g m^{-2}), interstellar incoming velocities ($v_\infty < 0.2\,c \approx 60{,}000$ km s^{-1}), and impact distances from the star ($r_{\rm min} \geq 5$ stellar radii, R_*, in steps of 0.1 R_*). Our analytical estimates for the sail's absorbed kinetic energy verify the numerical results.

Results: The maximum possible injection speeds at the α Cen system to park a sail with a mass-to-surface ratio similar to graphene (7.6×10^{-4} g m^{-2}) [11] in orbit around Proxima is about 13,725 km s^{-1} (4.6% c), most of which would be absorbed by the photon pressure of α Cen A during a fly-by at 5 R_*. This speed corresponds to travel times from Earth to α Cen A of about 96 yr and another 44 yr after encounter with α Cen B (with a residual velocity of 1,275 km s^{-1}) to Proxima. A sail with a mass-to-surface ratio between graphene and an aluminum lattice ship [12] could still arrive at α Cen A within a few hundred years even if its closest approach to the star were restricted to >10 R_*.

Conclusions: Arrival at Proxima with velocities of around 1,000 km s^{-1} from the direction of α Cen AB could result in an initially highly elliptical orbit around Proxima. The orbit could be circularized into a habitable zone orbit using Proxima's photon pressure near periastron. The time required for such an orbit transfer is small (years) compared to the total travel time. Once parked in orbit around Proxima, a sail could eventually use the stellar photon pressure to transfer into a planetary orbit around Proxima b.

References: [1] van Leeuwen F. (2007) *A&A* **474**, 653. [2] Stone E. C. et al. (2013) *Science* **341**, 150. [3] Marx G. (1966) *Nature* **211**, 22. [4] Lubin P. A. (2016) *JBIS* **69**, 40. [5] Heller R. and Hippke M. (2017) *ApJL* (in press). [6] Anglada-Escudé G. et al. (2016) *Nature* **536**, 437. [7] Barnes R. et al. (2016) arXiv: 1608.06919. [8] Ribas I. et al. (2016) arXiv: 1608.06813. [9] Meadows V. S. et al. (2016) arXiv: 1608.08620. [10] Turbet M. et al. (2016) arXiv: 1608.06827. [11] Peigney A. et al. (2001) *Carbon* **39**, 507. [12] Drexler K. E. (1977) *Design of a High Performance Solar Sail System*, MS Thesis, MIT Boston.



Successive deceleration of a graphene-style (7.6×10^{-4} g m^{-2}) photon sail with a mass-to-surface ratio similar to graphene during photogravitational fly-bys at α Cen A, B, and C. The sail's initial interstellar speed of 13,800 km s^{-1} is ultimately reduced to zero relative to Proxima, enabling stationary orbits around the star and low-velocity fly-bys at Proxima b.