A study of the orbital dynamics of the stellar system Alpha Centauri.

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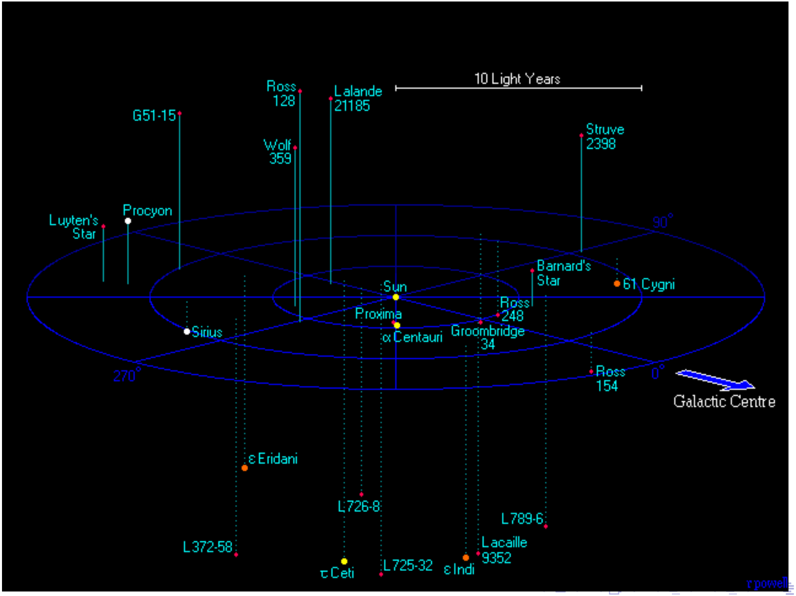
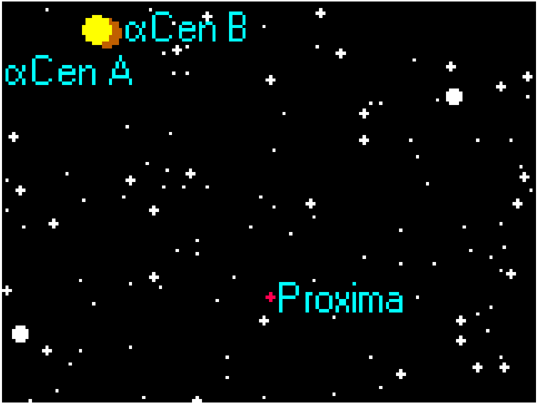
The stellar neighbourhood of the Sun



A hierarchical triple system



Star	Spectral type
α Cen A	G2V
α Cen B	K1V
Proxima	M5.5V

The orbital elements of the system

Orbital elements of the inner orbit (Pourbaix, D. & Boffin, H.M.J., 2016)	
P_1	(79.91 ± 0.013) y
T_1	(1955.66 ± 0.014) y
e_1	(0.524 ± 0.0011)
a_1	(17.66 ± 0.026) a
I_1	$(79.32 \pm 0.044)^\circ$
Ω_1	$(204.75 \pm 0.087)^\circ$
ω_1	$(232.3 \pm 0.11)^\circ$
Orbital elements of the outer orbit (Kervella, P. et al., 2017)	
P_2	$(5470. \pm 530.)$ c
T_2	$(2850. \pm 50.)$ c
e_2	(0.50 ± 0.09)
a_2	(188.62 ± 11.92) M
I_2	$(107.6 \pm 1.9)^\circ$
Ω_2	$(126. \pm 5.)^\circ$
ω_2	$(72.3 \pm 7.7)^\circ$

Star	Mass ($M_\odot$)	Reference
α Cen A	1.1055 ± 0.0039	Kervella, P. et al. (2016)
α Cen B	0.9373 ± 0.0033	Kervella, P. et al. (2016)
Proxima	0.1221 ± 0.0022	Mann, A. W. et al. (2015)

The Planets in the system

Planets in Alpha Centauri:

- Proxima (two confirmed and one unconfirmed):

b CONFIRMED (Anglada-Escudé, G. et al., 2016)
P = 11.186 d
e $<$ 0.35
a = 0.0485 u.a.
$M_p \sin I = 1.27\ M_\oplus$
c CONFIRMED (Damasso, M. et al., 2019)
P = 5.21 a
e = 0
a = 1.48 u.a.
$M_p \sin I = 5.8\ M_\oplus$
d CANDIDATE (Faria, J. et al., 2022)
P = 5.12 d
e = 0.37
a = 0.02886
$M_p \sin I = 0.40\ M_\oplus$

- Alpha Centauri B (one discarded and one unconfirmed)
- Alpha Centauri A (one unconfirmed)

What is TIDES?

- The TIDES numerical integrator (Abad et al. 2011, 2012; Abad & Barrio 2014) allows us to solve first order ordinary differential equations (ODEs) numerically using the Taylor series method.
- Solving many problems in Dynamical Systems and Astrodynamics.

$$\frac{d\mathbf{x}(t)}{dt} = \mathbf{F}(t, \mathbf{x}(\mathbf{t}), \mathbf{p}), \qquad \mathbf{x}(t_0) = y_0, \qquad t \in \mathbb{R}, \mathbf{x} \in \mathbb{R}^n, \mathbf{p} \in \mathbb{R}^m$$

$$\mathbf{x}(t) = \sum_{k=0}^{N} \mathbf{x}_k (t - t_0)^k, \qquad \mathbf{x}_k = \frac{1}{k!} \frac{d^k \mathbf{x}}{dt^k}(t_0)$$

$$\frac{d\mathbf{x}(t)}{dt} = \sum_{k=0}^{N} k \mathbf{x}_k (t - t_0)^{k-1}$$

$$\mathbf{F}(t, \mathbf{x}(t); \mathbf{p}) = \mathbf{F}(t, \sum_{k=0}^{N} \mathbf{x}_k (t - t_0)^k; \mathbf{p}) = \sum_{k=0}^{N} \mathbf{F}_k (t - t_0)^k$$

$$\mathbf{x}_{k+1} = \frac{1}{k+1} \mathbf{F}_k(\mathbf{x}_0, \ldots, \mathbf{x}_{k-1}), \qquad k = 0, \ldots, N-1$$

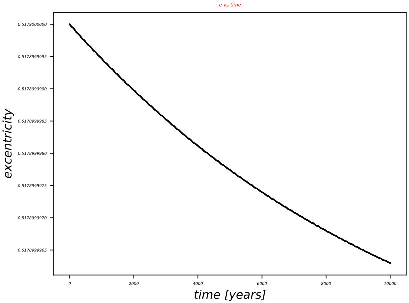
α Centauri system

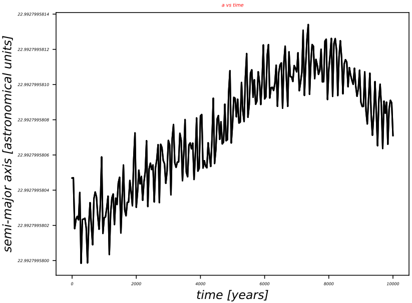
- Proxima (α Centauri C) very far from α Centauri A+B

Star	Distance (pc)	References
α Centauri A	1.3384 ± 0.0011	Kervella, P. et al., 2016
α Centauri B	1.3384 ± 0.0011	Kervella, P. et al., 2016
Proxima Centauri	1.3008 ± 0.0006	Benedict, G. Fritz et al., 1999
α-Prox	0.0628 ± 0.0013	Kervella, P. et al., 2017

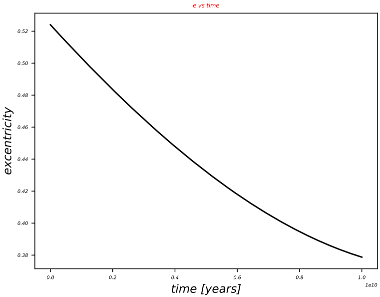
- $\pi_{GAIA}^{Proxima} = (768.066539187 \pm 0.049872905)$ mas (GAIA DR3)
  $\Rightarrow d_{GAIA}^{Proxima} = (1.301970531 \pm 0.000084541)$ pc
- Near Keplerian orbits
- Lidov-Kozai cycles?
- Time scales of many millions of Gyr

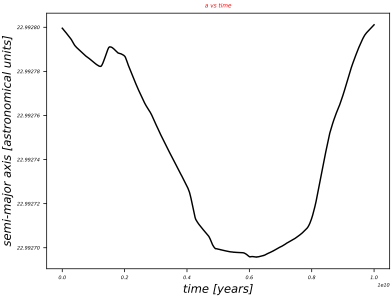
Results


e vs time
excentricity
0.5179000000
0.5178999995
0.5178999990
0.5178999985
0.5178999980
0.5178999975
0.5178999970
0.5178999965
0
2000
4000
6000
8000
10000
time [years]


a vs time
semi-major axis [astronomical units]
22.9927995814
22.9927995812
22.9927995810
22.9927995808
22.9927995806
22.9927995804
22.9927995802
22.9927995800
0
2000
4000
6000
8000
10000
time [years]

Results


e vs time
excentricity
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.0
0.2
0.4
0.6
0.8
1.0
1e10
time [years]


a vs time
semi-major axis [astronomical units]
22.99280
22.99278
22.99276
22.99274
22.99272
22.99270
0.0
0.2
0.4
0.6
0.8
1.0
1e10
time [years]

The Proxima planet system

Parameter	TM RVs	Units	References
planet b			Faria, J. P. et al., 2022
P	$11.1868^{+0.0029}_{-0.0031}$	days	
e	$0.02^{+0.04}_{-0.02}$		
ω	$3.3^{+1.8}_{-2.3}$	radians	
$M_p \sin i$	$1.07^{+0.06}_{-0.06}$	$M_\oplus$	
a	$0.04856^{+0.00030}_{-0.00030}$	au	
planet c			Benedict & McArthur, 2020
P	1928 ± 20	days	
e	0.04 ± 0.01		
ω	6.21 ± 0.07	radians	
$M_p \sin i$	7 ± 1	$M_\oplus$	
a	1.38 ± 0.01	au	
planet d			Faria, J. P. et al., 2022
P	$5.122^{+0.002}_{-0.036}$	days	
e	$0.04^{+0.15}_{-0.04}$		
ω	$4.0^{+2.0}_{-1.7}$	radians	
$M_p \sin i$	$0.26^{+0.05}_{-0.05}$	$M_\oplus$	
a	$0.02885^{+0.00019}_{-0.00022}$	au	

Results - Perturbations of planets caused by AB

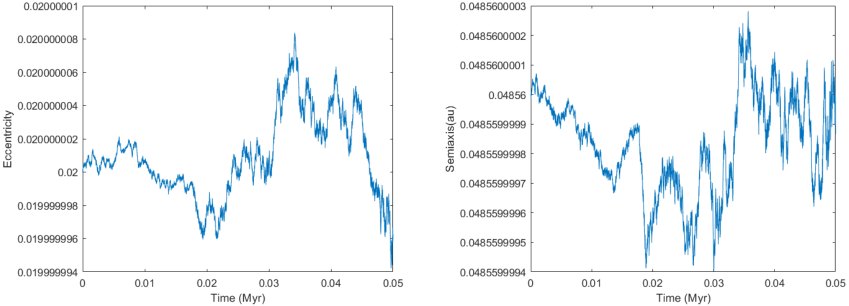
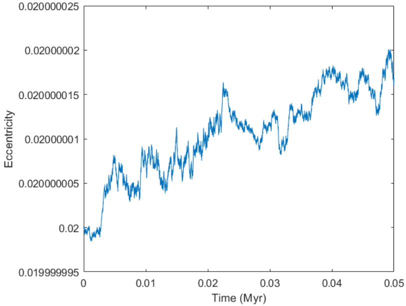


Figure: Initial inclination = 0 degrees

Results - Perturbations of planets caused by AB



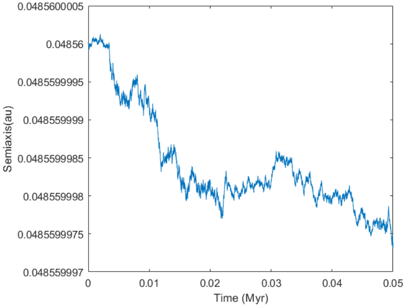
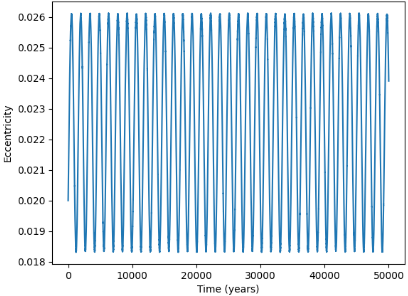
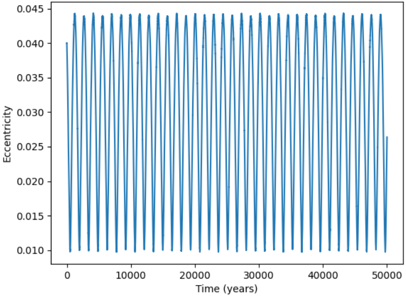


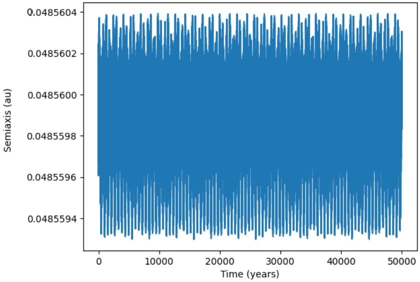
Figure: Initial inclination = 90 degrees

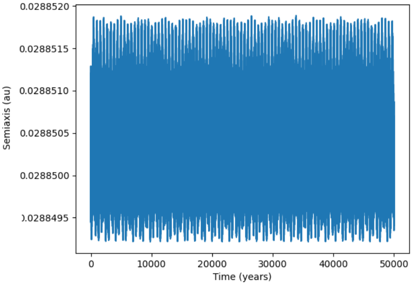
Results: Planet Proxima - b and - d



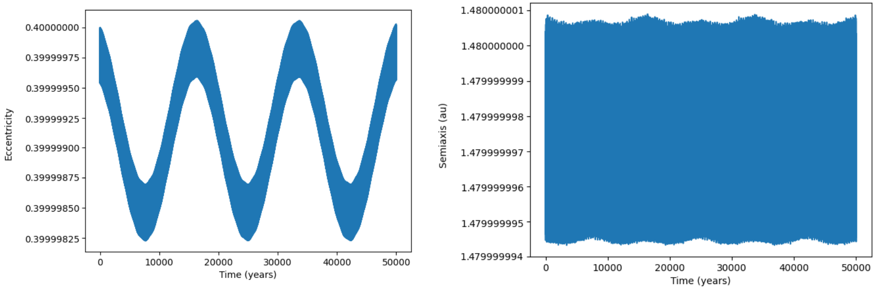


Results: Planet Proxima - b and - d





Results: Planet Proxima - c



Habitability

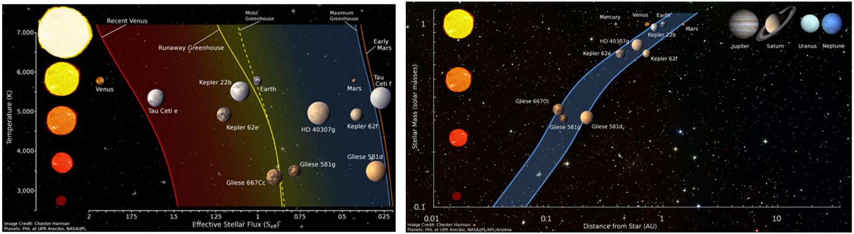


Figure: Diagram showing different HZ boundaries for star ranging in spectral type from F0 to M7 (Left panel) and in terms of log distance for zero-age main-sequence stars (Right panel). (James F. Kasting et al., 2014).

Habitability

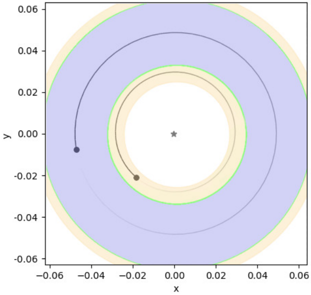


Figure: The planet Proxima Centauri b is in the outer orbit and d is in the inner orbit.

HZ	Inner edge (au)	Outer edge (au)
Conservative	0.031823	0.061544
Intermediate	0.031612	0.061544
Optimistic	0.024050	0.065608

Table: the numerical values of the HZ.

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3 Conclusions

Conclusions - I

- A full study of the stellar and planetary orbital dynamics of the Alpha Centaury system was carried out.
- Fist, we applied the TIDES package to the hierarchical triple star A-B——C in order to detect possible perturbations.
- Although the mutual inclination is high, the LK cycles were not detected due to the very large separation the Proxima.
- So, we focused our efforts in the planetary motions. We began studying the possible perturbations of the pair AB on the planets around Proxima.

Conclusions - II

- We have developed the calculations taking the hypothesis that the plane of the motion of the three planets coincides with that of the orbit of Proxima around AB.
- Graphs of the evolution of Proxima b have been obtained as it is perturbed by Alpha Centauri AB and we have verified that the perturbations are practically imperceptible.
- Graphs of the semimajor axis and eccentricity of planets b, c, and d over 10000 years have been obtained. It can be seen that the eccentricity of b and d influence each other. The semimajor axis of the 3 planets undergoes very small modifications.
- Habitability was analysed by taking three habitable zones: one optimistic, one conservative and one intermediate. The planet b seems to be in a very good position, right in the middle of the conservative HZ. The planet d also falls within the HZ but close to the inner limit of the optimistic HZ, so its habitability conditions are not expected to be optimal (it is probably slightly warm).

Thank you very much for your attention!