Improving orbit propagation of space objects: learning a propagator error

X Iberian Modelling Week

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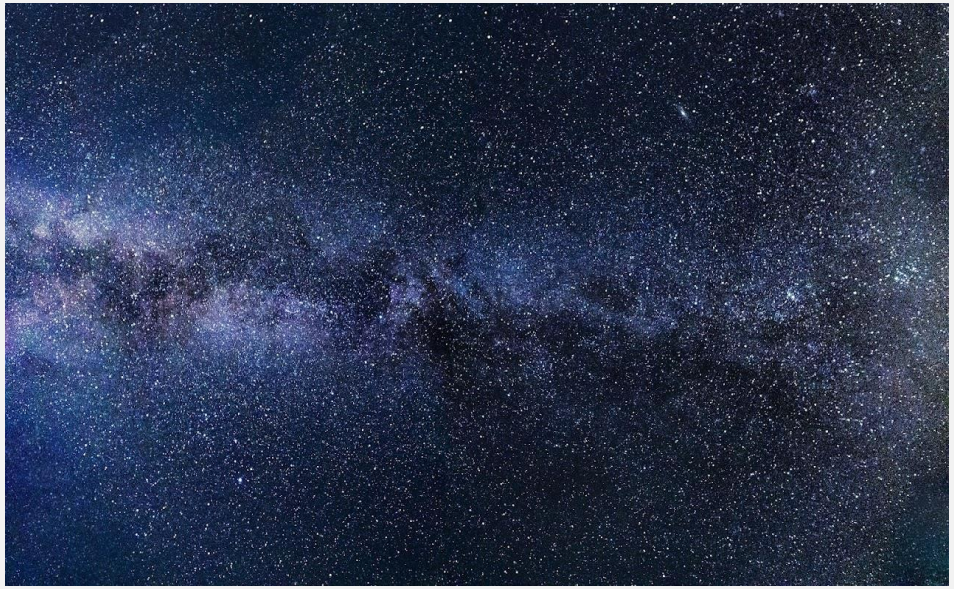
FACULDADE DE CIÊNCIAS E TECNOLOGIA

NOVALINCS
LABORATORY FOR COMPUTER SCIENCE AND INFORMATICS

NOVAMATH
CENTER FOR MATHEMATICS AND APPLICATIONS

NEURASPACE - AI Fights Space Debris

neuraspace Fighting space debris with AI

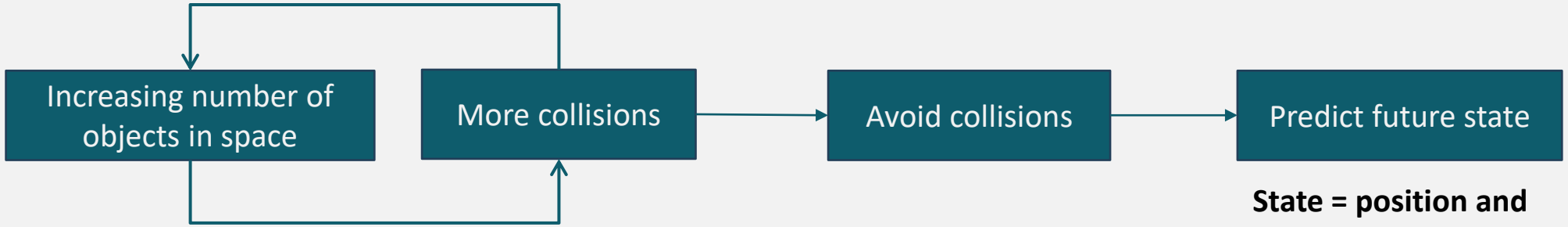


Project

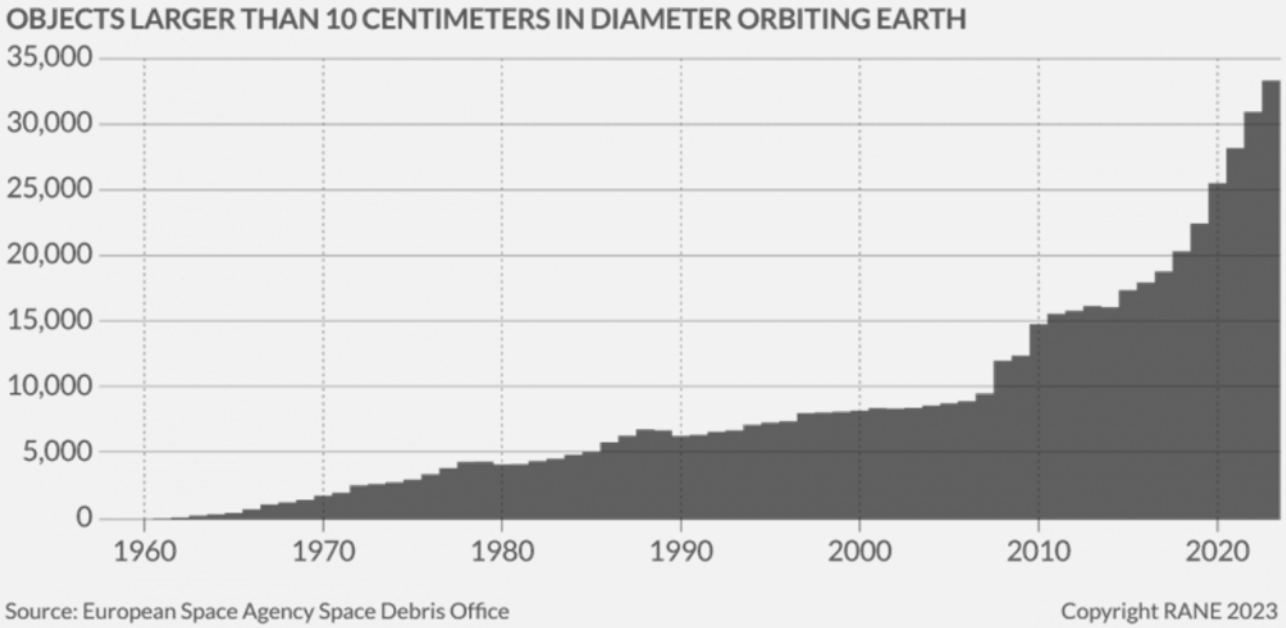
Neuraspaces' Space Traffic Management Platform for satellite operators

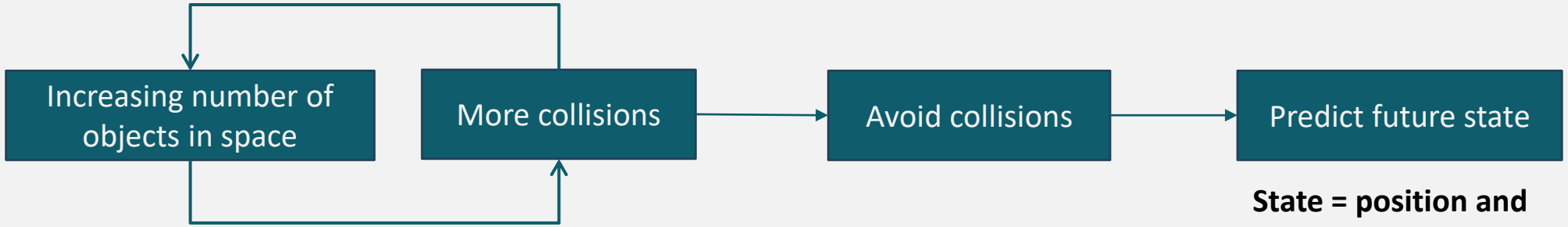
Artificial Intelligence and Machine Learning solutions

Safe space operations and collision avoidance



State = position and velocity

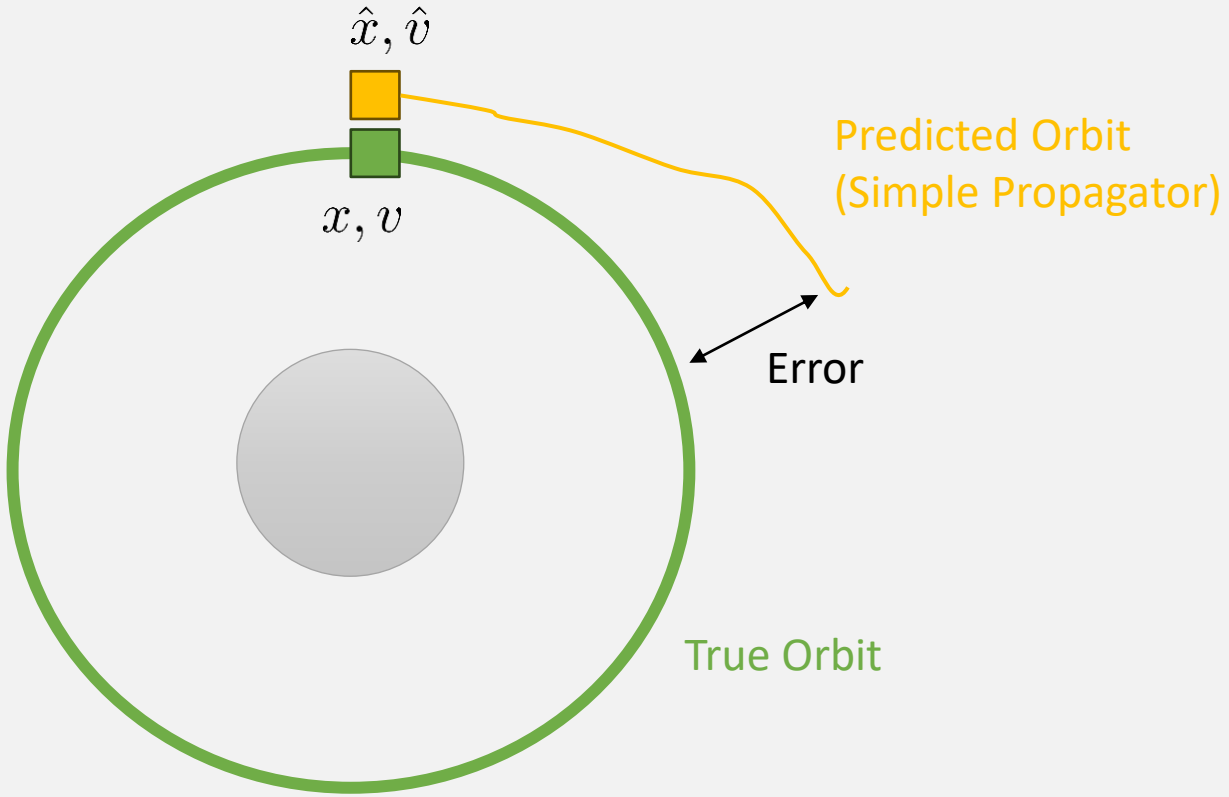




State = position and velocity

Current solutions	Problem	Solution
Physics-based models	Less accurate propagators	Learning from data
Increasing number of objects	Increased uncertainty	
Time consuming for multiple objects	Unnecessary manoeuvres	

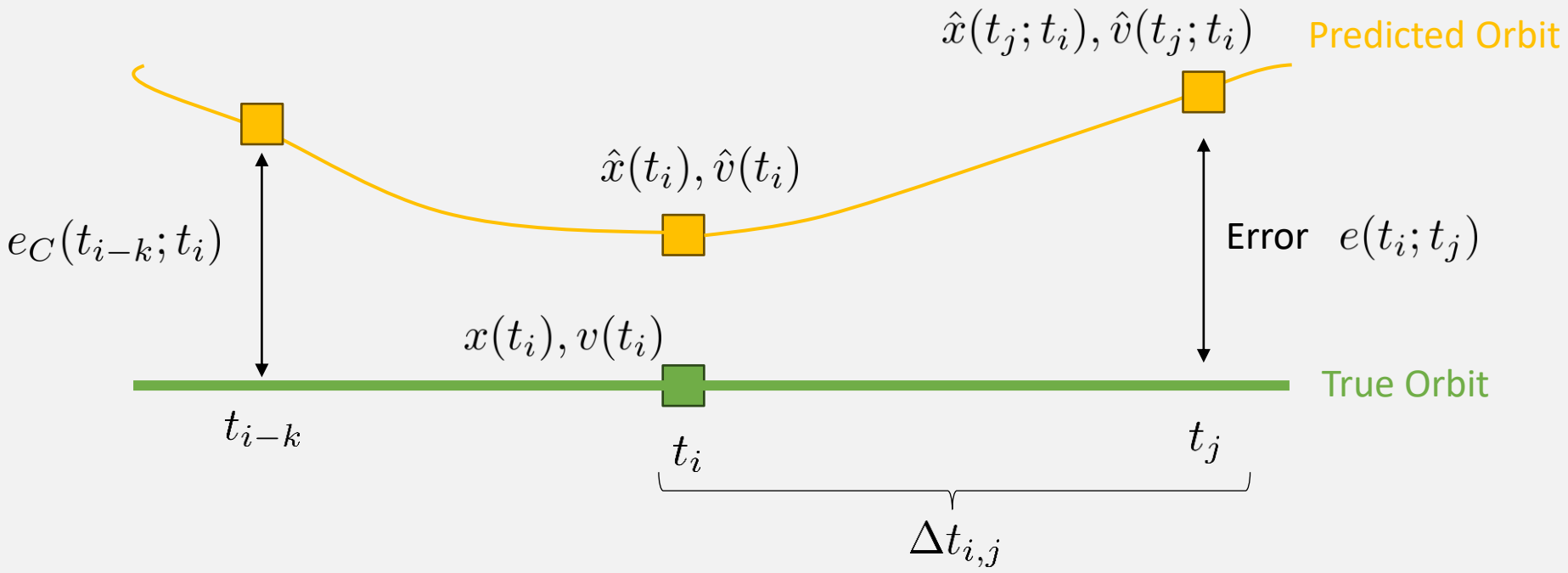
Overall goal Data-based approach to predict the future position and velocity of objects in space

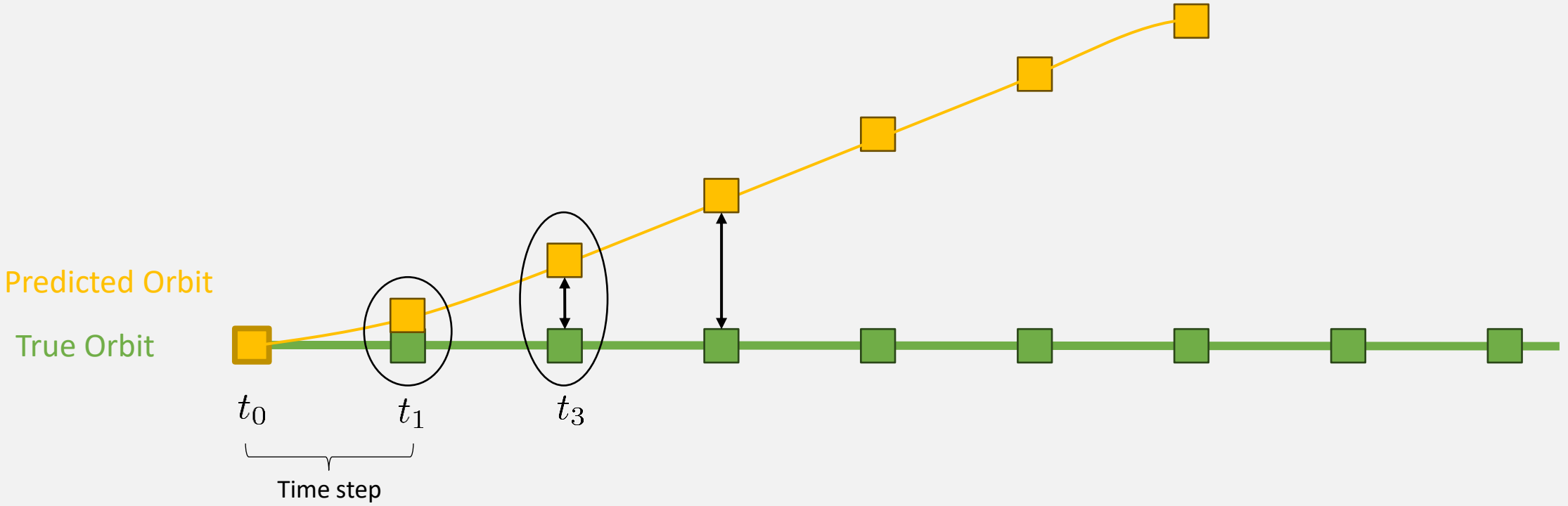


Propagation with simple model

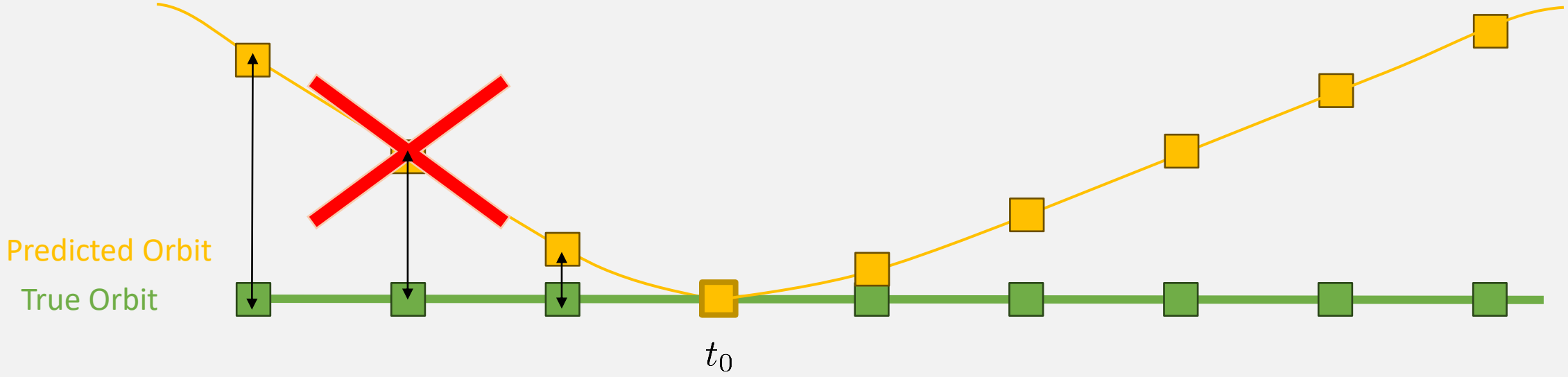
Learning the error with respect to real model

Apply correction at prediction time


$\hat{x}(t_j;t_i), \hat{v}(t_j;t_i)$
Predicted Orbit
$\hat{x}(t_i), \hat{v}(t_i)$
$e_C(t_{i-k};t_i)$
Error $e(t_i;t_j)$
$x(t_i), v(t_i)$
True Orbit
t_{i-k}
t_i
t_j
$\Delta t_{i,j}$

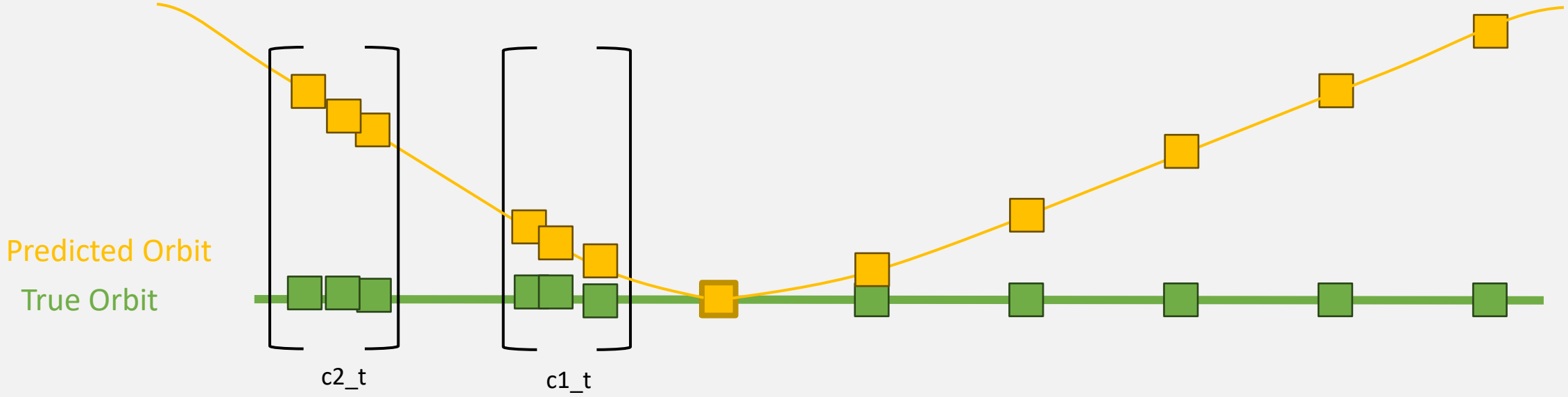


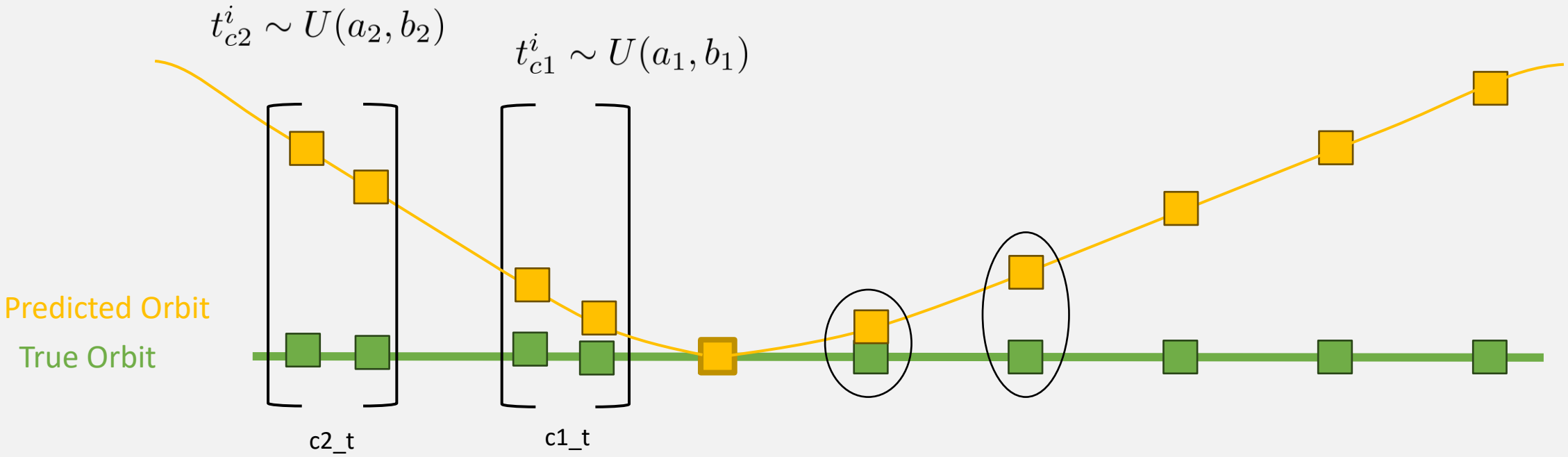
	Time	Delta_t	True	Approx	Target
Sample 1	t_0	$t_1 - t_0$	$x(t_1; t_0)$	$\hat{x}(t_1; t_0)$	$\hat{x}(t_1; t_0) - x(t_1; t_0)$
Sample 2	t_0	$t_2 - t_0$	$x(t_2; t_0)$	$\hat{x}(t_2; t_0)$	$\hat{x}(t_1; t_0) - x(t_1; t_0)$



Same consistency error for all points in same propagation sequence

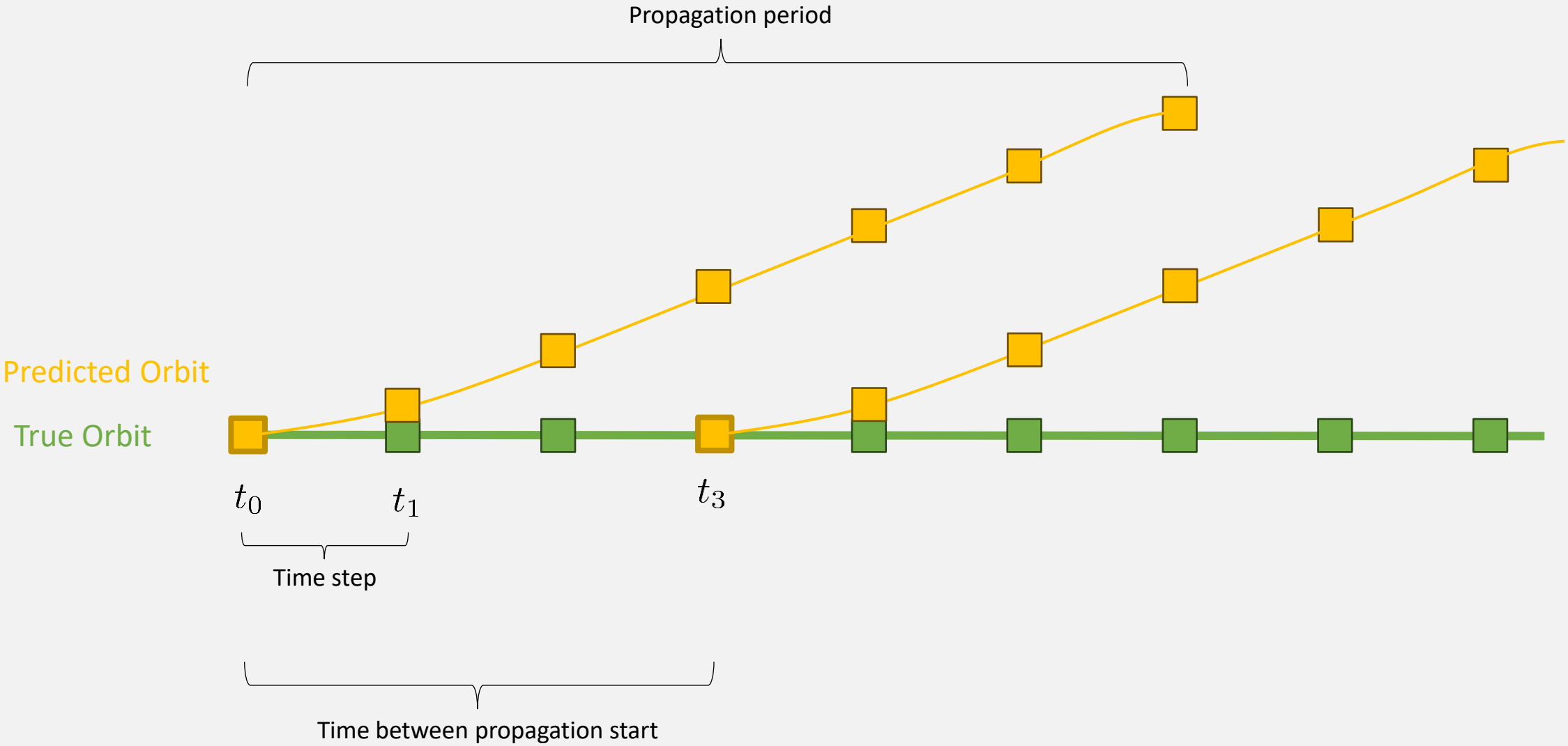
Consistency errors



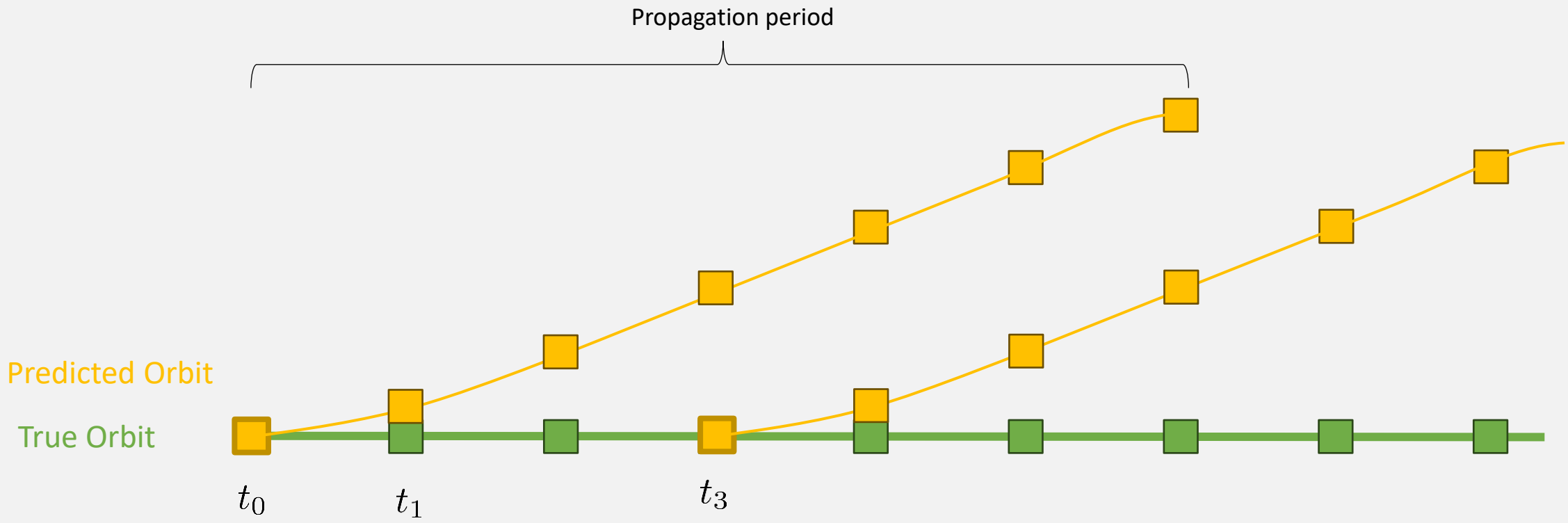


	Time	Delta_t	c1_t	c1_x	c2_t	c2_x	...	True	Approx
Sample 1	t_0	$t_1 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_1; t_0)$	$\hat{x}(t_1; t_0)$
Sample 2	t_0	$t_2 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_2; t_0)$	$\hat{x}(t_2; t_0)$

Multiple propagation samples



Multiple propagation sequences



	Time	Delta_t	c1_t	c1_x	c2_t	c2_x	...	True	Approx
Sequence 1	t_0	$t_1 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_1; t_0)$	$\hat{x}(t_1; t_0)$
	t_0	$t_2 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_2; t_0)$	$\hat{x}(t_2; t_0)$
Sequence 2	t_3	$t_4 - t_3$	...						
	t_3	$t_5 - t_3$							

Complete dataset

3 coordinates for position and 3 for velocity

	Time	Delta_t	c1_t	c1_x	c2_t	c2_x	...	True_x	Approx_x
Sequence 1	t_0	$t_1 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_1; t_0)$	$\hat{x}(t_1; t_0)$
	t_0	$t_2 - t_0$	t^i_{c1}	$e_c(t^i_{c1}; t_0)$	t^i_{c2}	$e_c(t^i_{c2}; t_0)$		$x(t_2; t_0)$	$\hat{x}(t_2; t_0)$
Sequence 2	t_3	$t_4 - t_3$	...						
	t_3	$t_5 - t_3$							

c1_x | c1_y | c1_z | c1_vx | c1_vy | c1_vz

c2_x | c2_y | c2_z | c2_vx | c2_vy | c2_vz

Parameters

	Value
Propagation period	7 days
Time step	5 minutes
Number of consistency errors	5
Time between propagation start	0.5 days
Number of propagation sequences	40

Backpropagation $t_{ci} \sim U(a, b)$

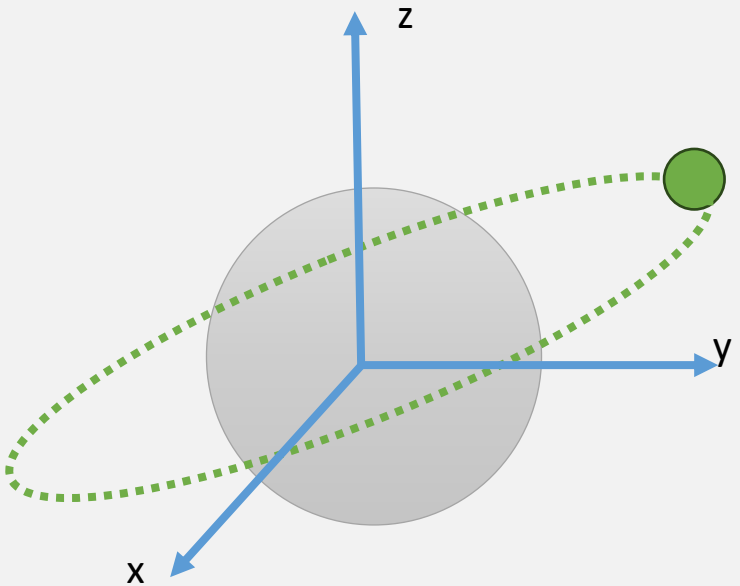
	a (days)	b (days)
C1	0	0.5
C2	1	1.5
C3	2.5	3
C4	5	5.5
C5	7.5	8

Force models

	Approximation	True
Gravity Model	✓	✓
Third body perturbations	✗	✓ Moon, sun
Atmospheric model	✗	✓
Drag model	✗	✓
Solar radiation pressure (SRP) model	✗	✓

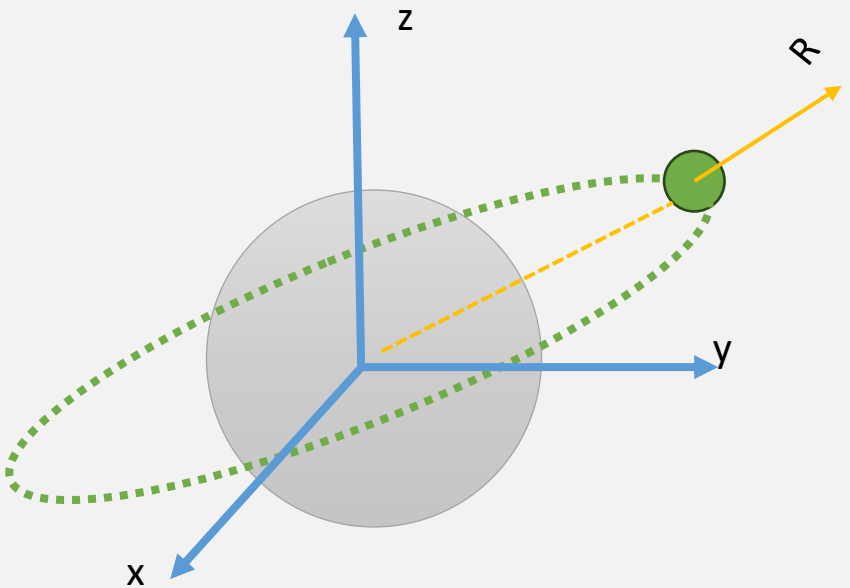
Two datasets for each orbit

X		
Y		
Z		



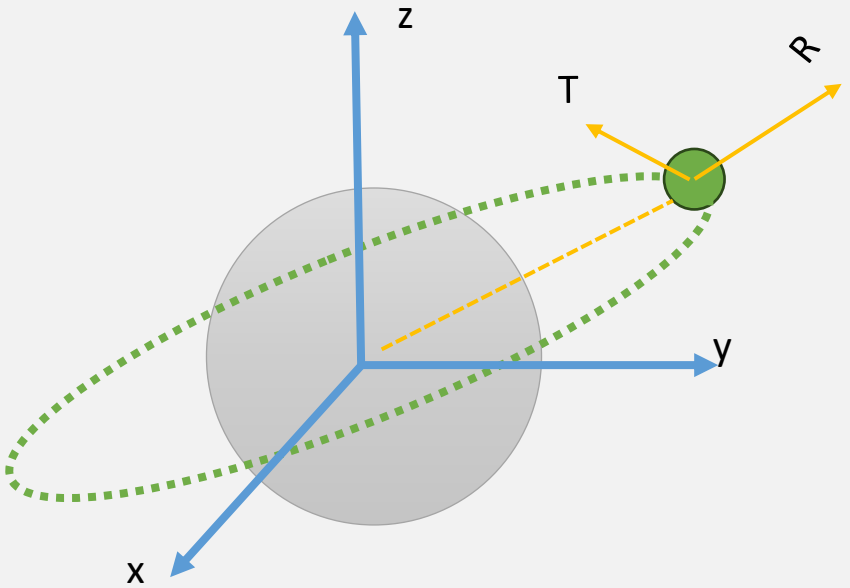
Two datasets for each orbit

		RTN frame
X	R	Radial (position vector)
Y		
Z		



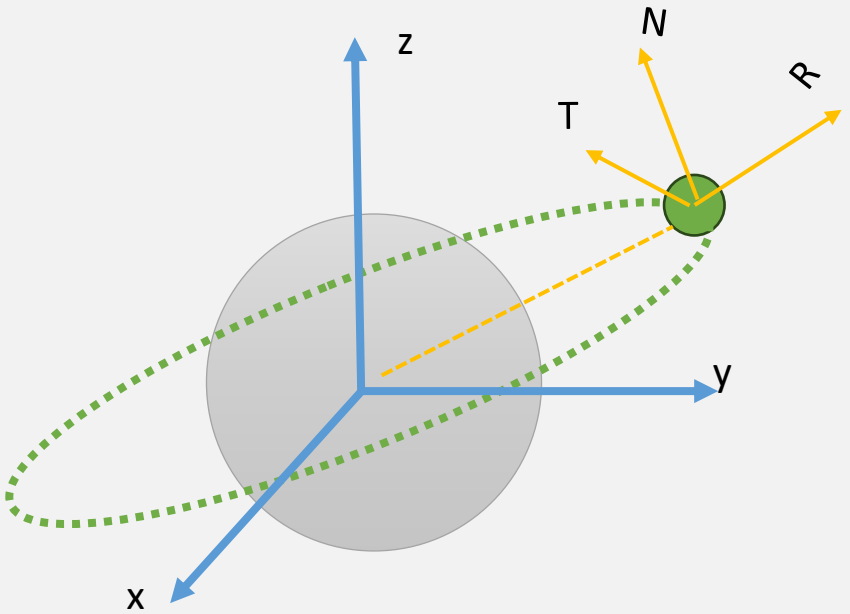
Two datasets for each orbit

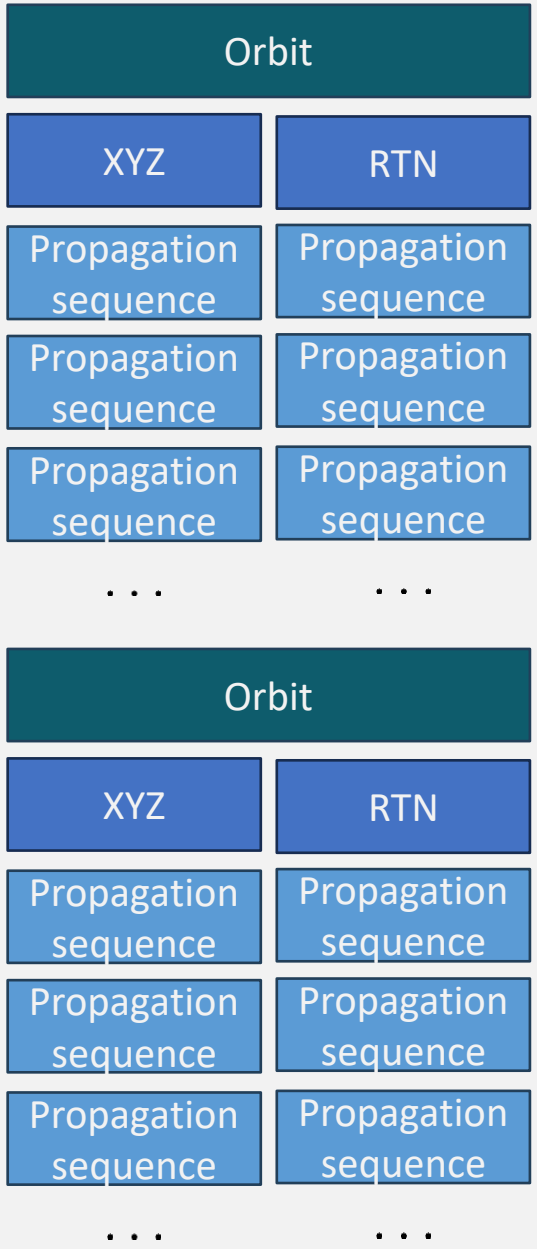
		RTN frame
X	R	Radial (position vector)
Y	T	Transverse/ along track (velocity vector)
Z		



Two datasets for each orbit

		RTN frame
X	R	Radial (position vector)
Y	T	Transverse/ along track (velocity vector)
Z	N	Normal (across track)





Main goals

Q1. Given past training propagation sequences, predict 7 days into the future from a new start point

Q2. Given samples from one orbit predict for another orbit

Relevant questions

1. Impact of reference frame
2. Impact of number and period of consistency errors
3. Impact of number of sequences used in training and time step
4. Behaviour of error over propagation period