APL II Report

Scheduler Optimisation for NIRPS Observations devoted to search for exoplanets around M dwarfs

by

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1 Introduction

1.1 Motivation

In the field of astronomy and scientific research, it is common for multiple researchers or Principal Investigators (PIs) to share observing time on telescopes and other observation facilities. These observations are often dedicated to specific programs aimed at various scientific objectives. However, due to the collaborative nature of these projects, there arises a pressing need to assist the observer in efficiently scheduling these observations.

Without proper assistance, scheduling observations manually can be an overwhelming and time-consuming endeavor. The observer must carefully consider the constraints imposed by each PI, such as the required observation duration and the optimal observing conditions. Sometimes the time windows for specific targets are very strict (eclipses, transits, etc.). In the context of frequency and the number of observations, cadence refers to the rate at which observations or measurements are taken or recorded. This is also and important factor to take into account. It represents the regularity or timing of data collection. Balancing these various factors while adhering to the shared observing time becomes a hectic task, often leading to oversights as the observer may forget to keep track of the instructions provided.
For instance , at the 3.6 m telescope at La Silla Observatory, Chile ,the GTO (Guaranteed Time Observations) includes 17 programs. In one run the average number of programs is around 8. These 8 programs involve observations of around 150 targets. Noting that there are 9-11 nights in a run, each program, each run and sometimes even each target has a specific instruction for observation. It is understandable that it is extremely difficult for the observer to keep a track of the same by themselves during observations.
To alleviate these challenges, we have recognized the need for automated or computer-assisted scheduling systems. These systems utilize algorithms and optimization techniques to efficiently allocate observing time among different projects, while taking into account the specific requirements and priorities set by each PI. By automating the scheduling process,the overall efficiency and productivity of the observing facilities can be greatly enhanced.

1.2 Goals of my work

My main goal was to understand and explore the functionalities of `Astroplan` and build an optimised scheduling sequence for a given set of targets. I tried building an optimised priority scheduler which took into consideration various constraints specific to the considered set of targets. Furthermore, we ran multiple tests with different conditions to try and understand what the scheduler was doing essentially and how it chose targets to create an optimised observing sequence. We have understood advantages and drawbacks about `Astroplan` in the process.

1.3 The Targets & their Properties

The PI's provide a detailed list of targets with various attributes related to them. Here are some examples of the types of properties typically considered:

Observing site: The first thing to note is the observing location for the targets which will determine the relative position of the targets based on the location. Our considered location was the 3.6m telescope at the La Silla Observatory in Chile $(29.2563°S, 70.7380°W)$.

Coordinates & Proper Motion: The ascension (RA) and declination (Dec) provide the celestial equivalent of longitude and latitude of targets, respectively. The proper motion is linked to the coordinates of the target. Coordinates are given for a specific epoch and proper motion is used to compute the coordinates at the date of observation.

Brightness or Magnitude: The brightness or magnitude of a target is an important parameter to consider. It provides information about the object's apparent or intrinsic brightness,allowing observers to minimise difference of magnitude of targets in order to minimise saturation of detector. Magnitude can be expressed in various systems such as visual magnitude (V), Johnson-Cousins magnitude (e.g., B, V, R), or other specialized filters.

Exposure time: Exposure time is a critical parameter in observational astronomy that determines the duration for which the telescope collects light from a target. It directly affects the quality and depth of the data obtained during an observation. This exposure time is usually set by the PI and must be respected. However, sometimes in order to not saturate the detector the exposure time is divided into multiple exposures. So the total exposure time for each target is the product of a single exposure and the number of consecutive exposures.

Airmass: Each target time periods during which it is observable from a given observation site at given airmass. Airmass quantifies the quantity of air encountered along the line of sight while observing a star or any celestial object from below Earth's atmosphere. It normally indicates relative airmass, the ratio of absolute airmasses (as defined above) at oblique incidence relative to that at zenith. So, by definition, the relative air mass at the zenith is 1.This is the best airmass value possible. The visibility windows are important to understand as they tell us the airmass for each target. These windows are determined by factors such as the target's declination and the latitude of the observation site. The airmass limit for each target is specified by the PI. The air mass X then is simply the secant of the zenith angle z.

$$X = \sec z$$

Specific Properties: Depending on the research objectives, observers may need to define specific instructions for the targets. In exoplanet studies, time critical observations like transits and eclipsing binaries could be good examples . Thus we need to define a specific time window for these observations and observe nothing but the mentioned target and schedule the night around this time window. By compiling and organizing this comprehensive information about the targets, we can proceed to the next steps of the observation scheduling process.

2 `Astroplan`

`Astroplan`* is a powerful Python package that provides tools and functionalities for astronomical observation planning and scheduling. It is designed to assist astronomers and researchers in efficiently organizing and optimizing their observing programs. One of the first basic features of Astroplan is its ability to calculate observability, which allows researchers to determine when a target is visible from a specific observation site. By considering factors such as the target's coordinates, the local horizon, and the observing constraints (e.g., minimum elevation or airmass), Astroplan can provide valuable insights into the visibility windows for each target.

Another important aspect provided by Astroplan is the calculation of airmass, which is a measure of the amount of atmosphere that the light from a target passes through during observation. By considering the airmass, researchers can optimize their observations by scheduling them during periods of lower airmass, which typically result in higher data quality.

Furthermore, Astroplan enables the inclusion of additional constraints, such as angular lunar distance and target priorities, in the scheduling process. By incorporating these constraints, we can fine-tune the schedule to ensure that observations are conducted under the most favorable conditions for their specific science objectives.

To create an optimized priority-based schedule, we can employ various strategies within the Astroplan framework. We can assign priority values to each target based on scientific importance, time sensitivity, or any other relevant criteria. By utilizing the functionalities provided by Astroplan, such as sorting and filtering, we can then generate a schedule that maximizes the allocation of observing time to high-priority targets while adhering to the constraints and limitations imposed by the observing facility.

Once the initial schedule has been created, we can iteratively refine and optimize it by experimenting with different parameters, adjusting the target priorities, and incorporating real-time updates or changes in the observing conditions. By actively "playing" with the code and iterating on the scheduling algorithm, we can fine-tune the schedule to achieve the best possible allocation of observing time and maximize the scientific output of the observation program.

3 Building the Scheduler

In order to build and optimise the scheduler we will have to follow a range of steps. We shall discuss them step by step. Once we have built a simple scheduler we will introduce complexities and run some tests to be able to create a realistic scheduler.

3.1 Defining time range

In order to schedule observations for our targets, it is necessary to define a specific time period during which we want to conduct the observations. This time range can vary depending on the specific requirements of the research and the availability of the observing facility. For instance, let's consider a period of 24 hours initially for our scheduling purposes, see Figure 1. To determine the optimal observing

```
start_time = Time('2023-04-30 18:00:00')
end_time = Time('2023-05-01 18:00:00')
```

Figure 1: *Time range definition on Astroplan by using the Time module from Astropy. The time displayed is in Universal Time Coordinated (UTC)*

period within this 24-hour time-frame, we can employ the concept of astronomical twilight. Astronomical twilight refers to the time intervals before sunrise and after sunset when the center of the Sun is between 12 and 18 degrees below the horizon. These twilight periods are characterized by a gradual change in lighting conditions, transitioning from daylight to darkness or vice versa.

By utilizing the Twilight Evening and Twilight Morning functions provided by tools like Astroplan, we can define a time range that is centered around the nighttime portion of the 24-hour period (Figure 2). These functions allow us to specify the time range for observation by considering the interval between two astronomical twilights . This way, we ensure that the observations are scheduled during the darkest part of the day when the sky is least affected by sunlight. It is important to note that the specific times of astronomical twilight vary depending on the observer's geographical location and the date. These times are influenced by factors such as the latitude, longitude and airmass. Therefore, when using the Twilight Evening and Twilight Morning functions, it is necessary to input the appropriate location and date parameters to accurately define the observing time range.

```
observe_start =  Obs.twilight_evening_astronomical(start_time, which='next')
observe_end = Obs.twilight_morning_astronomical(end_time, which='nearest')
```

Figure 2: *Time range definition on Astroplan by using the Time module from Astropy and the astronomical twilight functions*

3.2 Constraints

In the process of creating a realistic schedule for observing targets, it is important to consider various constraints that help ensure the feasibility and scientific validity of the observations. These constraints serve as limitations or rules that need to be respected when scheduling the observations. Let's delve into some of the key constraints mentioned.

- **Airmass Constraint**: Airmass as mentioned before is a relative measure of the amount of atmosphere that the light from a celestial source passes through when observed from below Earth's atmosphere. It affects the quality and accuracy of the observations, with lower airmass values generally leading to clearer and more precise data(best airmass being at 1 and worst at 3). The PI sets specific airmass values for each program, indicating the acceptable range for observing the targets. The airmass constraint for our targets has been taken to be below 1.5. Adhering to these values helps ensure that the observations are conducted under optimal atmospheric conditions. By incorporating the airmass constraint into the scheduling process, the observer can prioritize targets that have lower airmass values during the specified observing time.

- **Twilight Constraint**: The inclusion of Astronomical twilight, as the time between two Astronomical twilights (-12 to -18 degrees), is a common approach to defining the observing period for nighttime observations. However, it is worth noting that the PI may have specific requirements regarding observing during twilight. If the PI intends to observe during the twilight periods, the constraint related to Astronomical twilight should be removed from the scheduling algorithm. This flexibility allows for customization based on the specific scientific objectives and preferences of the PI.

- **Moon Separation Constraint**: The Moon can introduce unwanted brightness and interference in observations, particularly for targets observed in the optical wavelength as the moon reflects the light of the sun in the visible wavelength range. However, for M dwarfs or stars different from the sun, the Moon separation constraint is not considered a significant issue as we are observing in the Near-Infrared range and they have spectral features different from solar type stars. Therefore, a default value of 10 degrees is often used as a practical limit. For faint solar-type targets, the sky background due to Moon light is diffused by the atmosphere which in turn might contaminate the spectra.

Thus, here, the moon separation constraint is taken to be 30 degrees.
By considering these constraints and incorporating them into the scheduling algorithm, the observer can create a realistic and optimized schedule that respects the limitations set by the PI and ensures the highest quality observations. These constraints help in prioritizing targets based on airmass values, defining appropriate observing periods while considering twilight preferences. Ultimately, the goal is to strike a balance between scientific objectives, practical constraints, and available observing resources to maximize the scientific output of the observation program.

3.3 Observability

After defining the appropriate time range and constraints for our observation program, the next step is to determine which objects from our target list are actually observable during that period. This assessment ensures that we allocate our observing time and resources efficiently.

To perform this assessment, we can utilize the observability module provided by Astroplan. This module offers functionalities that allow us to check the observability of celestial objects based on specified constraints and conditions. By using the observability module, we can obtain valuable information such as the fraction of time each target is observable within the defined time range and constraints. The

	target name	ever observable	fraction of time observable	DEC	RA
0	WASP-178	True	0.64	-42.704967	227.270327
1	HD 225213	True	0.04	-37.367744	1.383284
2	G 158-27	False	0.00	-7.546475	1.676350
3	LP 938-71	False	0.00	-37.627709	15.720962
4	V TZ Ari	False	0.00	13.044071	30.058987
...	...	...	...	...	...
106	TIC 389040826	True	0.24	4.213186	141.997143
107	TIC 277833995	True	0.36	2.513868	156.405506
108	K2-239	True	0.36	4.441376	160.594121
109	K2-33	True	0.56	-19.319386	242.561362
110	UCAC4 511-050629	True	0.24	12.191111	160.324950

111 rows × 6 columns

Figure 3: *A snapshot of the output table created by Astroplan providing information about the observability of targets provided by the the user.We see the observability table for the night of 30.04.2023. The table contains Boolean responses for the targets being observable all throughout the night or only during a certain period along with the fraction of the total time given targets are observable. We have also added the RA and Dec values to the table for convenience.*

observability module takes into account various factors that determine the observability of a target. These factors include airmass limits, twilight constraints, Moon separation, and any other user-defined constraints. By considering these factors, the module calculates the fraction of time that each target is visible and observable throughout the specified time range (Figure 3).

Targets with a higher fraction of observability are more accessible and offer more opportunities for successful observations. Conversely, targets with a lower fraction of observability may require careful planning or alternative scheduling options.
However, we must note that fraction of observability is important but not sufficient for optimisation, as it does not say when in the night a particular target is observable.

3.4 Observation Blocks

Once we have determined the observability of targets and defined the constraints for our observation program, the next step is to create observation blocks that encapsulate all the necessary information for each target. the blocks correspond to a time duration whose creation needs the definition of constraints and essential details, such as target name, celestial coordinates, priority, exposure time and observing mode (Figure 4).

The observation blocks act as containers for the specifications required to successfully observe a particular target. They enable us to efficiently allocate and schedule the observations within the defined time range, taking into account the available resources and instrument capabilities. Here are some key components that are typically included in an observation block:

1. **Target Information**: Each observation block includes the name or identifier of the target being observed.

2. **Celestial Coordinates** & **Proper Motion**: The observation block contains the right ascension (RA) and declination (Dec)of the target. These are essential in order to minimise the movement of the telescope and guiding camera.

3. **Priority**: The priority of the observation block indicates the relative importance or urgency of observing a particular target. Prioritization helps in organizing the schedule, ensuring that high-priority targets are given preference when scheduling conflicts arise.We go from a priority of 1 (highest) to a 3 or 4 (lowest) in our code.

4. **Exposure Time**: The exposure time specifies the minimum duration for which the telescope should point at a region in the sky. It also depends on the scientific goal and thus the observers should try and not change the exposure periods for the targets.

5. **Observing Mode**: The observing mode refers to the specific instrument configuration or observing setup required for a particular target. It may involve selecting different optical fibers, filters, or observing modes tailored to the characteristics of the target or the science objectives. The observing mode ensures that the instrument is configured appropriately to capture the desired information. For

our instrument of interest on the 3.6m telescope, NIRPS, the HA (High Accuracy, 0.4 arcsecond, for brighter targets) and HE (High Efficiency, 0.9 arcsecond, for faint targets) mode are the two configurations of optical fibers on the spectrograph. We must know the modes as it helps us to compute the time taken if modes between two observations is changed.

6. **Time Critical and Airmass Constraints**: The observation block includes any time critical dates and time duration along with airmass limits associated with the target. These constraints define the allowable time range and airmass values during which the target can be observed effectively.

```
blocks.append(ObservingBlock.from_exposures(targets[i], priority[i],
                                             target_exposure[i]*u.second,
                                             n, read_out,configuration = {'mode': mode[i]},
                                             constraints = [night_tc,
                                                            AirmassConstraint(max = 1.9, boolean_constraint = False)]))
```

Figure 4: *Defining the observing block by using specific constraints*

3.5 Transitioner

The observation blocks created are unscheduled blocks of time. In order to arrange and switch between these blocks in the night, we need a Transitioner (Figure 5). A transitioner considers the movement of the telescope between different targets or observing configurations. The transition between observations involves factors such as the slew rate, which represents the time taken for the telescope to move from one RA & Dec value to another. Additionally, the time required to switch between optical fibers or observing modes based on target requirements should be considered. Typically, a duration of approximately 4 minutes is taken as a standard value for these transitions, although this can be adjusted based on the specific properties and capabilities of the instrument being used.This information is stored in the **"Transitioner"**.

```
slew_rate = .8*u.deg/u.second
transitioner = Transitioner(slew_rate,{'mode':{('HA','HE'): 240*u.second,
                                               ('HE','HA'): 240*u.second,'default': 30*u.second}})
```

Figure 5: *Defining the transitioner while including the skew rate (0.8° per second and time required to change between the HA and HE modes ~ 4 minutes.*

4 Implementing the Scheduler

When it comes to scheduling the created observation blocks and managing the allocation of resources, two common approaches are the sequential scheduler and the priority scheduler. Both schedulers consider the observation blocks, global constraints, and the defined time range of observation. However, it is important to ensure that the global constraints are not overly restrictive, as they apply to all targets and should accommodate the diverse requirements of the observation program.The biggest difference between the two kinds of schedulers is **priority**.

4.1 Sequential Scheduler

For a sequential scheduler, a linear order of RA is considered. The sequential scheduler operates by sequentially assigning observation blocks to available time slots within the defined time range. It follows a first-come, first-served approach, where the blocks are scheduled in the order they were created or based on their position in the target list. This scheduler ensures that each observation block is allocated a time slot without overlap, maintaining a sequential and orderly progression through the target list.

4.2 Priority Scheduler

In contrast to the sequential scheduler, the priority scheduler focuses on assigning observation blocks based on their priority levels. Each observation block is assigned a priority value that reflects its relative importance or urgency.For each minute of the night a score given to each observation block and the best score is used for optimisation of the order of observations. The scheduler considers these priorities and allocates time slots accordingly, giving higher priority blocks precedence over lower priority ones.

While scheduling with the priority scheduler, the global constraints play a crucial role in ensuring that the observations adhere to overall program objectives.

By employing either the sequential or priority scheduler, the observer can effectively manage the scheduling process and optimize the allocation of observing time and resources. While the sequential scheduler offers a straightforward and chronological approach, the priority scheduler allows for the strategic assignment of observation blocks based on their priority levels. Both approaches take into account the global constraints, ensuring that they are flexible enough to accommodate the various requirements of the observation program without imposing overly rigid restrictions.

5 Running Tests

To produce a good observing sequence, we can explore the features we mentioned and incorporate them into our approach. Let's go step by step:

5.1 Using a random target list with equal priorities

In this case, we can create a list of targets where each target has the same priority level. This ensures that all targets are considered equally important for observation. The observing sequence can then be generated randomly, taking into account the available observing time and selected constraints. We do this tests to check if all conditions are the same, whether or not the sequential and priority scheduler produce the same output.

5.2 Adding two priority levels to the targets

Instead of having equal priorities for all targets, we can assign two priority levels to the targets, such as high(1) and low(2). The high-priority targets are considered more important and should be observed first, while the low-priority targets can be observed later if time permits. The observing sequence can be generated by sorting the targets based on their priority levels, with the high-priority targets given precedence. This test is done to see how an elementary prioritisation works and how only a high and low priority division is utilised.

5.3 Adding more priorities

If we want to have more than two priority levels, we can assign additional levels such as 1(highest),2,3(lowest), etc., depending on the specific requirements of the observing program. We can also try and see these priorities are discrete or continuous prioritisations. We essentially do this test to see how far the priorities are respected and how many and how far down the list are the low priority targets scheduled.

5.4 Adding a time-critical target

In some cases, there may be targets that have time-sensitive observations or specific observing windows for example, a transit or an eclipsing binary. In such cases, the time-critical target needs to be observed at a specific time or within a specific time-frame. To accommodate this, we can incorporate the time constraints into the observing sequence generation algorithm, ensuring that the time-critical target is scheduled accordingly and given the highest priority during its observing window. The main issue however not to schedule the time critical but to manage the night around the time critical as it poses a huge constraint on observation planning.Thus this time critical test in is essential.

6 Results

Here is a quick guide on how to study the plots hereon. We first see in Figure 6 what the plotted schedule looks like. Both the priority and sequential scheduler give

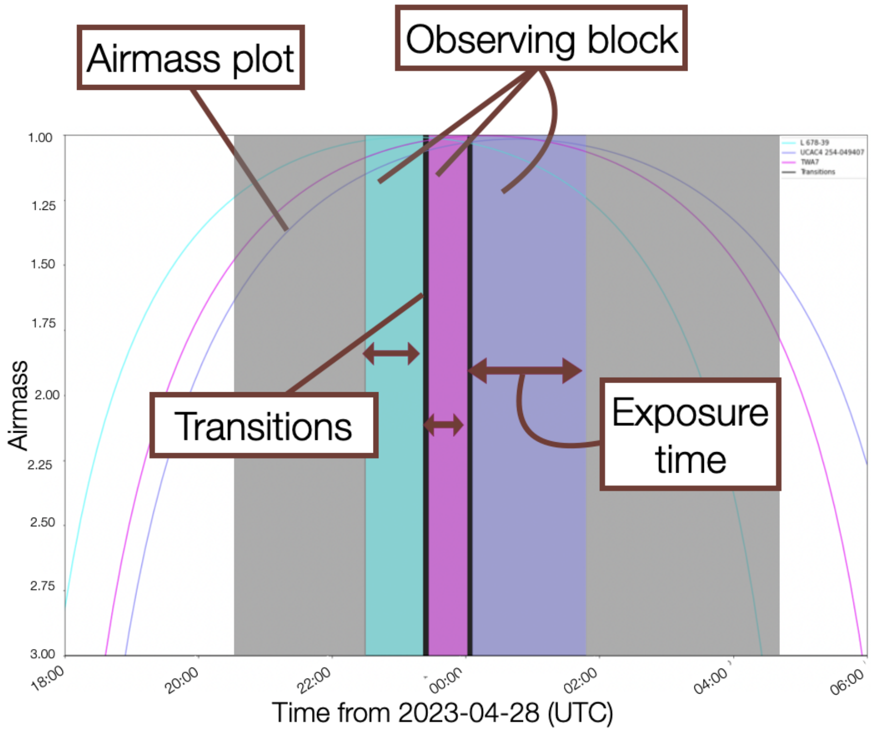
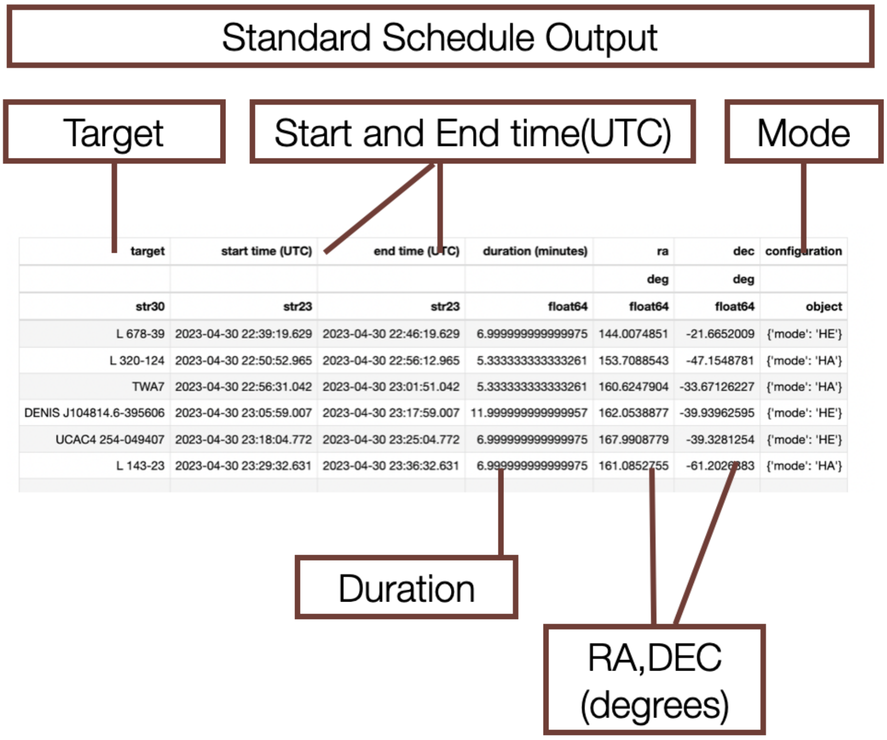


Figure 6: *Plot showing how a sequential or priority schedule is displayed on Astroplan. The coloured blocks are the blocks in time created for different targets and the width depends not he exposure time allotted for each target . The black vertical lines show the transition the include both the slew rate and the time taken to change between the modes as mentioned before. The curves are the airmass plots, with their peaks showing the best possible airmass for the targets with worst value at 3.00 and best value at 1.00. They shaded gray region shows the "night" of observation between two astronomical twilights.*

output lists containing target name, star and end time of observation , coordinates and mode (Figure 7).
Its finally time to explore the different results.



target	start time (UTC)	end time (UTC)	duration (minutes)	ra	dec	configuration
				deg	deg	
str30	str23	str23	float64	float64	float64	object
L 678-39	2023-04-30 22:39:19.629	2023-04-30 22:46:19.629	6.999999999999975	144.0074851	-21.6652009	{'mode': 'HE'}
L 320-124	2023-04-30 22:50:52.965	2023-04-30 22:56:12.965	5.333333333333261	153.7088543	-47.1548781	{'mode': 'HA'}
TWA7	2023-04-30 22:56:31.042	2023-04-30 23:01:51.042	5.333333333333261	160.6247904	-33.67126227	{'mode': 'HA'}
DENIS J104814.6-395606	2023-04-30 23:05:59.007	2023-04-30 23:17:59.007	11.999999999999957	162.0538877	-39.93962595	{'mode': 'HE'}
UCAC4 254-049407	2023-04-30 23:18:04.772	2023-04-30 23:25:04.772	6.999999999999975	167.9908779	-39.3281254	{'mode': 'HE'}
L 143-23	2023-04-30 23:29:32.631	2023-04-30 23:36:32.631	6.999999999999975	161.0852755	-61.2026[illegible]83	{'mode': 'HA'}

Figure 7: *Table showing names of the FixedTarget Objects; start and end time of observation with date and time in hours:minutes:seconds; the duration between the given start and end times; coordinated of the target and the mode in which they have been observed.*

6.1 Using a random target list with equal priorities

A " sequential schedule" created with a target list sorted by RA values having same priorities does not care about the RA values , it goes down the list of targets or the blocks created in order on a first come first serve basis and puts the targets at the best airmass (Figure 8).

On the other hand, a "priority schedule" takes the RA values into account whilst still respecting the best possible airmass at given right ascension. We also notice that the priority schedule tries to fill the beginning and end of the night. Since RA is given importance, there are more gaps in this schedule as compared to the sequential schedule meaning lesser target blocks have been put in the sequence. This is because the program could not find a target in the list with a suitable RA value while also fulfilling the constraints defined (Figure 9).

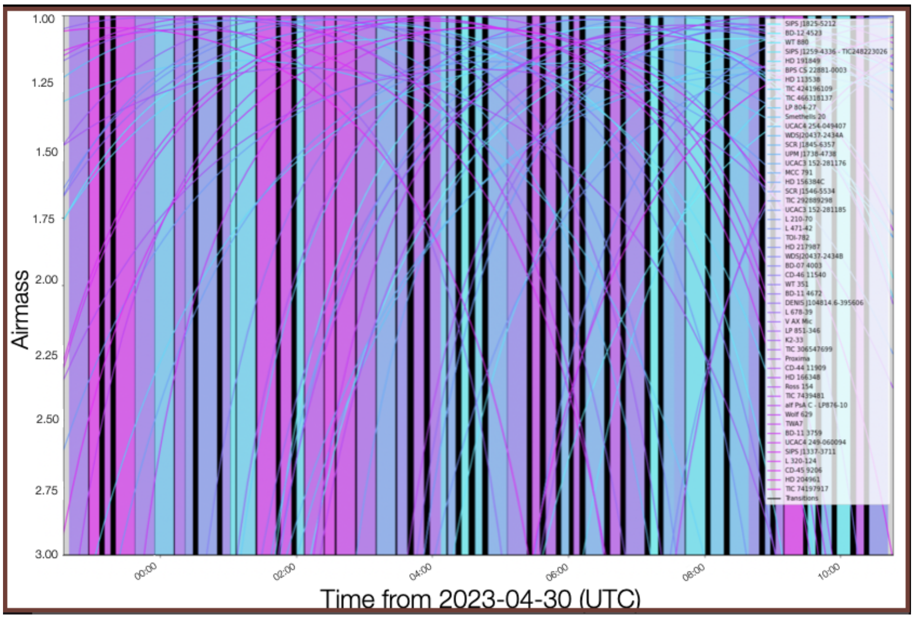


Figure 8: *Sequential Schedule created for target list with equal priorities. Total number of targets scheduled is 52*

6.2 Adding two priority levels to the targets

Now we increase the number of assigned priorities and see how the scheduler changes. Target "TIC 466318137" marked with a cube in Figure 10 can be clearly seen to move down the sequence (Figure 11) as the priority is downgraded to 2.Initially it was scheduled well before 2:00 AM UTC, now it can be seen to be scheduled at 2:00 AM UTC. Having traced the airmass curve for the aforementioned target, we see that the airmass value in Figure 11 is lower than the value in Figure 10 while still respecting the airmass limit.

We also note from the output table that targets with the same RA and same priorities do not get scheduled as the code comes to a clash of choice. Thus the solution to schedule similarly placed objects would be to schedule them on different nights.

6.3 Adding more priorities

When we incorporate additional priorities into the scheduling process, we can observe that the prioritization is upheld and respected. At times, we may come across instances where targets with lower priority levels are scheduled before higher priority ones. Take, for instance, the scenario presented here in Figure 12, where we notice a priority 3 target positioned between two targets with a priority level of

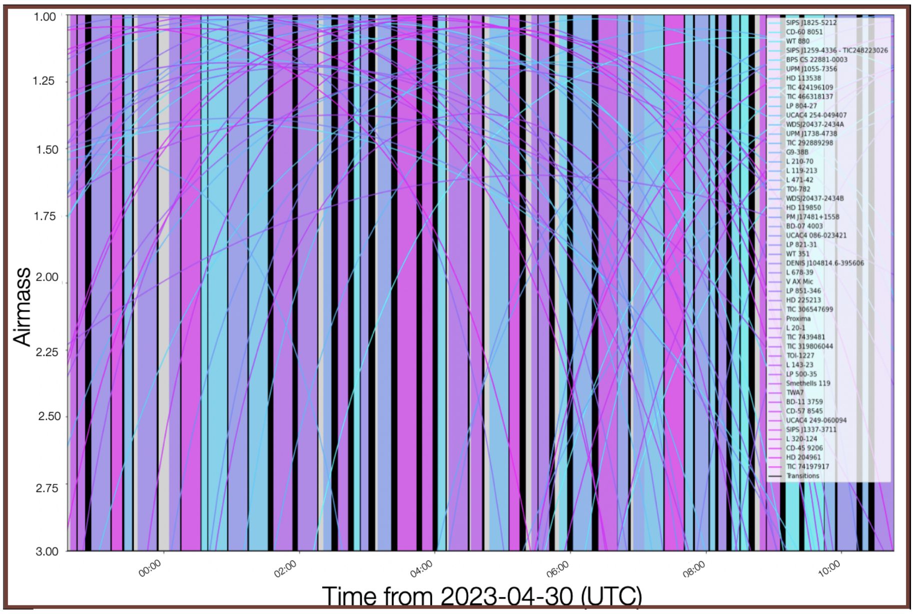


Figure 9: *Priority Schedule created for target list with equal priorities. Total number of targets scheduled is 48*

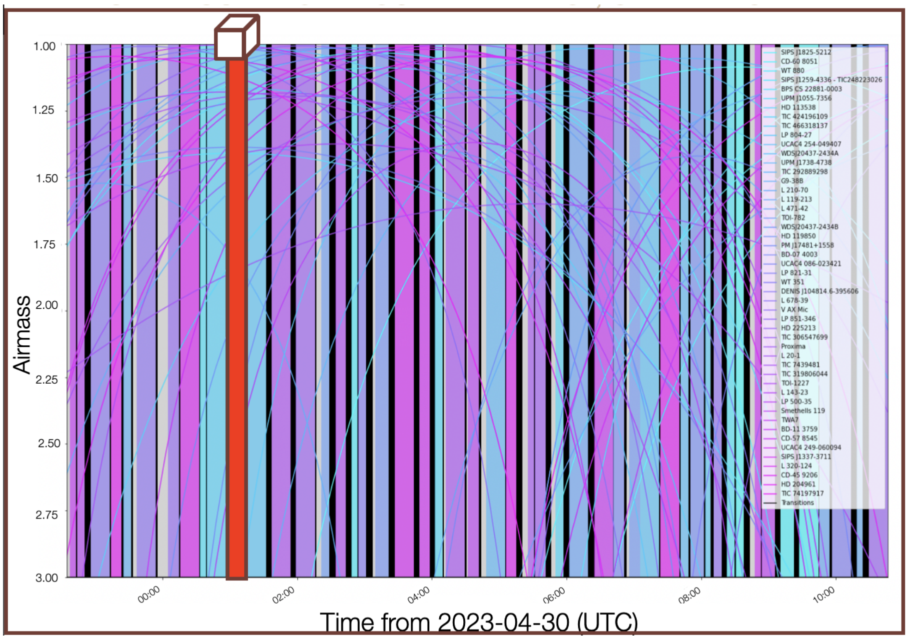


Figure 10: *Priority Schedule created for target list with equal priorities.The target "TIC 466318137" is marked with a cube and has equal priority as all other targets in this figure. We will see the change in sequence for this target in Figure 11.*

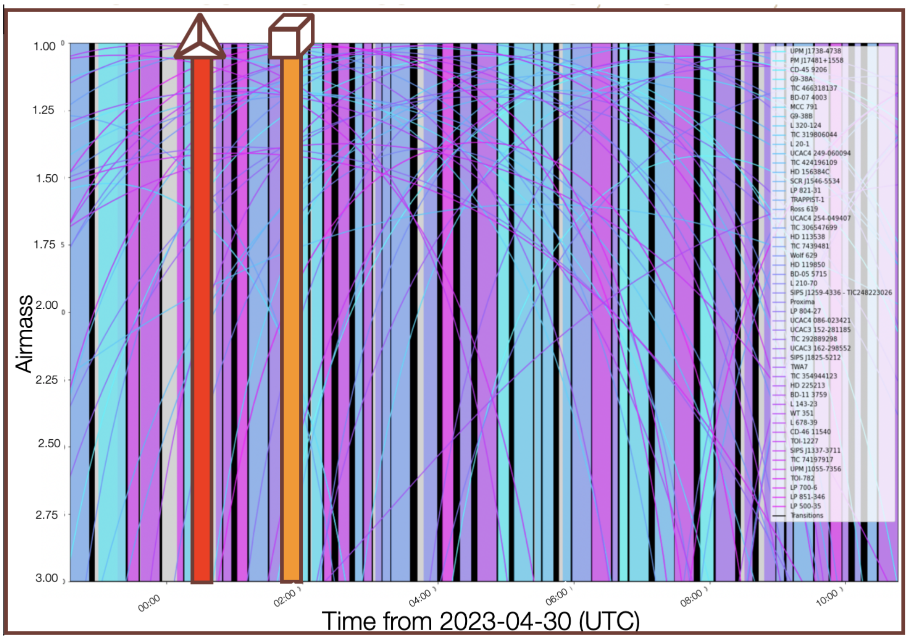


Figure 11: *Priority Schedule created for target list with two priorities.The target "TIC 466318137" is marked with a cube and now has priority 2. Target "TWA7" here is marked with a triangle and has a priority of 1. COLOR GUIDE : RED: Priority 1 ORANGE: Priority 2*

2. This occurrence can be attributed to the absence of any higher priority targets available at the given right ascension (RA), prompting the algorithm to allocate the third priority to that specific target. Likewise, if we consider the target "TWA7" shown in the previous figure (Figure 11), we observe that it retains its position in the schedule despite its priority being downgraded from 1 to 3. This is due to the unavailability of any other high priority targets to replace it during the scheduling process.

These examples illustrate how the algorithm takes into account the availability and priority of targets, making adjustments and decisions based on the constraints and conditions at hand. The aim is to maximize the efficiency and effectiveness of the observing sequence while respecting the specified priorities.

6.4 Adding a time-critical target

We now come to the final complexity in our work thus far, which involves incorporating a Time Critical Target into the scheduling process. A time critical target carries the utmost priority and must be scheduled at a specific predetermined time, as allocated by the observing facility, such as ESO (European Southern Observatory). This introduces a significant constraint on our observations, as during that

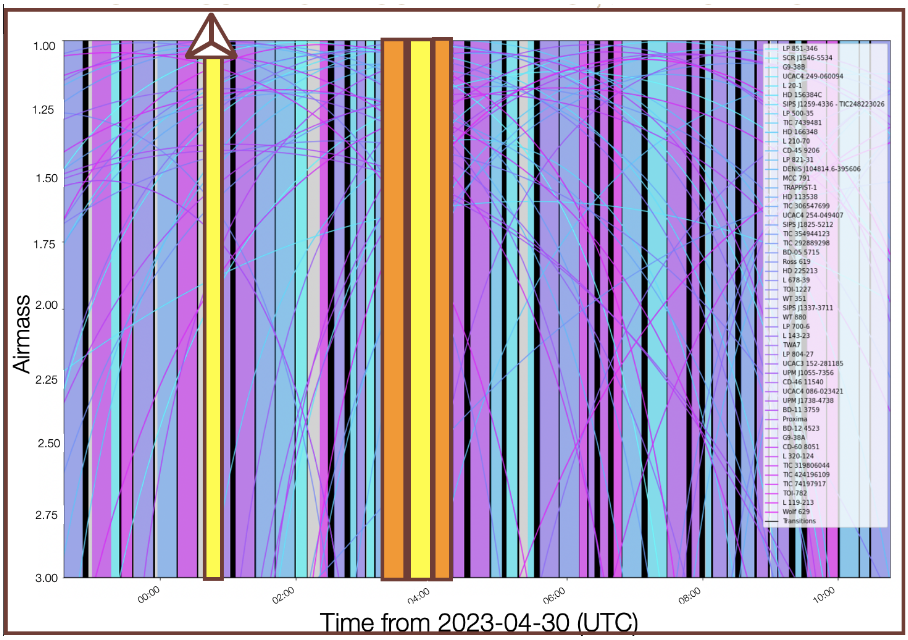


Figure 12: *Priority Schedule created for target list with three priorities. Target "TWA7" here is marked with a triangle and has a priority of 3. COLOR GUIDE : RED: Priority 1 ORANGE: Priority 2, YELLOW: Priority 3*

particular period in the night, we cannot observe any other targets. To address this challenge, we have endeavored to construct a schedule that accommodates a large block of uninterrupted observation time, ensuring that no other targets interfere with the time critical observation. However, upon examining the resulting schedule(Figure 13), we observe that the time critical target has not been scheduled as expected.

The reason behind this discrepancy lies in the nature of the sequential schedule we previously employed. The sequential schedule adheres to a straightforward approach of iterating through the list of targets, prioritizing them based on their airmass values. However, once the schedule reaches the time critical target at the beginning of the list, it faces a limitation in finding sufficient space to accommodate the large block of observation time required. This is because a time critical target often necessitates an extensive exposure duration, such as 14,000 seconds. However, with the introduction of the priority scheduler(Figure 14), we can observe significant improvements in respecting the rigid time constraints imposed by the time critical target. The priority scheduler not only seeks to fill the beginning and end of the night to optimize observations but also endeavors to find suitable gaps within the schedule to adjust the substantial block of time required for the time critical target. By considering the priorities and constraints more comprehensively, the code can effectively allocate adequate space and time for the time critical observation, while still optimizing the schedule for other targets.

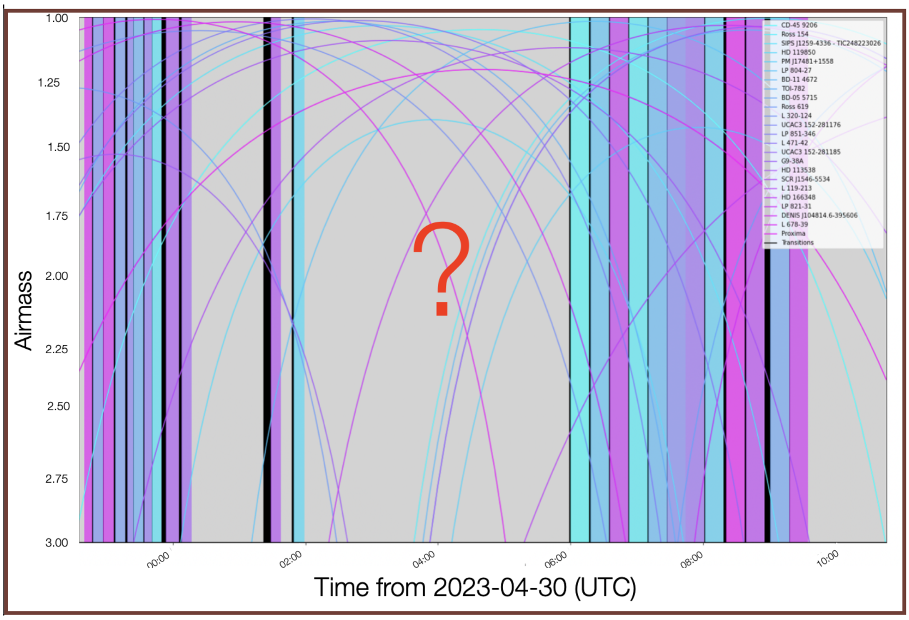


Figure 13: *Sequential Schedule created for target list with a time critical object. Time critical object has not been scheduled on this plot.*

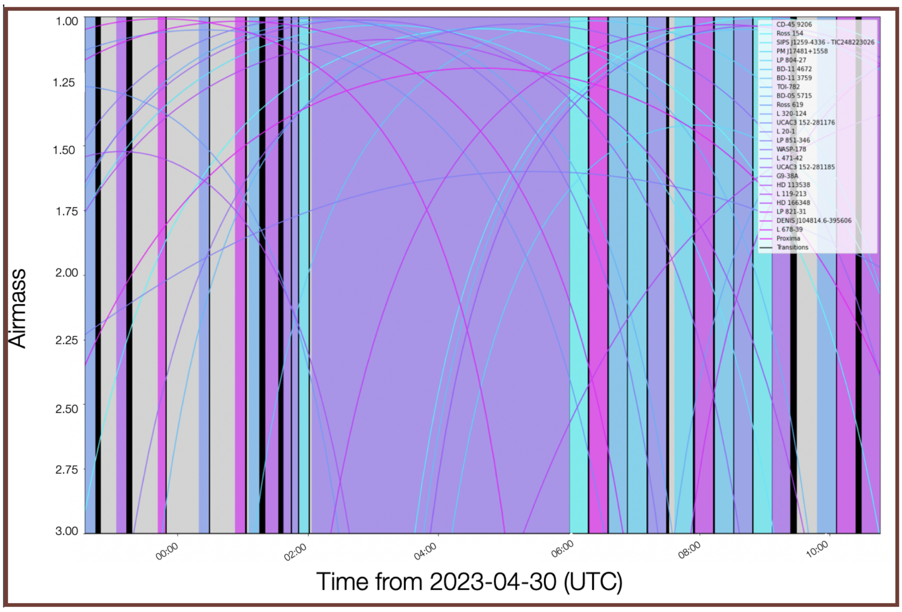


Figure 14: *Priority Schedule created for target list with a time critical object. Time critical object has been successfully scheduled on this plot a shown by the big purple block with a scheduled time of about 4 hours.*

Thus the integration of a time critical target into the scheduling process introduces unique challenges due to its strict time requirements. While the sequential schedule may face limitations in accommodating the lengthy observation period, the priority scheduler demonstrates enhanced capability in respecting the inflexible time constraints.

7 Discussion & Conclusion

Based on our extensive testing, we have discovered several crucial factors to consider when creating a schedule. The code need three essential information to be able to create an optimised schedule : **"Situation"**,i.e., the location of the telescope in order to understand the relative position of targets, **"Target"**,i.e, the various properties previously listed like coordinates and proper motion and finally the **"Condition"**,i.e., the various constraints we put on the observation of given targets. These key points should be kept in mind throughout the process:

1. **Priority, Airmass, and RA Dependency**: The scheduling algorithm heavily relies on three primary factors: priority, airmass, and right ascension (RA). The priority determines the order in which targets are scheduled, while the airmass helps prioritize observations under optimal atmospheric conditions. Additionally, the RA plays a vital role in determining the order of targets, as the algorithm selects targets based on their position in the sky.

2. **Order of the List**: The order of the target list is not necessarily significant since the scheduling algorithm takes RA into account. The algorithm scans through the targets, considering their priority, airmass, and available time slots, rather than strictly following the order of the list.

3. **Top Priority for Time Critical Targets**: Time critical targets must be assigned the highest priority level. These targets have strict time constraints and must be observed at specific times allocated by the observing facility. Giving them the utmost priority ensures that they are scheduled as intended, without any interference from other targets.

4. **Rigid Time Constraints for Block Creation**: When creating blocks of continuous observation time, it is crucial to adhere to rigid time constraints. These constraints define specific periods during which the time critical target must be observed exclusively, without scheduling any other targets. By respecting these constraints, the schedule can ensure the uninterrupted observation of the time critical target during the allocated time window.

5. **Carefully Constructed Input Target List**: The input target list should be meticulously constructed, taking into account the target's RA and exposure time required to fill the entire night. By providing comprehensive and accurate information about the targets, the priority scheduling algorithm can work more efficiently and effectively, optimizing the schedule and ensuring that the available observing time is utilized optimally.

As a concluding remark on the tests that we have run, we understand that the priority schedule proves to be more effective in optimizing the observing sequence while considering both airmass and RA values, as well as accommodating time critical targets with strict time requirements while optimising the transitioner. However, since the priority schedule tries to fill the beginning and end of the night and considers RA values it results in more gaps in the schedule compared to the sequential schedule. The sequential schedule may face limitations in accommodating the lengthy observation period required by the time critical target. When additional priority levels are introduced, the scheduler upholds and respects the prioritization. Targets with lower priority levels may be scheduled before higher priority ones if there are no higher priority targets available at a specific RA. Discrete priorities of up to 4 have been respected, but this is still open to be extended depending on the length of the target list and number of nights. Targets with the same RA and the same priorities may not get scheduled due to clashes in choice. To schedule similarly placed objects, they should be scheduled on different nights.

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