Artificial Intelligence for the EChO Mission Scheduler

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Introduction

The Exoplanet Characterisation Observatory (EChO)[1] is an 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 (see Figure 1). This can be achieved using high-precision spectrophotometric observations of two types of events: transit (primary eclipse) and occultation (secondary eclipse). In order to yield measurements of sufficient Signal-to-Noise Ratio to fulfill the mission objectives, the events of each exoplanet may need to be observed several times.

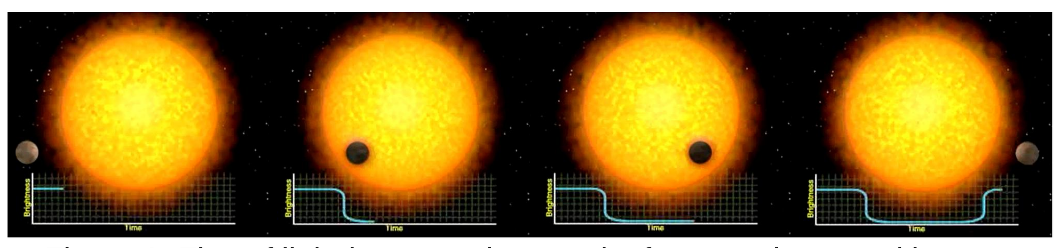

Figure 1. Flux of light between the transit of an exoplanet and its star

A suitable mission plan is expected to increase the efficiency of telescope operation, which will represent an important benefit in terms of scientific return and operational costs. Nevertheless, the planning for this mission has several constraints that must be respected for fulfilling the mission objectives. Thus, this process becomes unaffordable for human planers due to the complexity in computing the huge amount of possible combinations in search for an optimum solution.

In this contribution we present a Long Term Mission Planning Tool (LT-MPT) for EChO based on Genetic Algorithms (GAs), a well-known Artificial Intelligence technique focused on solving optimization problems, which have the ability to be adapted to new environments and constraints.

[1] http://echo-spacemission.org/

Planning Conditions of the EChO Mission

Operation tasks
- Science observations
- Downlink communications
- Station keeping operations
- Calibration tasks

Hard constraints (conditions that must be satisfied)
- Orbital constraint: Visibility of the EChO telescope.
- Transit constraint (see Figure 2): The exact occurrence of an eclipse (T_c) can be calculated in advance, and the duration of the eclipse ($T14$) is known. The event duration is $2{\cdot}T14$.
- Target completeness constraint: Target observation are useful if the target is observed, at least, an 80% of its required number of events (in this case, the target is considered complete).
- Slewing constraint: The time to transfer to a new configuration must be taken into account.
- Overlapping constraint (see Figure 3).

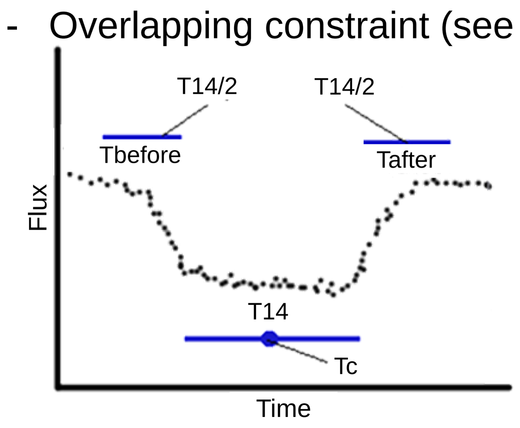

Figure 2. Transit light curve of an exoplanet with the total observation time of its event in blue colour.

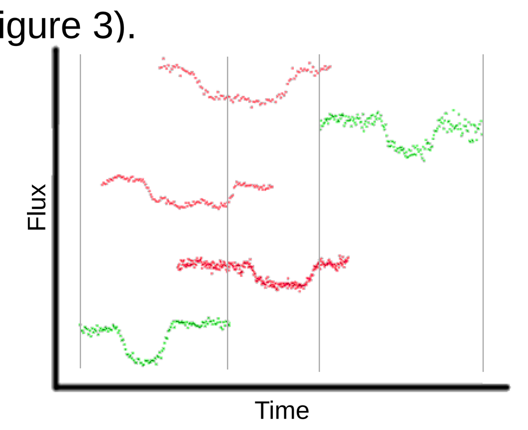

Figure 3. Transit light curves of different exoplanets. The best target at any time (green colour) has to be selected to avoid overlapping.

Soft constraints (conditions that should be satisfied)
- Optimization of resources
  - The time that the telescope is observing target events should be promoted
  - Slew time of the telescope should be reduced
- Optimization of scientific return
  - Observation of the priority targets should be promoted
  - The observation of complete targets should be promoted

Proposal Based on Artificial Intelligence

The LT-MPT uses a GA for finding a planning solution which respects all the hard constraints and promotes the soft constraints.

LT-MPT inputs (see Figure 6)
- Visibility of the EChO telescope
- Exoplanet list to be observed. This list can be:
  - A real scenario: exoplanets currently discovered and that EChO can observe. This is an incomplete list because until 2022 other exoplanets will be discovered.
  - MRS scenarios (artificial scenarios): hypothetical list of exoplanets obtained from the general exoplanet classes than EChO can observe. This classes are described by the Mission Reference Sample (MRS). See Figure 5.

LT-MPT output (see Figure 6)
- Timeline for all the planned days that indicates when each observation will be done and its duration.

Long Term Mission Planning Tool (LT-MPT) Design

LT-MPT process for obtaining the final mission plan
- Step 0. Calculate the time windows of each target event
- Step 1. Clean up impossible targets See Figure 4
- **Step 2. Insert downlinks and station keepings by minimizing:**
  - **Potential conflicts with priority targets**
- **Step 3. Obtain observation planning by maximizing:**
  - **The time that the telescope is observing target events (planning efficiency)**
  - **The number of complete targets weighted with their priority**
- 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 additional observations

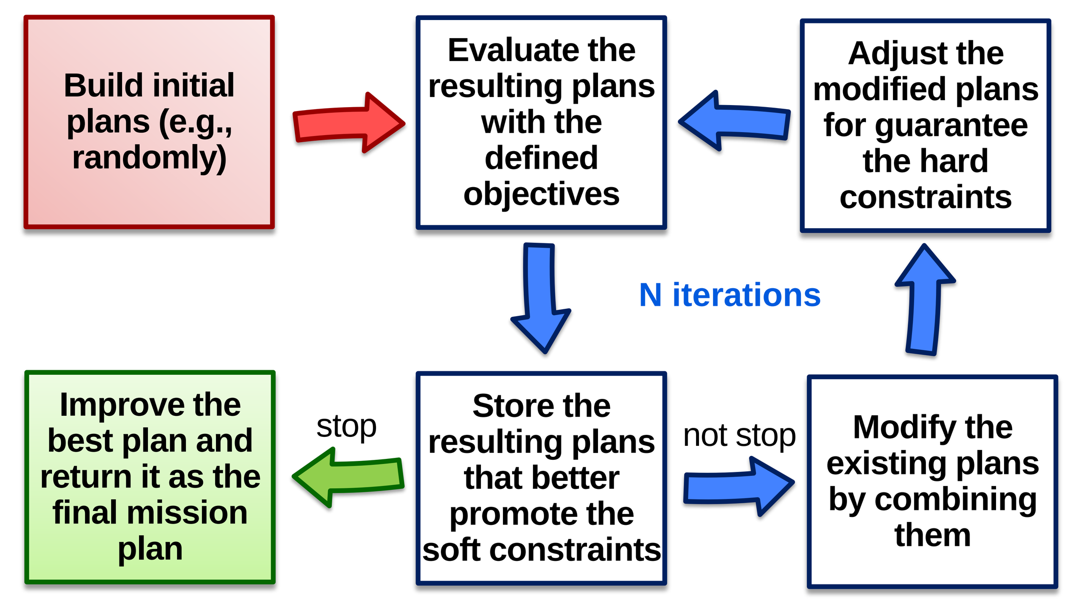

Figure 4. Cycle followed in the optimization steps based on Genetic Algorithms.

Mission Reference Sample (general classes to be observed)

Typ	Ms	Teff	Rs	dist	Ks	Tpl	P	a (10^9 m)	Rpl	Mpl	T14	num	nev	p1	p2
HSE M2	0.37	3580	0.37	27.94	8.60	1000	0.64	1.56	1.8	7	2515.82	1	344	0.5	2
HSE M0	0.54	4060	0.54	27.83	7.40	1200	0.79	2.04	1.8	7	3470.03	2	202	0.5	5
HSE K1	0.76	5000	0.76	27.92	6.30	1500	1.06	2.79	1.8	7	4811.57	3	132	0.5	12
HJ F8	1.14	6200	1.2	137.79	8.50	1500	3.29	6.76	10	300	9665.27	5	12	1	60

Mission Reference Sample Scenario (artificial scenario)

Typ	Ms	Teff	Rs	dist	Ks	Tpl	P	T0	Rpl	Mpl	T14	#ev	RA	Dec
HSE M2	0.37	3580	0.37	27.09	8.53	966	0.71	2456000.60	7	1.8	2604	334	9.85	-34.72
HSE M0	0.54	4060	0.54	25.84	7.24	1322	0.59	2456000.09	7	1.8	3149	158	9.07	6.33
HSE M0	0.54	4060	0.54	26.40	7.29	1397	0.50	2456000.22	7	1.8	2979	156	1.89	-42.42
HSE K1	0.76	5000	0.76	25.39	6.09	1040	3.19	2456001.90	7	1.8	6939	157	14.81	9.23
HSE K1	0.76	5000	0.76	19.59	5.53	1867	0.55	2456000.26	7	1.8	3864	52	18.34	10.79
HSE K1	0.76	5000	0.76	27.93	6.30	1733	0.69	2456000.02	7	1.8	4165	114	17.43	32.92
HJ F8	1.14	6200	1.2	118.55	8.17	1503	3.26	2456001.29	300	10	9641	8	11.59	45.83
HJ F8	1.14	6200	1.2	148.70	8.67	1365	4.36	2456002.54	300	10	10621	15	10.69	-57.08
HJ F8	1.14	6200	1.2	128.16	8.34	1257	5.58	2456000.74	300	10	11530	12	16.88	-53.21
HJ F8	1.14	6200	1.2	137.71	8.50	2177	1.07	2456001.00	300	10	6657	8	11.38	-16.01
HJ F8	1.14	6200	1.2	149.81	8.68	1291	5.15	2456004.19	300	10	11224	16	13.40	14.43

Figure 5. Extract of some classes defined in the Mission Reference Sample and extract of the list of hypothetical exoplanets built from this classes.

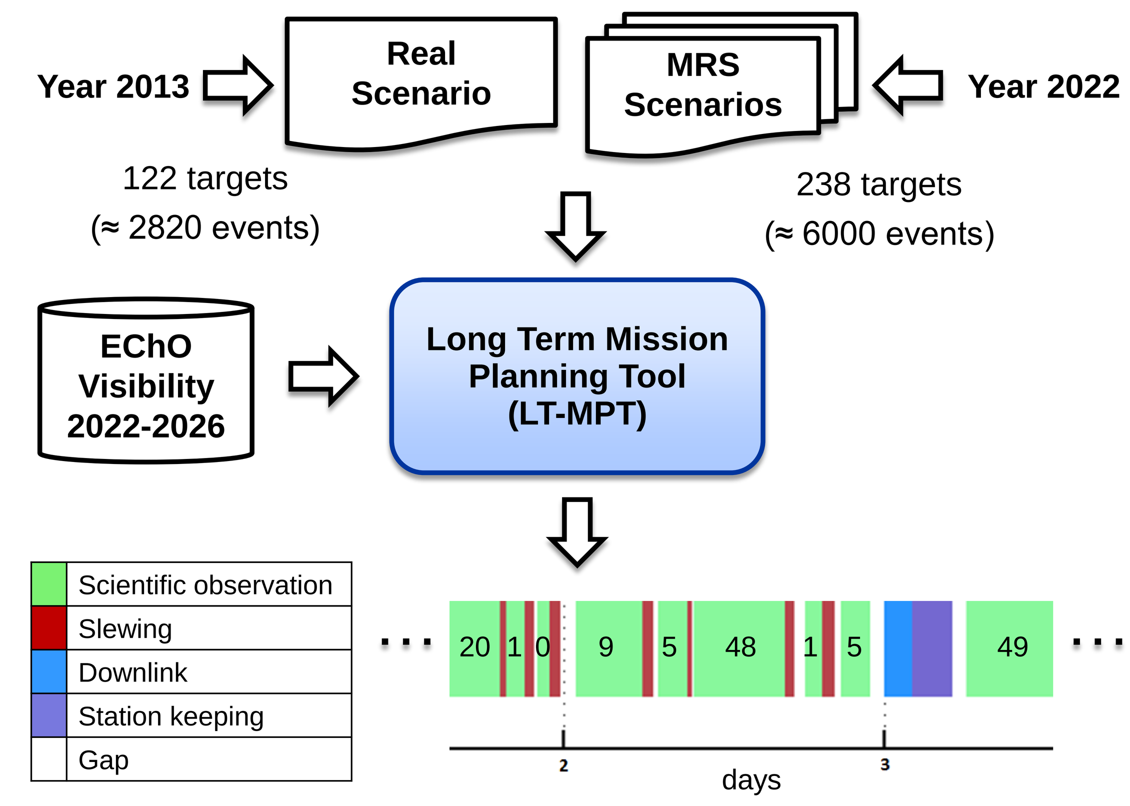

Figure 6. Inputs needed by the LT-MPT to obtain as output the mission plan.

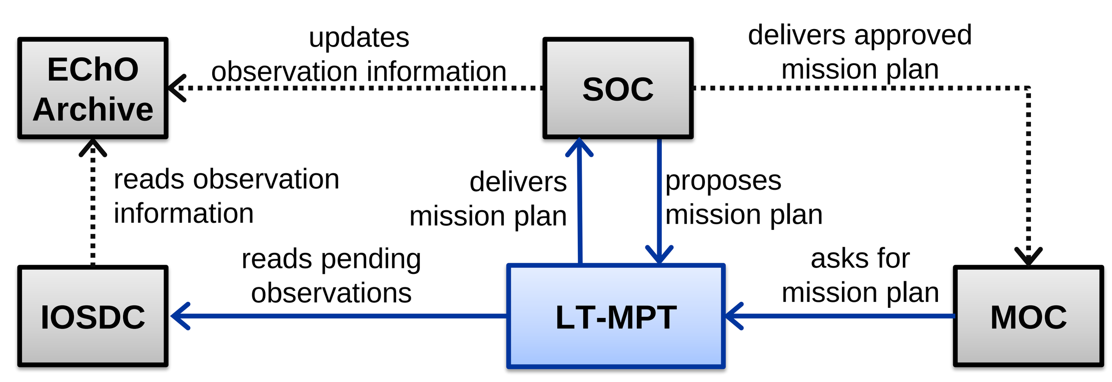

Figure 7. LT-MPT interaction with the other elements that communicate with it, which are Science Operation Centre (SOC), Mission Operation Centre (MOC), Instrument Operations and Science Data Centre (IOSDC) and EChO Archive. The origin of the arrow indicates the element that makes the action.

LT-MPT in the EChO operational design (see Figure 7)
- LT-MPT optimizes the mission plan for five years (or the remaining time of the mission)
- LT-MPT sends to the Science Operation Centre the first six months of the mission plan
- The Mission Operation Centre requires a new mission plan:
  - Each 6 months
  - When identifies that a science observation has failed

Results

Test bench configuration (see results in Table 1)
- 10 MRS scenarios and 1 real sample scenario
  - 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

Scenario	Total Input Time	Planning Efficiency	Slew Time	Events Planned	Targets Completed
MRS Avg.	27773 hours	86.82% ±1.05	4.69% ±0.05	91.48% ±0.74	96.90% ±0.37
Real	17392 hours	98.57% ±0.02	2.00% ±0.01	98.78% ±0.01	100.00% ±0.00

Table 1. Results obtained (mean and deviation) with the LT-MPT for the defined scenarios after 100 trials. The first row is referred to the average results of the 10 MRS scenarios and the second row is referred to the real scenario. Planning Efficiency is computed according to the total input time, which is the time covered by the whole sample, Slew Time is calculated according to the overall time of the mission (5 years), the Events Planned is the percentage of events observed from the overall number of required events, and Targets Completed is calculated as the percentage of complete targets from the overall sample of targets.

Computational cost
- The LT-MPT expends 45 minutes for obtaining a mission plan (CPU Intel® Core™2 Duo Processor E6600 2.40 GHz with 6GB of RAM).

Why Slew Time reduction is not promoted? (see Figure 7)
- The optimization of the Slew Time (minimization) and of the Planning Efficiency (maximization) with a Multiobjective Genetic Algorithm (NSGA-II) has been tested.
- Results show that the reduction of the Slew Time implies a reduction of the Planning Efficiency, and that the increase of the Planning Efficiency implies an increase of the Slew Time.
- The solutions with high scientific return are found in the region where the Planning Efficiency is maximized.

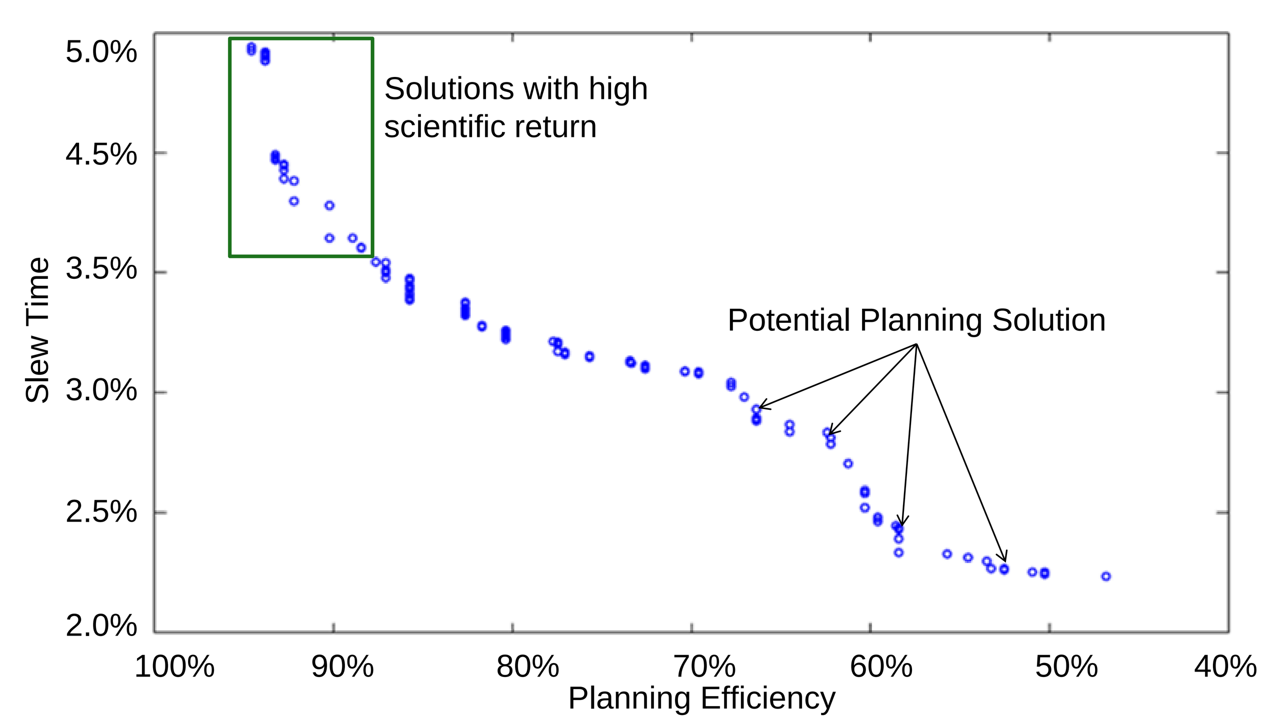

Figure 7. Pareto optimal front of one scenario after optimizing the Slew Time and Planning Efficiency with a Multiobjective Genetic Algorithm. Each blue bullet represents a potential mission plan.

Conclusions

The proposed LT-MPT is a 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

Implementation of a visualization tool for interacting with the LT-MPT and the mission plan.

Analyze how to generalize the planning tool for other missions.

Acknowledgements

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Poster available at:
http://goo.gl/6BMQde