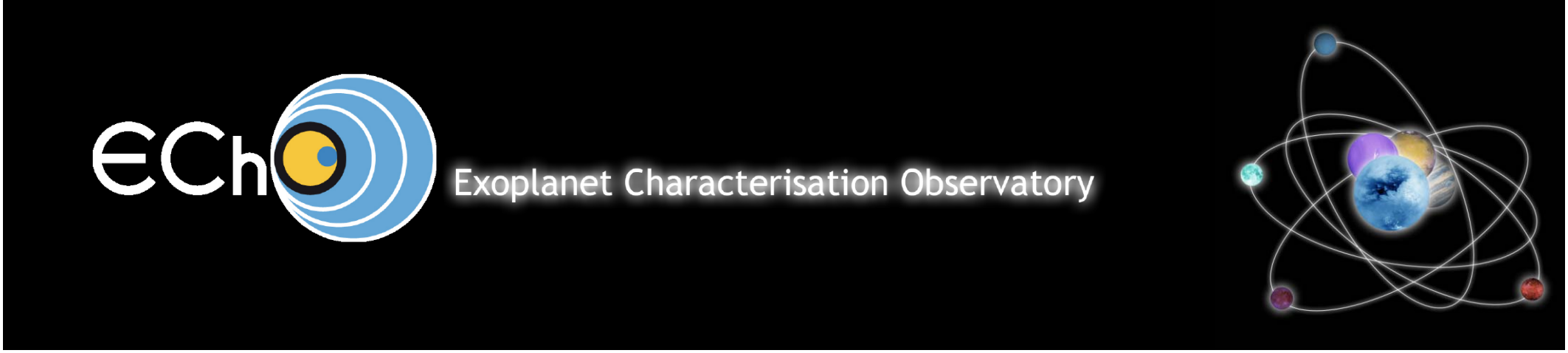

Artificial Intelligence for the EChO Mission Scheduler

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SCIOPS 2013
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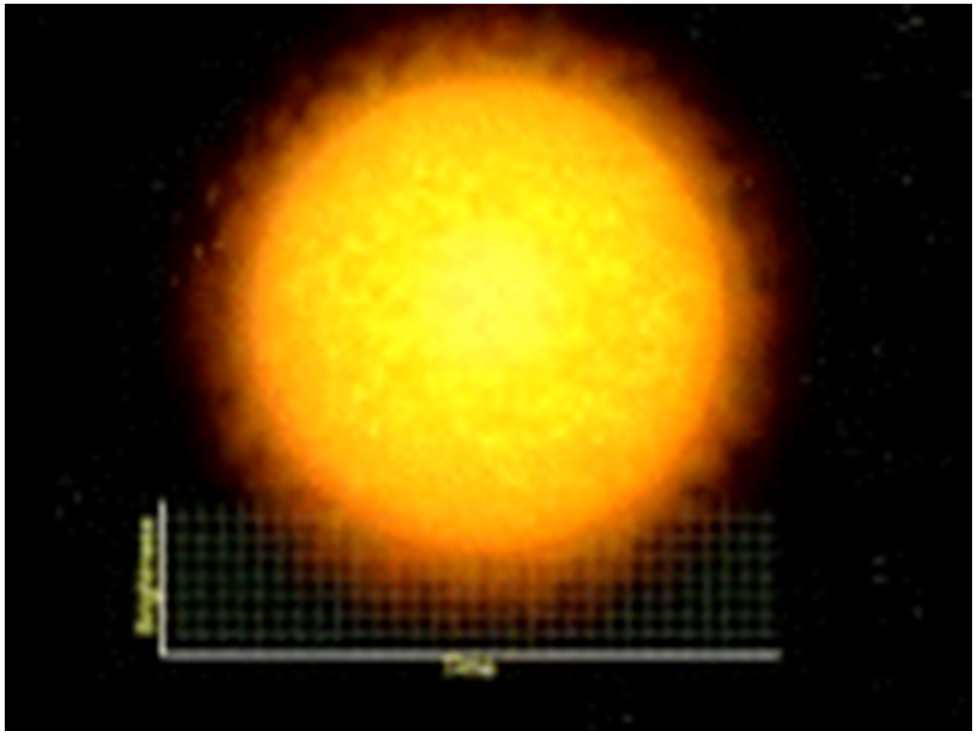
Introduction

- Exoplanet Characterisation Observatory (EChO)
  - ESA M3 mission candidate
    - Currently assessed for an expected launch in 2022
  - It could be the first dedicated mission to investigate the physics and chemistry of Exoplanetary Atmospheres
  - The primary objective is to study the atmospheres of a representative sample of exoplanets (>200) by using the differential technique of transit spectroscopy



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EChO Exoplanet Characterisation Observatory

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EChO Operation Tasks

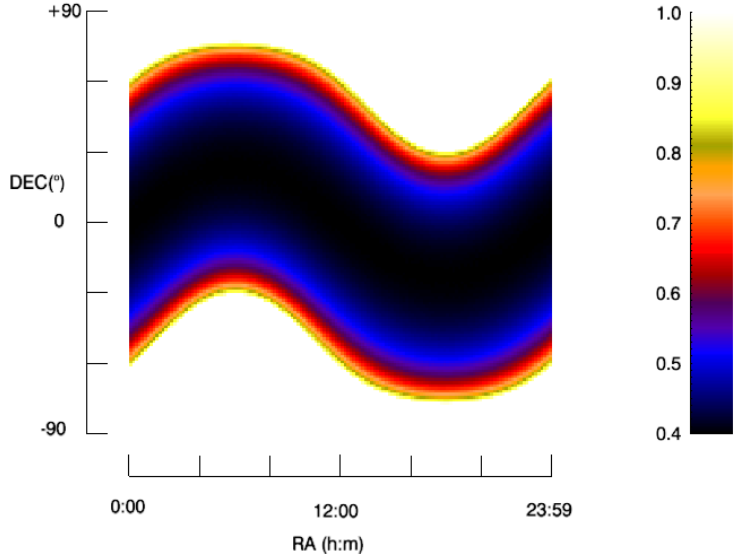
o The EChO mission will have to deal with a variety of observation patterns:

- **Science observations** are the observations of target objects.
- **Downlink** communication is used for transferring data from the spacecraft to stations on Earth.
- **Station keeping** operations are defined to keep the spacecraft in the assigned orbit.
- **Calibration** tasks are associated to science observations.

o Several operation tasks have to be done in fixed slots of time and they involve a temporary stop of the scientific operations

EChO Hard Constraints (I)

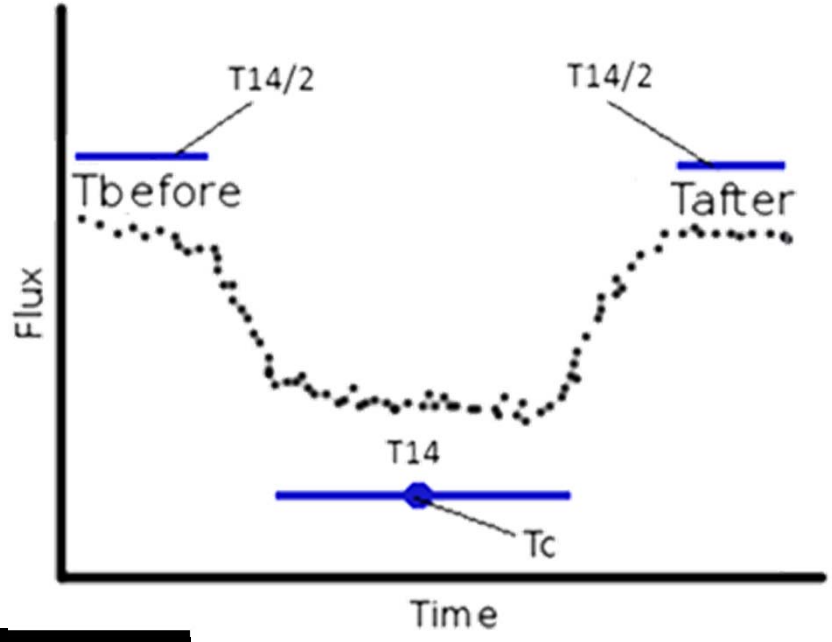
o Orbital Constraint



o Transit Constraint (event)

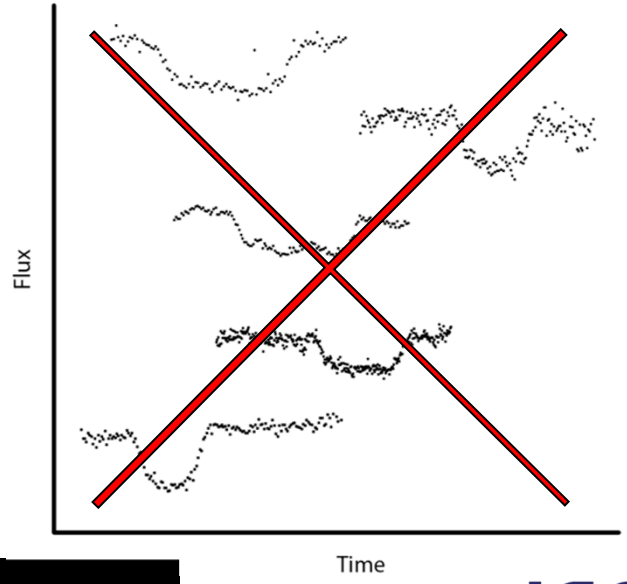
- Event occurrence known (Tc)
- The event duration is known (T14)
- Total observation time:

T14 + Tbefore + Tafter = 2·T14



EChO Hard Constraints (II)

- Target Completeness Constraint
  - Each target has to be observed a required number of events
    - Targets observed less than an 80% are not interesting
- Slewing Constraint
  - Pointing to a particular target and acquiring data requires a specific configuration which depends on the slewing speed of the satellite
- Overlapping Constraint
  - Collisions between operation tasks must be solved



EChO Soft Constraints

- Optimization of Resources
  - Observation time of the telescope should be promoted
  - Slew time of the telescope should be reduced

- Scientific Return
  - Observation of the priority targets should be promoted
  - The observation of complete targets should be promoted

EChO Soft Constraints

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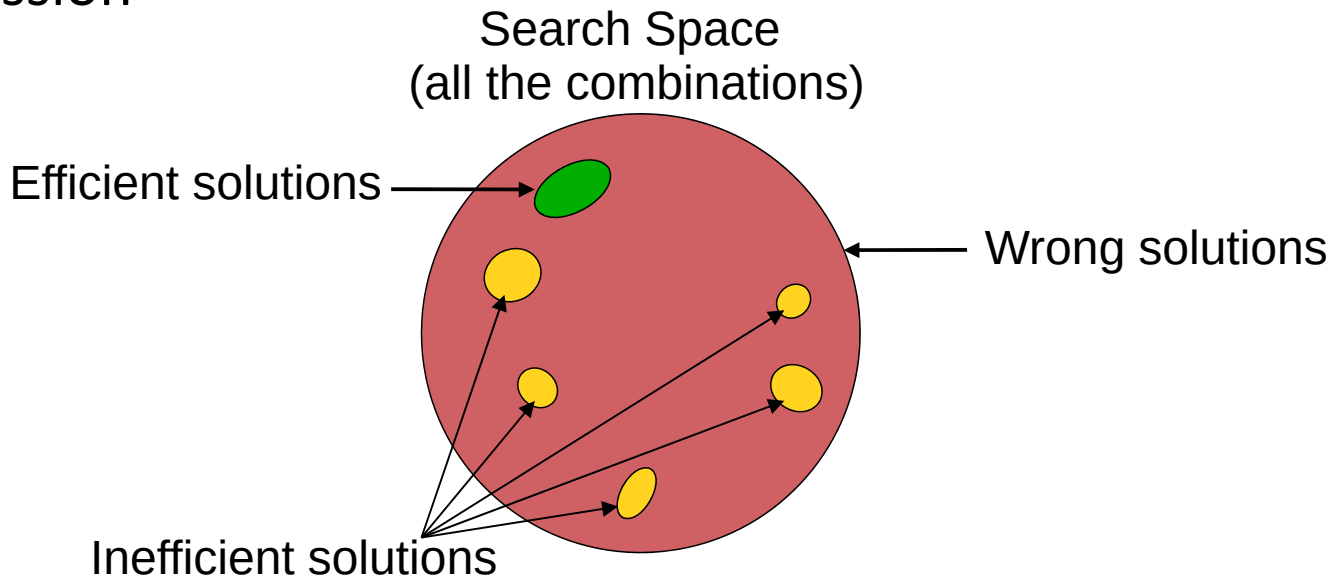
  - The observation of complete targets should be promoted

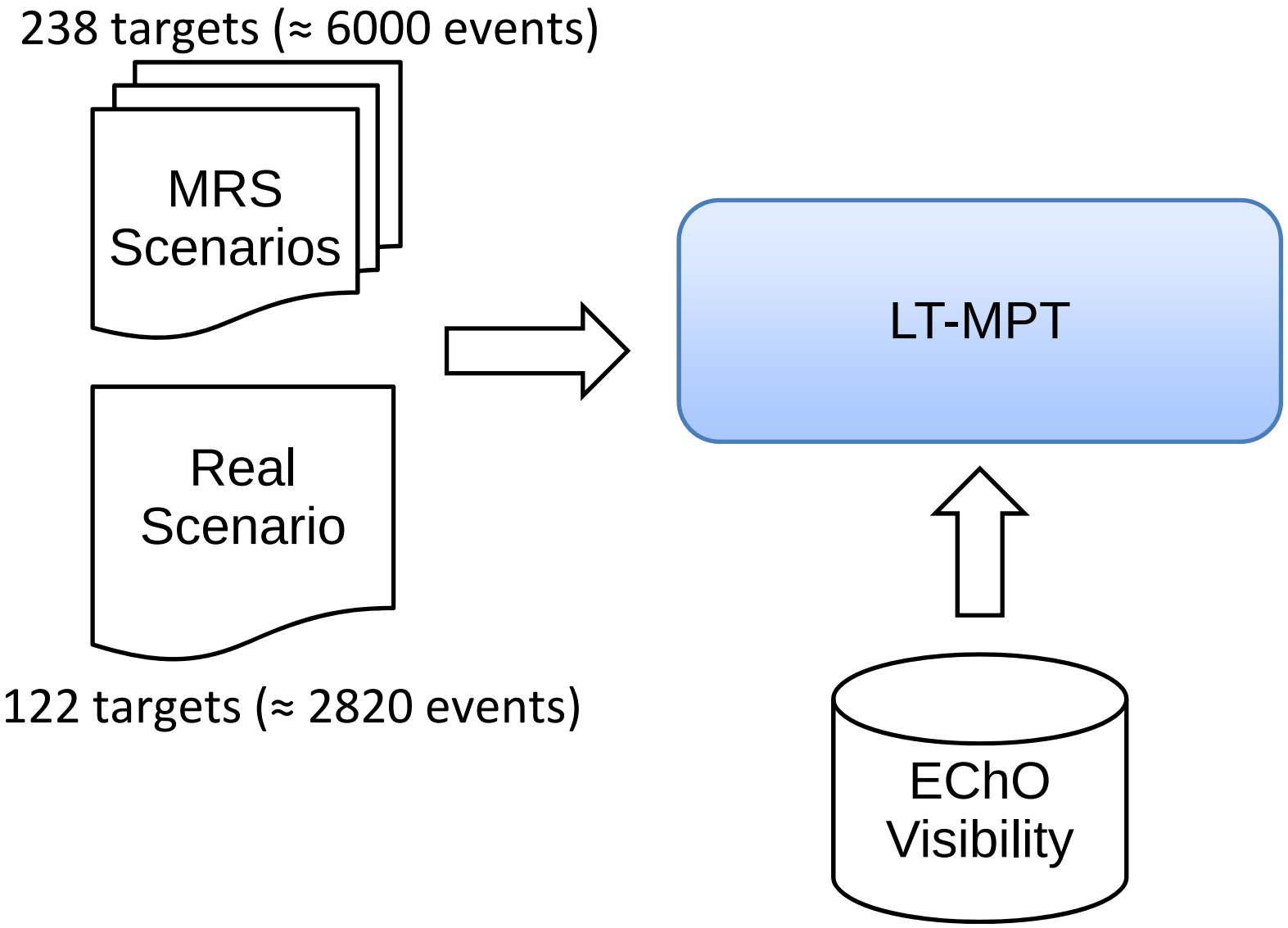
Mission Objectives

Long Term Mission Planning Tool (LT-MPT)

- Collection of time-critical events for five years of EChO:
  - 200 targets
  - 30 events (observations) per target (average value)
  - Each target can be observed in 500 different windows (average)
  - Number of combinations: $(200 \cdot 25)^{500} \sim 10^{1800}$
- What is an "efficient solution"?
  - A planning solution that highly optimizes the objectives defined in the mission

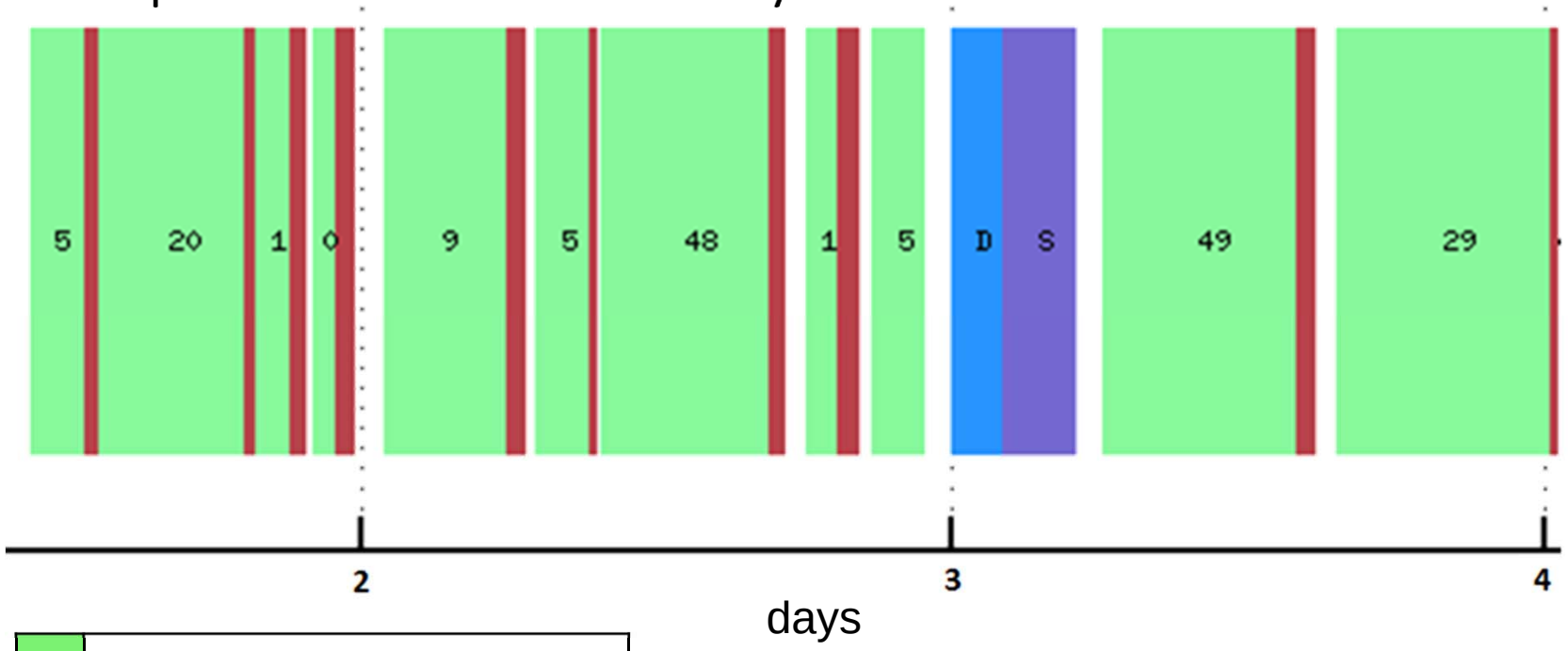


LT-MPT Input


238 targets (≈ 6000 events)
MRS Scenarios
Real Scenario
122 targets (≈ 2820 events)
LT-MPT
EChO Visibility

LT-MPT Output

- Long Term Mission Plan (LTMP)
  - Example of a LTMP of a few days



	Observation of a target
	Slewing between targets
	Downlink
	Station Keeping
	Gap

LT-MPT Objectives

- Maximize planning efficiency (observing time)

- Maximize scientific return (i.e., the number of completed targets)
  - It is computed with the number of completed targets weighted according the target priority

LT-MPT Design

- Process:
  - **Step 0.** Calculate the time windows of each target event
  - **Step 1.** Clean up impossible targets
  - **Step 2.** Insert downlinks and station keepings minimizing potential conflicts with priority targets
  - **Step 3.** Obtain observation planning avoiding overlaps and optimizing the defined objectives
  - **Step 4.** Remove observations of incomplete targets (targets observed less than an 80% of their required number of events)
  - **Step 5.** Fill gaps with calibrations or new observations

LT-MPT Design

- Process:
  - **Step 0.** Calculate the time windows of each target event
  - **Step 1.** Clean up impossible targets

Optimization Steps

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  - **Step 3.** Obtain observation planning avoiding overlaps and optimizing the defimed objectives
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Representation of a LTMP

- Example (3 targets)

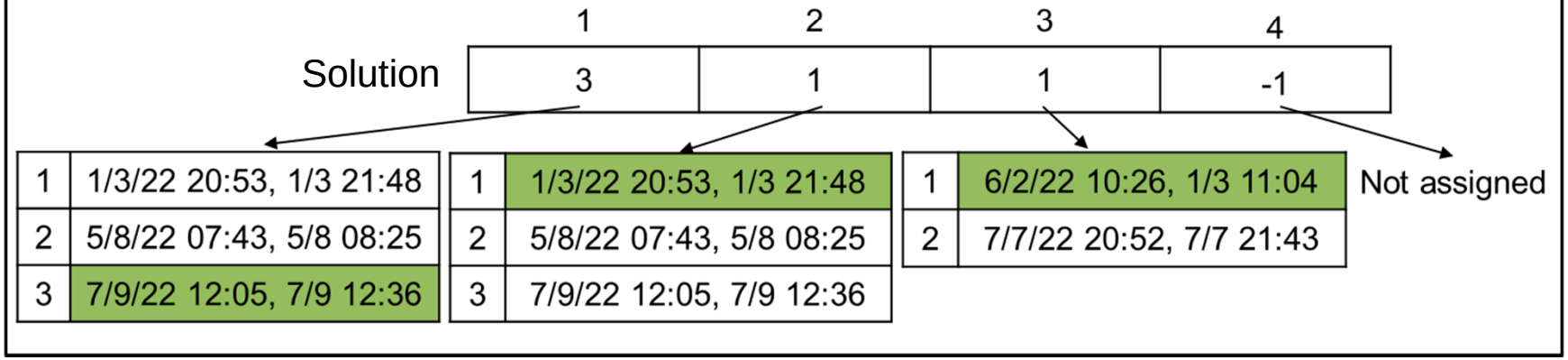
Targets to Be Planned

Target 1	
Number of events: 2	
Potential time windows:	
1	1/3/22 20:53, 1/3 21:48
2	5/8/22 07:43, 5/8 08:25
3	7/9/22 12:05, 7/9 12:36

Target 2	
Number of events: 1	
Potential time windows:	
1	6/2/22 10:26, 1/3 11:04
2	7/7/22 20:52, 7/7 21:43

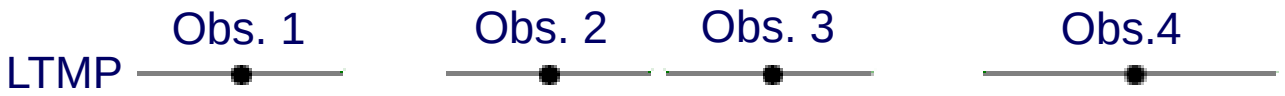
Target 3	
Number of events: 1	
Potential time windows:	
1	6/2/22 10:26, 1/3 11:04

Individual Representation of a Potential Solution



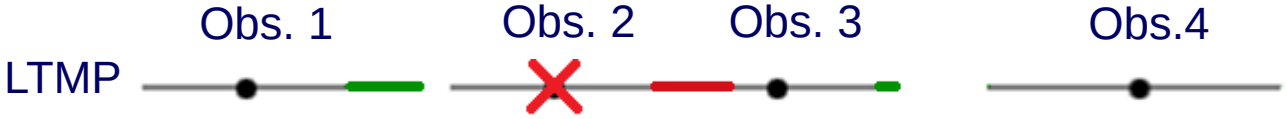
Optimizing the LTMP

- Observations of the targets are planned

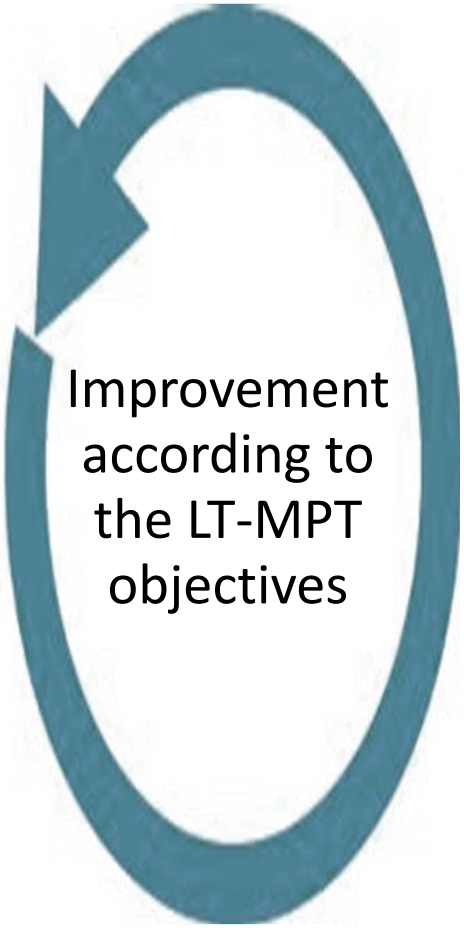


  - Slew time must be placed for each planned observation

  - Conflicts among observations must be removed



  - Potential solution (hard constraints are respected)



- Improvement of the LTMP (additional observations can be planned)

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Optimizing the LTMP

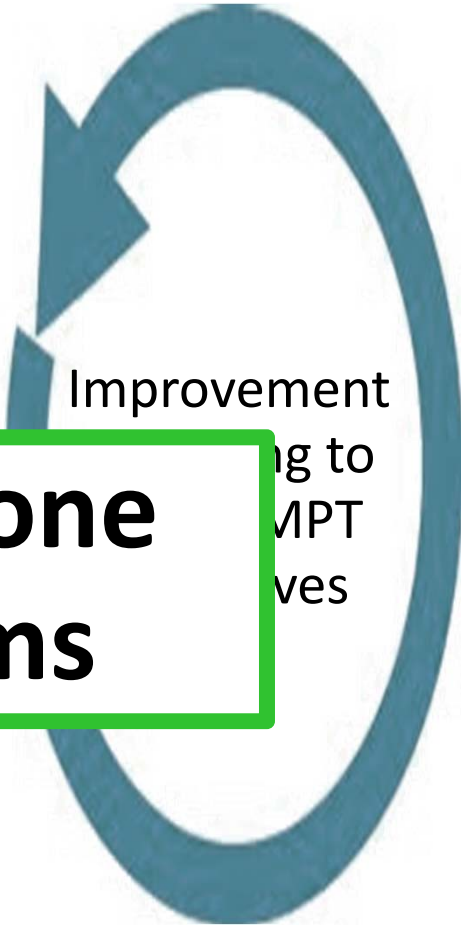
- Observations of the targets are planned

  - Slew time must be placed for each planned observation

  - Co
  - LT

Optimization process done with Genetic Algorithms

  - Potential solution (hard constraints are respected)



Improvement
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MPT
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- Improvement of the LTMP (additional observations can be planned)

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Test Bench Configuration

- 10 MRS scenarios and 1 real sample scenario
  - MRS: 238 targets (≈ 6000 events)
  - Real: 122 targets (≈ 2820 events)
  - Executed 100 times with different random seeds
- Long Term Mission Plan (five years, 2022-2026)
- 520 Downlinks (2 hours / 3.5 days ± flexibility)
- 65 Station Keepings (8 hours / 28 days ± flexibility)
- Slew time between targets
  - Slew speed of 45 degrees per 10 minutes plus a flat 5-minute overhead
- No calibrations considered

Result Summary

o MRS Scenarios and Real Scenario (computational cost ≈ 45 minutes *)

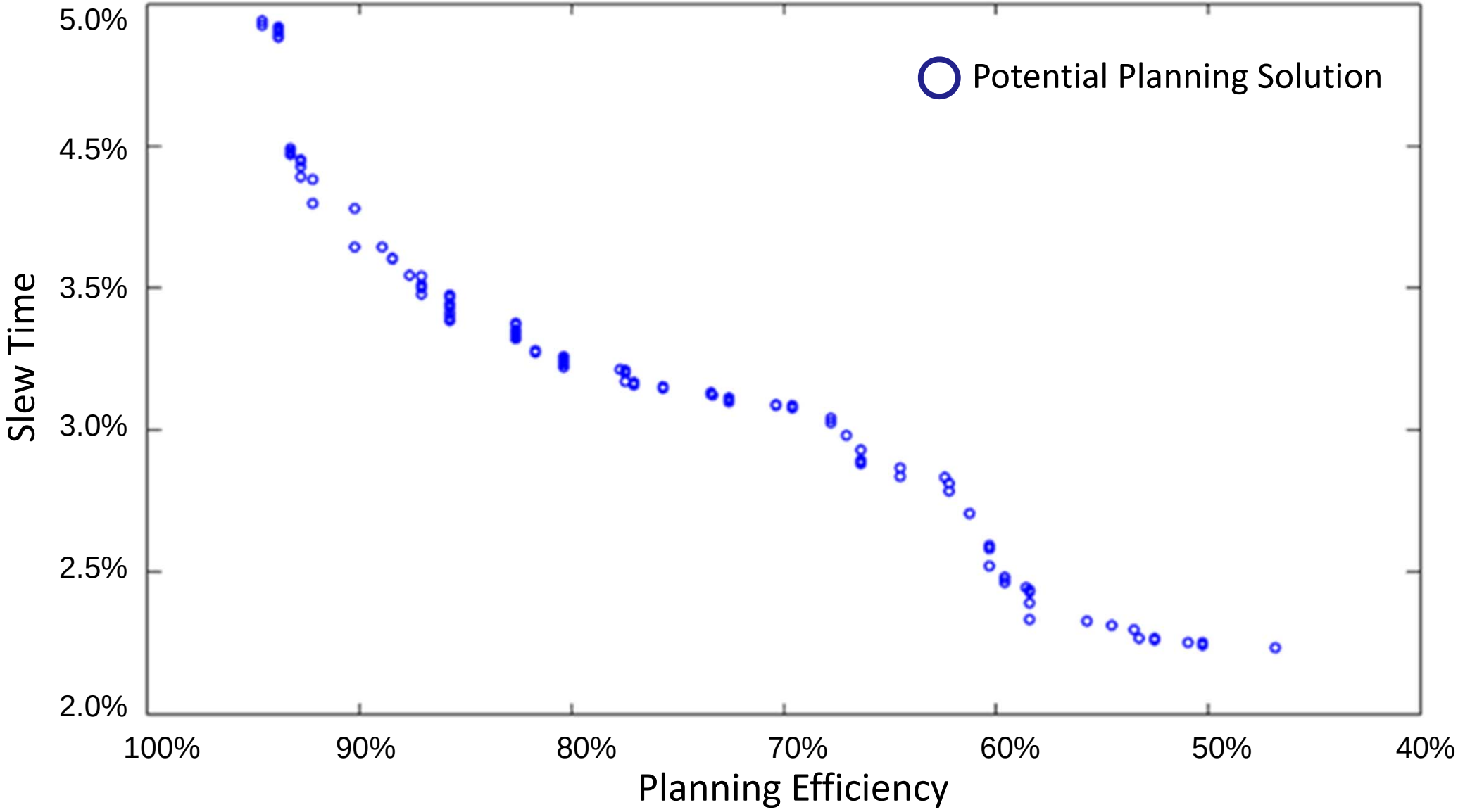
- 100 trials for each scenario
- Usable Science Time: 31671 hours

Scenario	Total Input Time	Planning Efficiency	Slew Time	Events Planned	Targets Completed
MRS 0	27925 hours	85.21% ±0.98	4.86% ±0.04	91.69% ±0.54	95.84% ±0.34
MRS 1	25778 hours	92.02% ±0.74	4.66% ±0.04	95.09% ±0.60	97.75% ±0.37
MRS 2	26734 hours	83.73% ±0.90	4.58% ±0.06	88.98% ±0.78	96.75% ±0.25
MRS 3	29378 hours	76.77% ±1.47	4.58% ±0.11	82.76% ±1.36	94.06% ±0.64
MRS 4	26321 hours	90.93% ±0.94	4.86% ±0.04	94.01% ±0.64	97.93% ±0.40
MRS 5	27557 hours	84.98% ±1.32	4.66% ±0.07	89.65% ±1.03	96.67% ±0.32
MRS 6	26902 hours	87.41% ±0.92	4.62% ±0.02	93.04% ±0.35	96.95% ±0.35
MRS 7	25954 hours	87.56% ±0.83	4.53% ±0.03	92.81% ±0.36	96.85% ±0.36
MRS 8	24839 hours	91.83% ±0.98	4.71% ±0.05	94.91% ±0.59	98.56% ±0.21
MRS 9	26337 hours	87.72% ±1.40	4.83% ±0.07	91.81% ±1.12	97.63% ±0.43
Real	17392 hours	98.57% ±0.02	2.00% ±0.01	98.78% ±0.01	100.00% ±0.00

* CPU Intel® Core™2 Duo Processor E6600 2.40 GHz with 6GB of RAM

Why Slew Time Reduction Is Not Promoted?

o Multiobjective Genetic Algorithm (NSGA-II)



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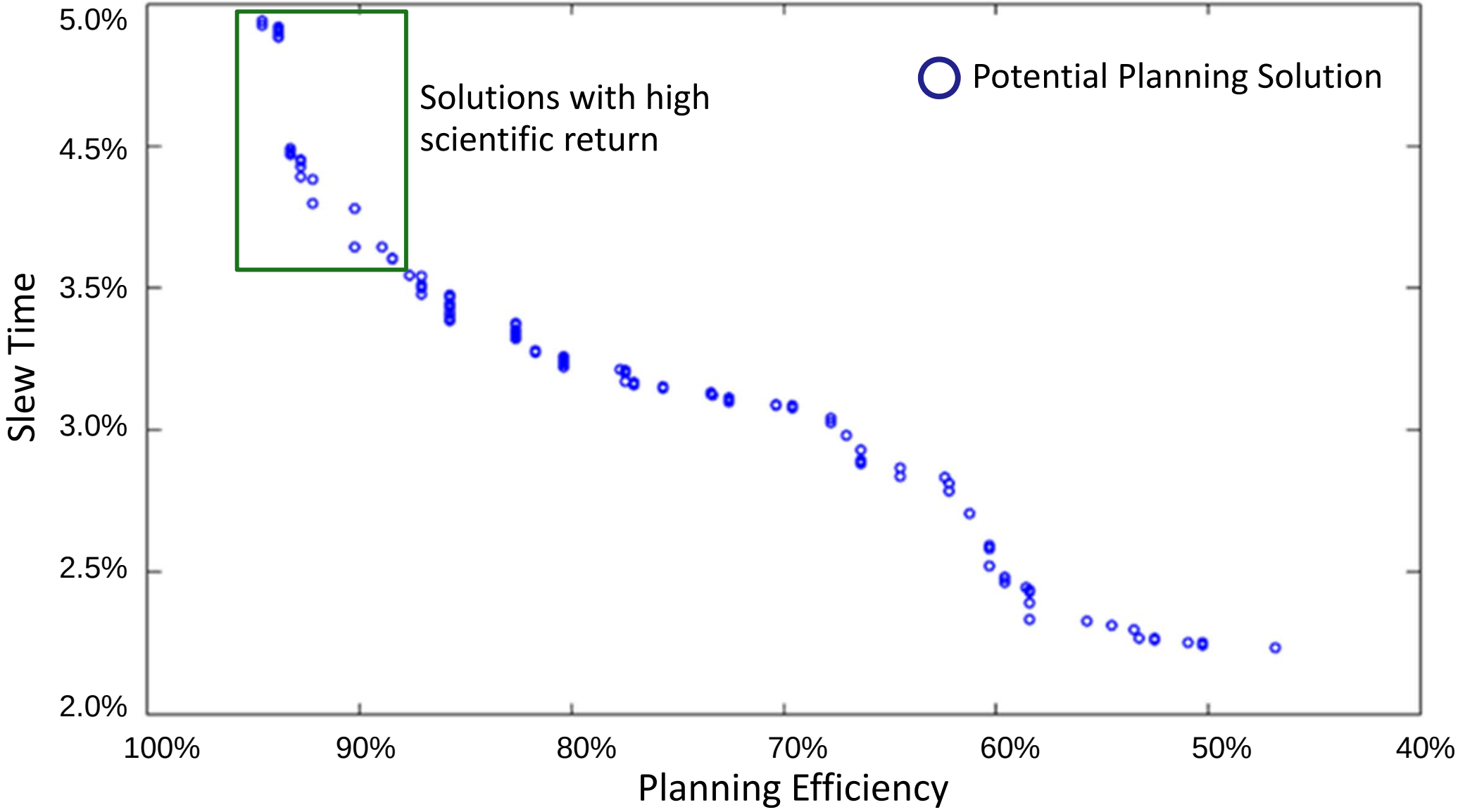

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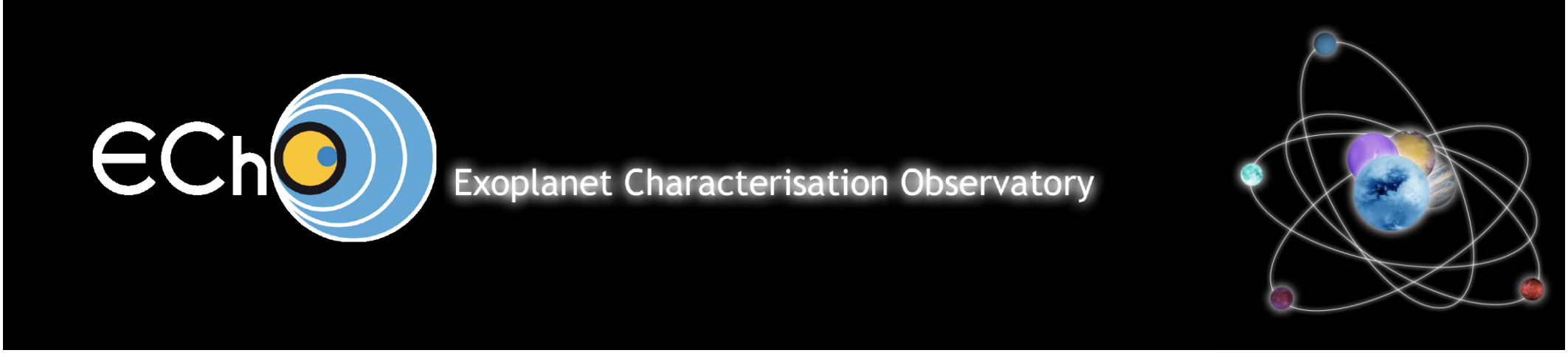
Summary

- Robust and stable planning tool
  - Similar results on different scenarios
  - High planning efficiency (around 90%)
  - Almost all the targets can be completed (observed >80% of events)
  - Reasonable computational cost
- Slew time cannot be reduced without affecting the efficiency
  - A multiobjective algorithm based on minimizing the slew time and maximizing the planning efficiency has been analyzed with no real gain
- Further work
  - Interactive visualization tool
  - How to generalize the planning tool for other missions?



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