A technique for designing Earth-Mars low-thrust transfers culminating in ballistic capture

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Outline

1. Introduction
2. Concept
3. Assumptions
4. Ballistic capture
5. Low-thrust targeting
6. Results
7. Conclusions

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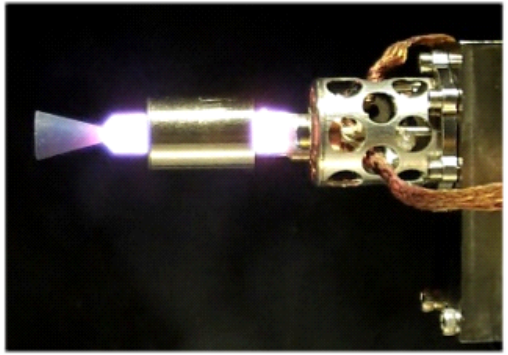
Introduction



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What are the characteristics of Earth–Mars transfers that combine ballistic capture with low-thrust propulsion?

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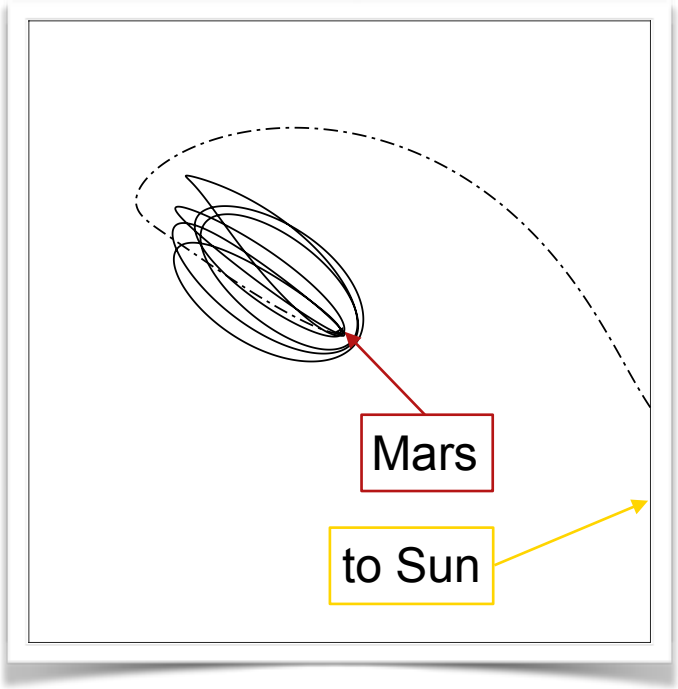
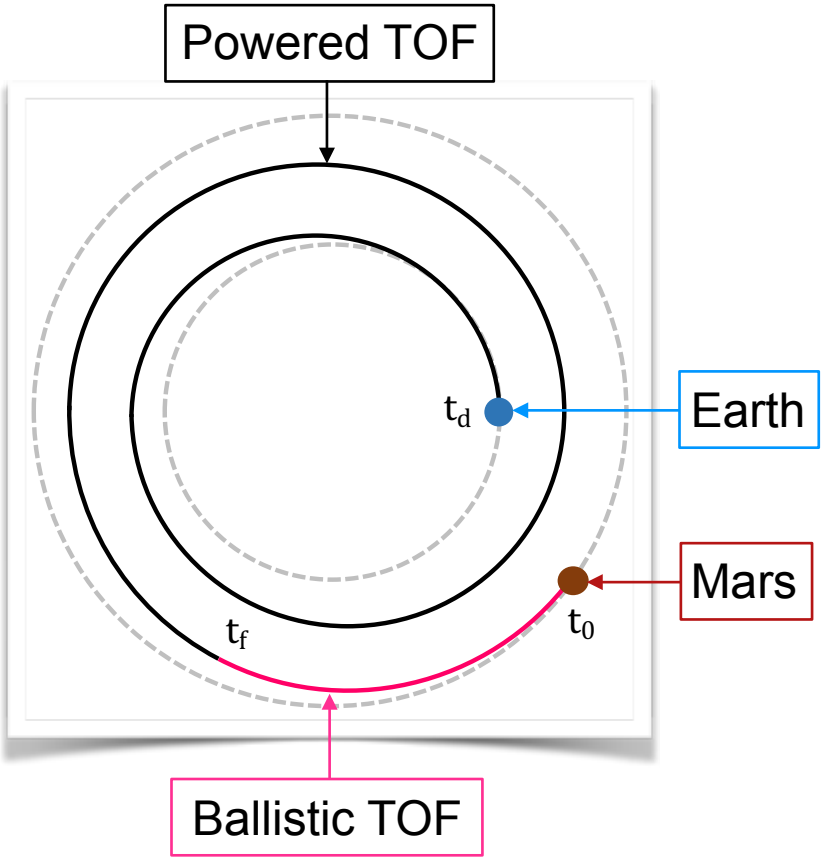
Concept





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Assumptions

(Casado, 2017)

r_d	$\vec{v}_d$
$r_E + R_{SOI,E}$	$\vec{v}_E$

A (m^2)	m_{wet} (kg)	C_R
0.52	26	1.1

T (mN)	I_{sp} (s)
[0.66, 1.24]	[1400, 2640]

m_{BC} (kg)
≈ 20.5

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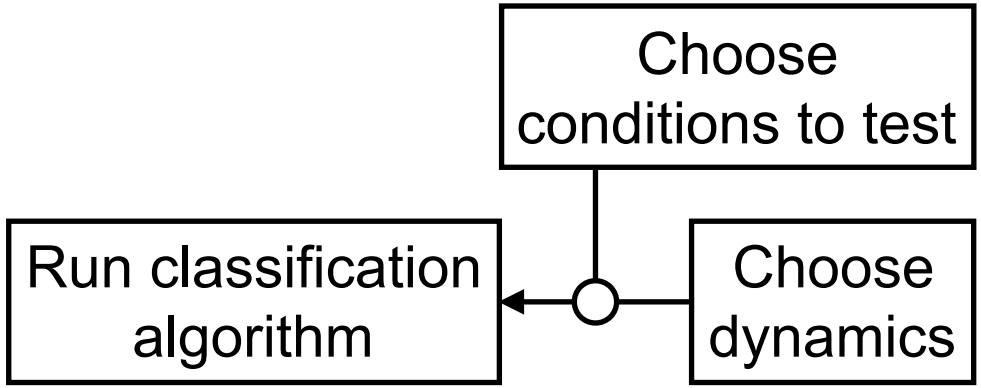
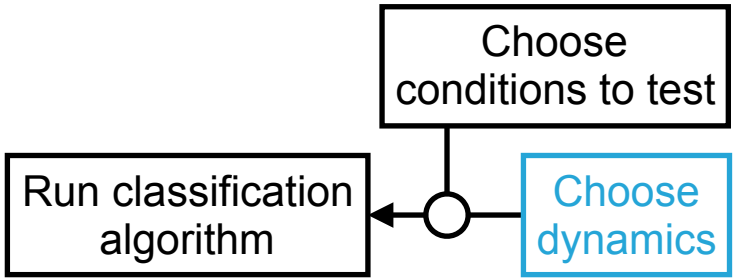
Ballistic capture



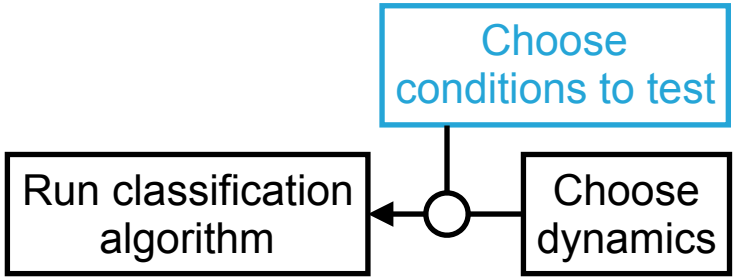
Ballistic capture



2B	TB		SRP	NSG
Mars	Sun	Mercury – Neptune	Cannonball	20x20

Required for capture	May facilitate capture	Improves validity of results

Ballistic capture



Ω_0 (°)	i_0 (°)	e_0
0	22.5	0.99

Reduce search space	Maximise chances of capture

ω_0 (°)	h_{p0} (km)
[0, 359]	[250, 4R_M]

Consistent with past work

$t_0 - t_{01}$ (days)
[0, 800]

Includes synodic period

$t_{01} \equiv$ 08 MAY 2024
Mars at periapsis

n
6

Past work

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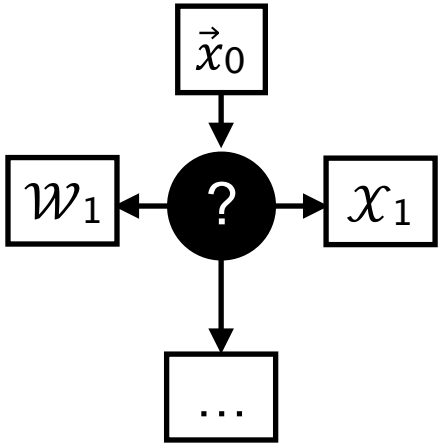
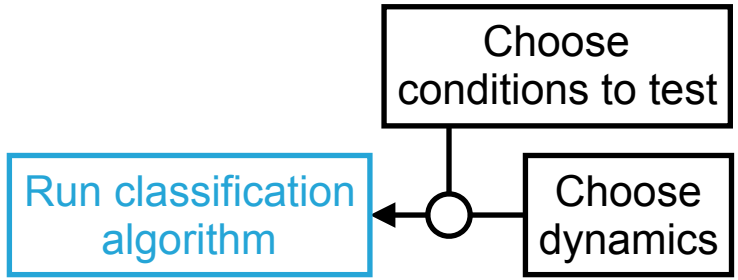
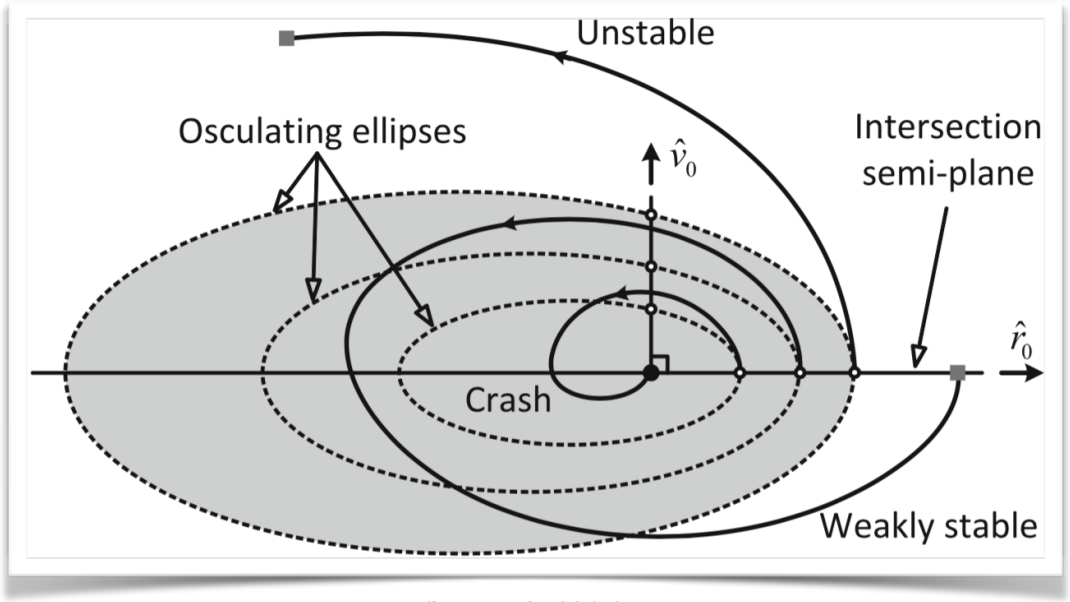
Ballistic capture



$$\mathcal{C}^6_{-1} \equiv \mathcal{W}_6 \cap \mathcal{X}_{-1}$$





(Luo et al., 2014)

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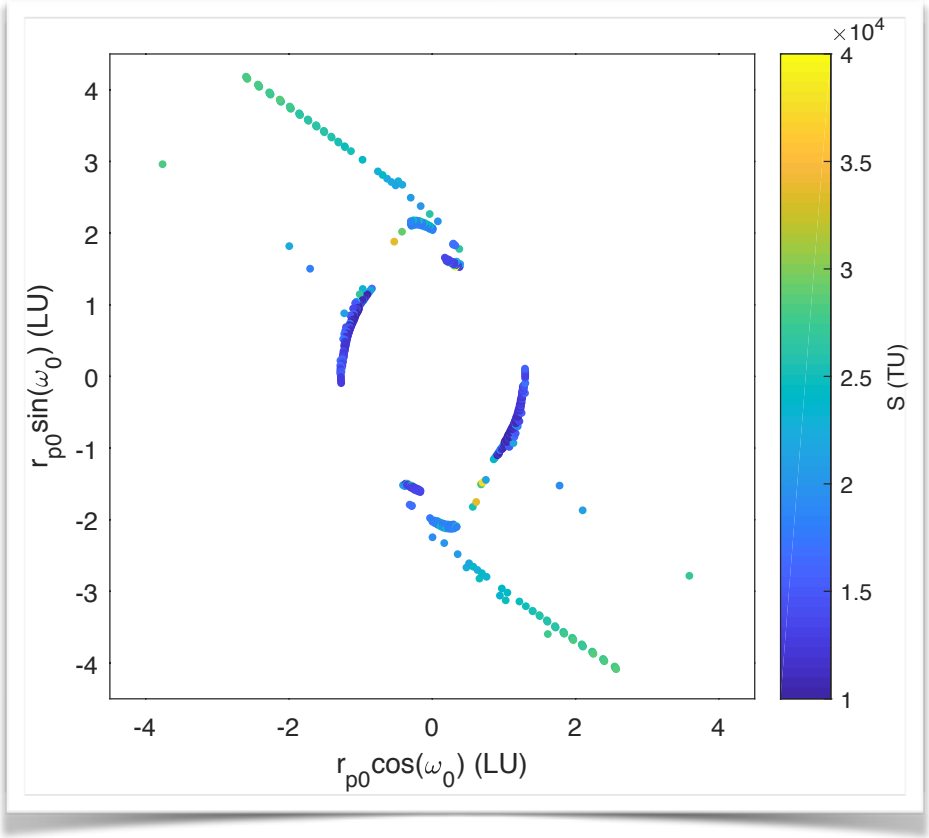
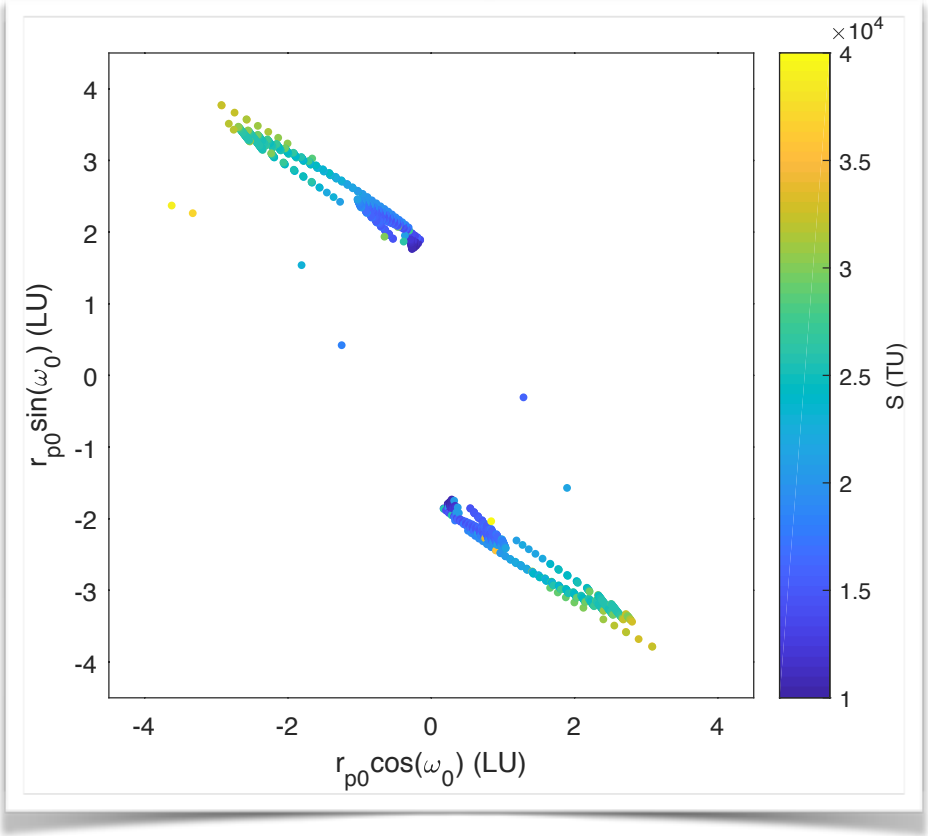
Ballistic capture



$t_0 = t_{01} + 150$ days

$T_M = 687$ days

Ballistic capture



$t_0 = t_{01} + 600$ days

$T_M = 687$ days

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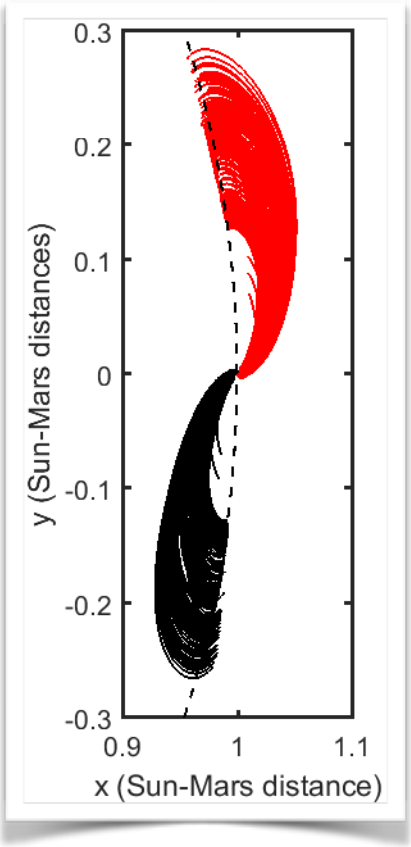
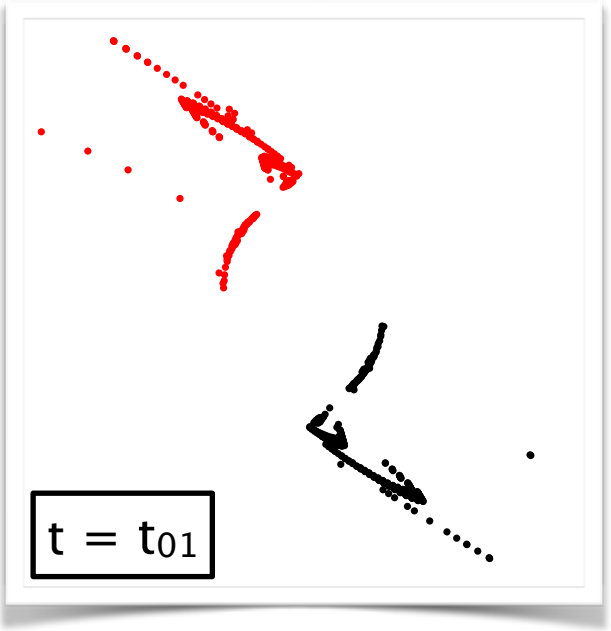
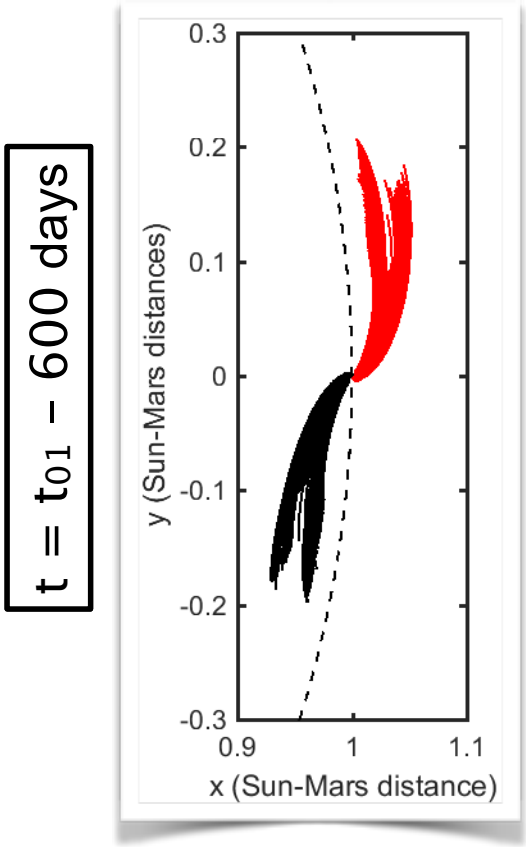
Ballistic capture

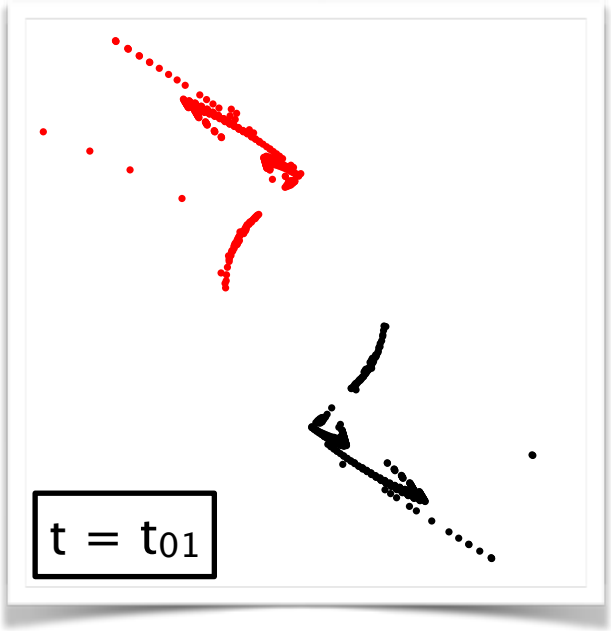
$t = t_{01} - 800$ days



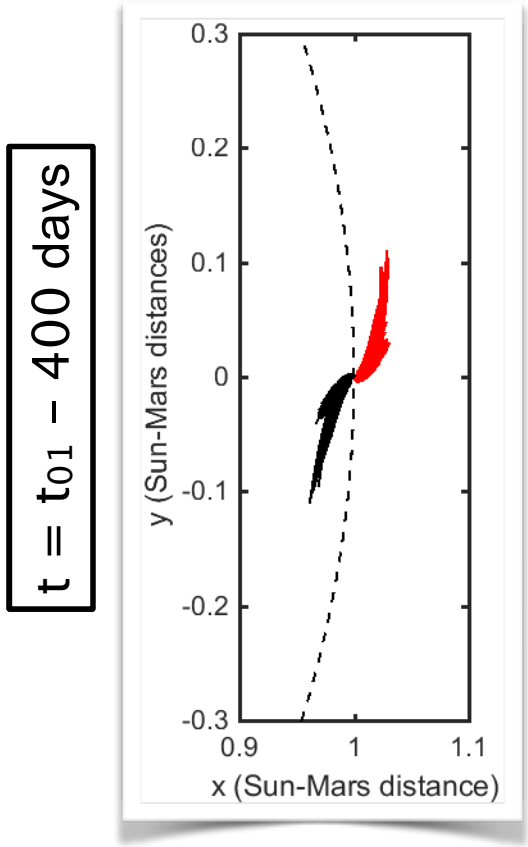


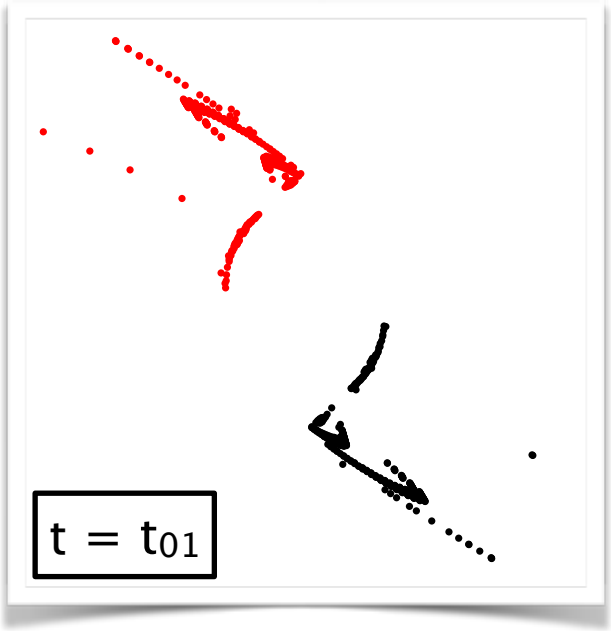
Ballistic capture





Ballistic capture





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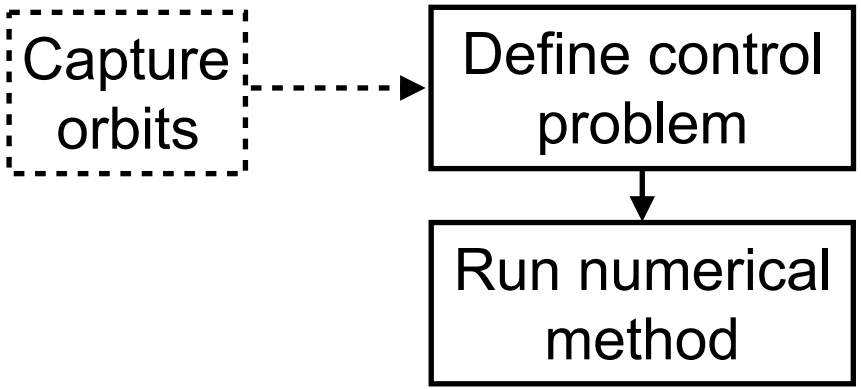
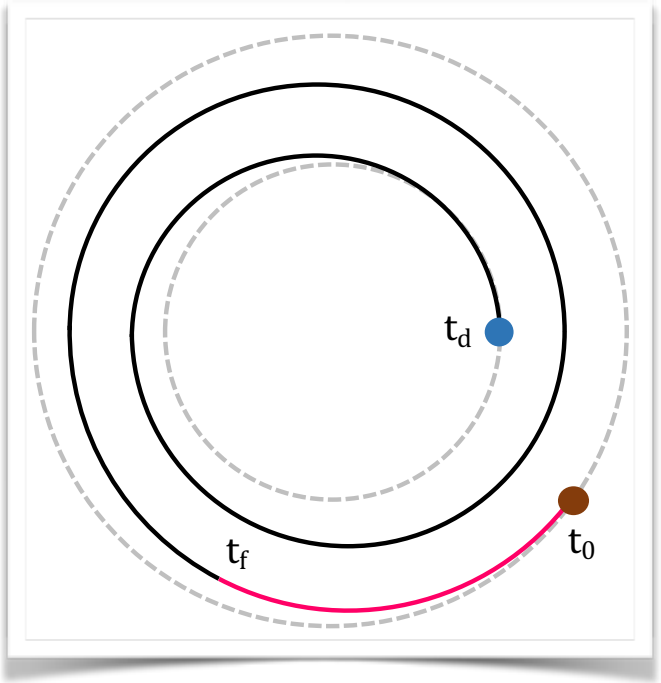
Low-thrust targeting



Low-thrust target.



Capture orbits → Define control problem → Run numerical method

2B
Sun

Required for transfer

$t_0 - t_{01}$ (days)	Δt_{TOF} (days)
[0, 800]	[1200, 2200]

$\vec{r}_d$	$\vec{v}_d$	m_d
$\approx \vec{r}_E(t_d)$	$\vec{v}_E(t_d)$	m_{wet}

$\vec{r}_f$	$\vec{v}_f$	m_f
$\vec{r}_C(t_f)$	$\vec{v}_C(t_f)$	free

t_d	t_f
$t_0 - \Delta t_{TOF}$	free

J
$-m_f$

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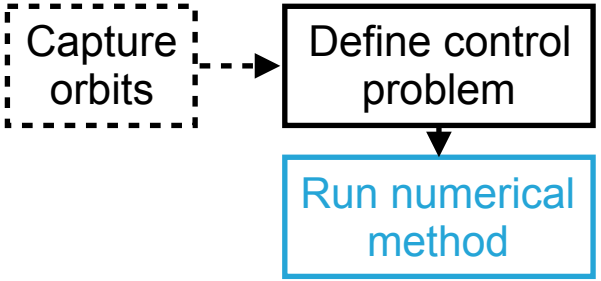
Low-thrust target.



- Good convergence
- Easy initial guess

Direct collocation

Variables

- Discrete states
- Discrete controls
- Final time

Constraints

- Defect constraints
- Boundary conditions
- Pointwise path constraints

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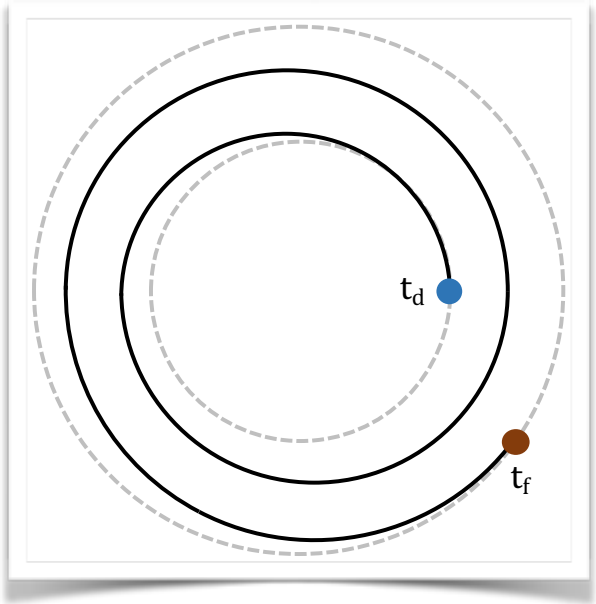
Rendezvous with Mars

(no capture)



t_d	t_f
$t_0 - \Delta t_{TOF}$	$\approx t_0$

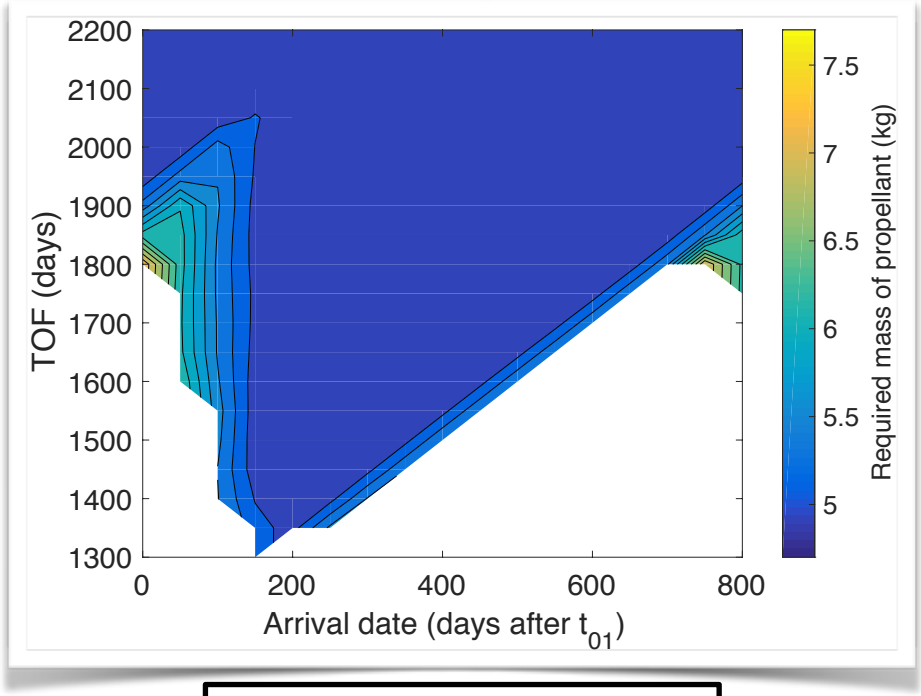
J
$-m_f$

$\vec{r}_d$	$\vec{v}_d$	m_d
$\approx \vec{r}_E(t_d)$	$\vec{v}_E(t_d)$	m_{wet}

$\vec{r}_f$	$\vec{v}_f$	m_f
$\approx \vec{r}_M(t_f)$	$\vec{v}_M(t_f)$	free

Rendezvous with Mars

(no capture)



$\min(\Delta m) \in [4.9, 5.1]$ kg

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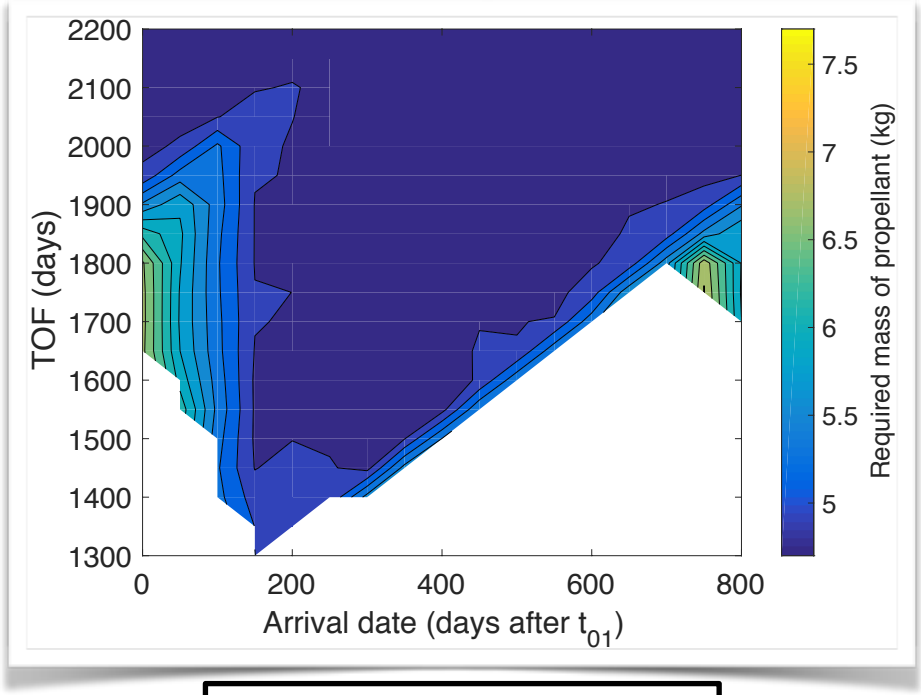
Results

(with ballistic capture)



$\min(\Delta m) \in [4.7, 4.9]$ kg

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Conclusions

- The spacecraft requires roughly the same fuel regardless of Earth departure or Mars arrival dates;
- Ballistic capture does not carry additional costs, when compared to simply rendezvousing with the planet;
- 5 kg of propellant are required to reach Mars and get ballistically captured (20% of the spacecraft's mass at departure);
- The spacecraft needs to fly for at least 3.6 years.

Thank you for your attention.

Questions?

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References

Images

- Casado, Á. S. (2017). Preliminary Systems Design of a Stand-Alone Interplanetary CubeSat to Mars (Unpublished master's thesis). Universidad Carlos III de Madrid, Politecnico di Milano.
- Luo, Z.-F., Topputo, F., Bernelli-Zazzera, F., & Tang, G. J. (2014). Constructing ballistic capture orbits in the real Solar System model. Celestial Mechanics and Dynamical Astronomy, 120(4), 433–450. doi: 10.1007/s10569-014-9580-5

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Backup slides

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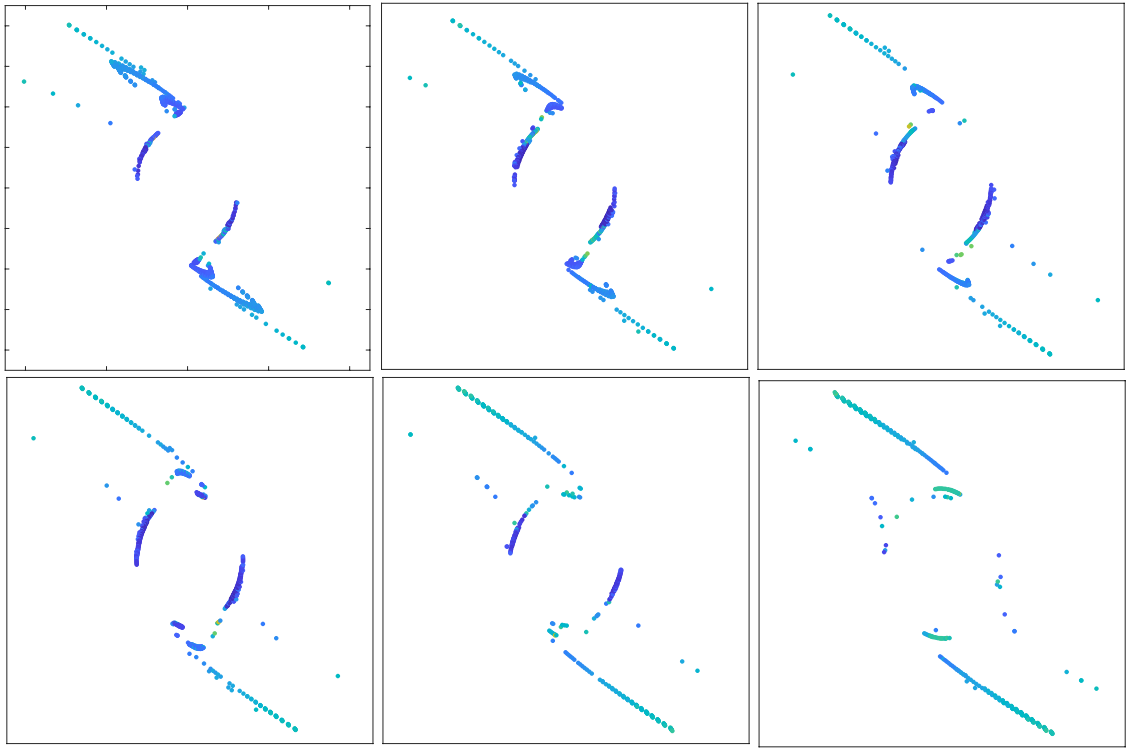
Ballistic capture



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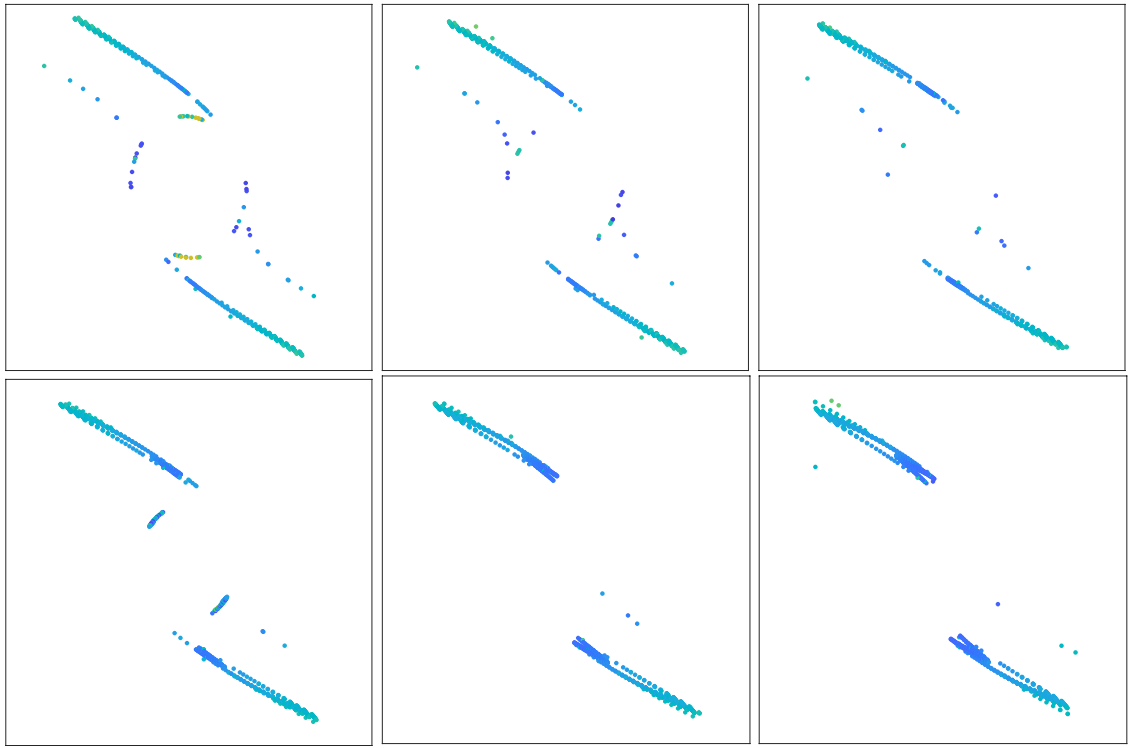

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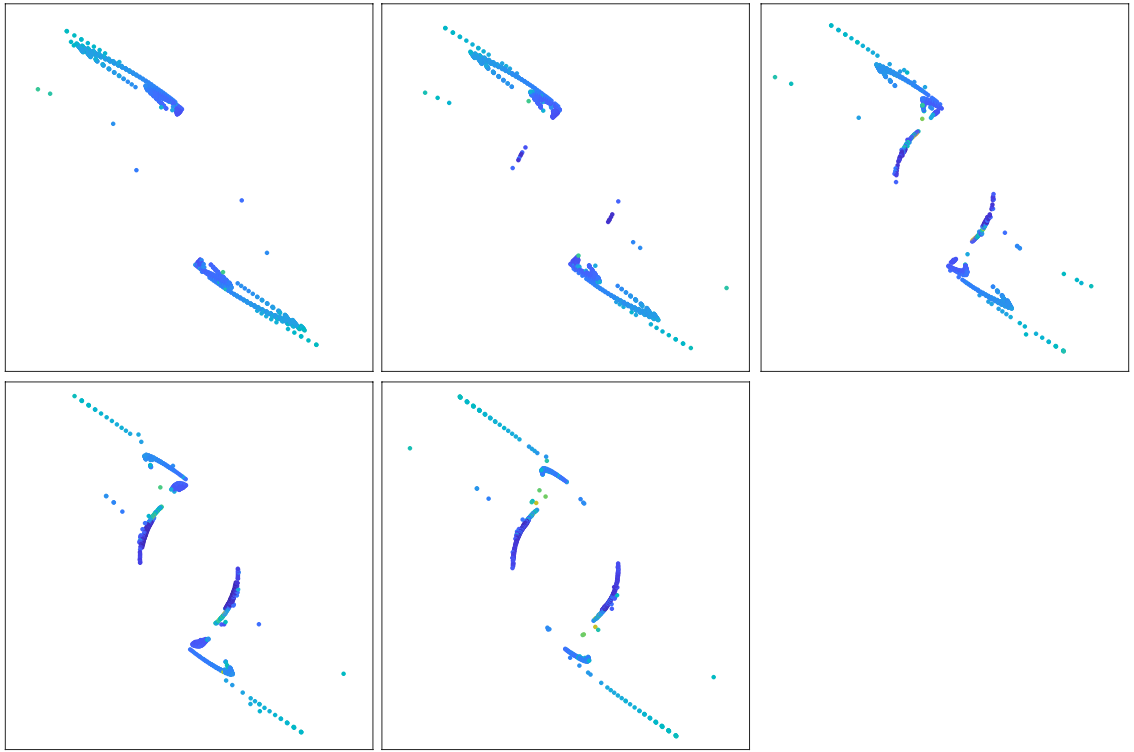

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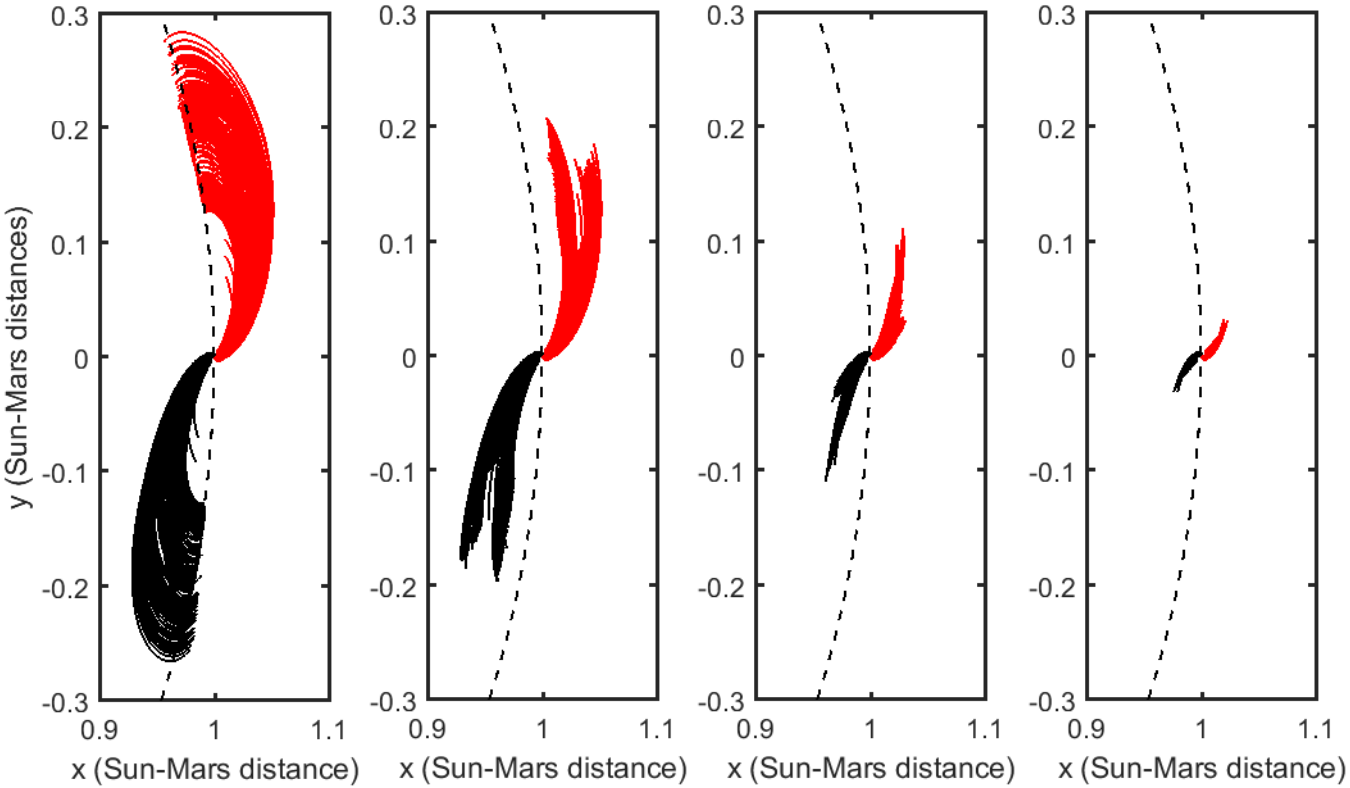
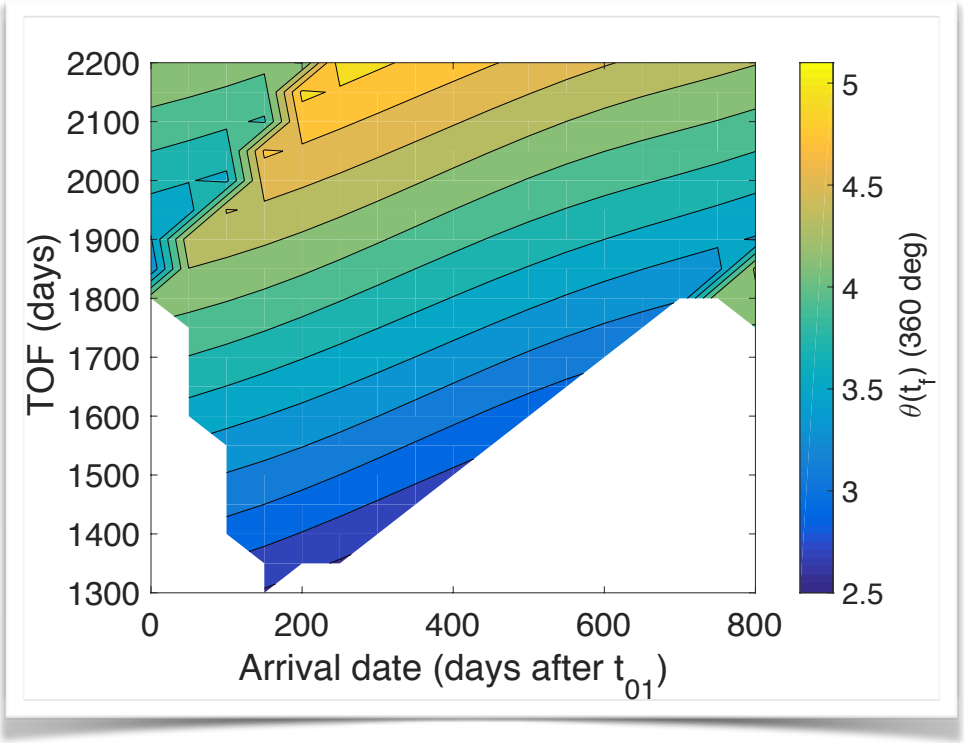


Rendezvous with Mars

(no capture)



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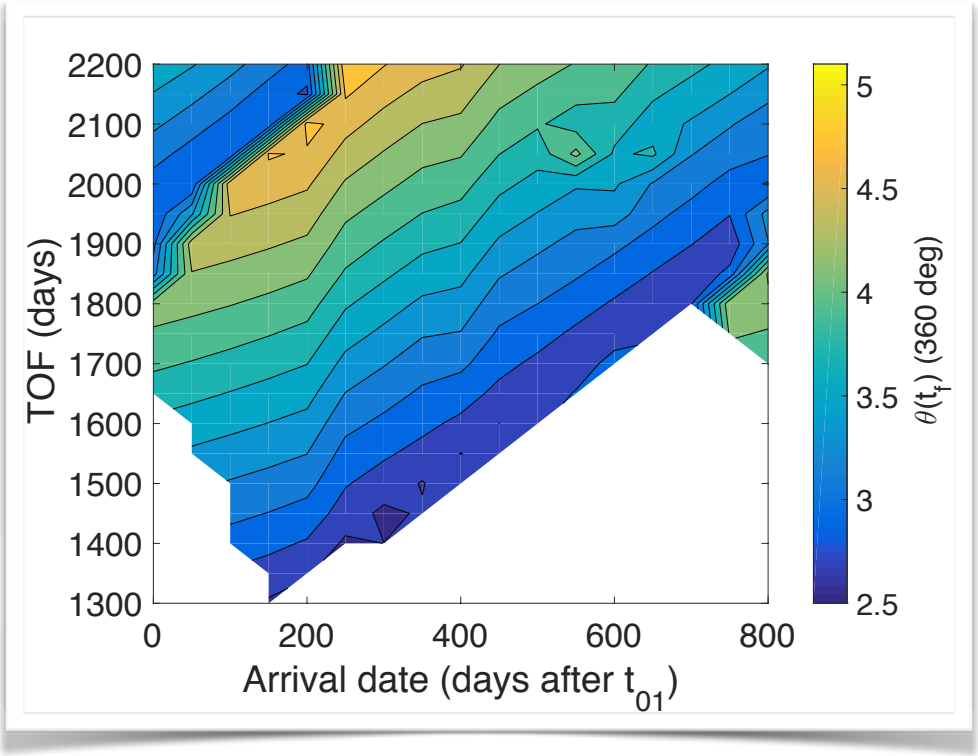
(with ballistic capture)



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Results

(with ballistic capture)