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# AUTONOMOUS SCHEDULING AT THE TJO TELESCOPE

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RESUMEN

Disponer de un planificador autónomo y eficiente es un aspecto fundamental para cualquier telescopio robótico, dada su influencia directa en el rendimiento científico de un observatorio. Un sistema de este tipo debería priorizar e identificar observaciones críticas, tener en cuenta las coordenadas de los cuerpos celestes, considerar las condiciones meteorológicas y asegurar que las observaciones cumplan con diversas restricciones definidas por el usuario. Todo esto debe lograrse a la vez que se optimiza la lista de objetos a observar dentro de un intervalo de tiempo predefinido, todo ello sin requerir intervención humana.

En este artículo presentamos ISROCS, el programa de planificación autónoma del telescopio Joan Oró (TJO), un telescopio totalmente robótico de 0,8 m de apertura, situado en el Observatorio del Montsec y dedicado a la investigación astrofísica y a actividades de vigilancia y seguimiento espacial. Explicamos cuales son los procesos empleados por ISROCS para producir planificaciones eficientes y revelamos mejoras recientes destinadas a hacer posible la planificación dinámica durante la propia ejecución de las observaciones. Esto incluye la capacidad de planificar rápidamente nuevas observaciones enviadas por los usuarios, logrando tiempos de reacción de menos de 2 minutos. Esta nueva función permitirá a los usuarios el uso de alertas de eventos transitorios emitidas por sistemas externos para enviar observaciones en tiempo real de manera automática, la cual será crucial para la rápida observación de fenómenos astrofísicos de corta duración.

ABSTRACT

Efficient autonomous scheduling is a paramount aspect of a fully robotic telescope, given its direct influence on the scientific yield of an observatory. Such a system should prioritize tasks and identify critical observations, factor in the coordinates of celestial bodies, consider weather conditions, and ensure that the tasks meet various user-defined constraints. All of this must be achieved while optimizing the list of tasks to be observed within a predefined time interval, all without requiring human intervention.

In this proceedings we introduce ISROCS, the autonomous scheduling software of the Joan Oró telescope (TJO), a fully-robotic 0.8m telescope at the Montsec Observatory dedicated to astrophysical research and Space Surveillance and Tracking activities. We explain the processes employed by ISROCS to deliver time-efficient schedules and reveal recent upgrades aimed at enabling dynamic planning during the observations. This includes the capability to swiftly include new tasks submitted by users, with a reaction time of under 2 minutes. This new feature will enable users to use alerts issued by external alert systems for real-time observations with minimal oversight, which will be crucial for the rapid observation of short-lived astrophysical phenomena.

*Key Words:* telescopes — instrumentation: miscellaneous

## 1. INTRODUCTION

Observing time on multi-million telescopes represents a valuable and limited resource in astronomy. As these instruments operate within finite lifetimes, the efficient utilization of their observing time becomes of the upmost importance. The optimization of observing schedules is therefore crucial not only for maximizing the scientific return of these telescopes but also for justifying the substantial investments made in these facilities.

Traditionally, the creation of observation schedules has been an intensive manual process, often referred to as queue scheduling, which needs to select tasks meeting various constraints and objectives. While this manual approach is capable of producing decent results it has its drawbacks: it is time-consuming and requires a continuous supervision by the staff, hindering the ability to rapidly respond to changing observing conditions, weather losses, and target-of-opportunity events (Bellm et al. 2019).

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Fig. 1. Night view of the OdM. Image Credit: E. Herrero.

Given the surge of new fully-robotic telescopes in the last decades (Steele & Carter 1997; Bakos et al. 2002), there have been a growing interest in exploring different automated scheduling techniques (see e.g. Granzer 2004; Colomé et al. 2012). This interest is not only aimed at reducing the workload on human operators, but also at optimizing scheduling strategies for enhanced scientific outcomes.

One of the most used automated scheduling algorithms is the dispatch scheduling (Denny 2004). This method involves selecting the most advantageous task based on current conditions and a merit function. The dispatch scheduler is notably fast, and therefore can easily handle changes in observing conditions and the addition of target-of-opportunity events autonomously. This technique, however, only focuses on scheduling one task at a time, potentially overlooking the broader, long-term objectives outlined in various research proposals, such as survey completeness. Another challenge is the difficulty in scheduling calibration observations, since the scheduler does not know ahead of time the tasks to observe.

Another common scheduling algorithm is optimal scheduling (Granzer 2004). Similar to queue-scheduling, it autonomously constructs a schedule prior to actual observations by evaluating many possible combinations of tasks and selecting the one with the highest yield. This has the advantage that minimizes the slewing time over the whole night, while also defining calibration tasks. However, the computational requirements for computing an optimal schedule make this technique vulnerable to unexpected changes in conditions, such as changing weather or the addition of new urgent observation of transient events.

In this proceedings, we provide a brief overview of the scheduling algorithm employed at the fully-robotic Joan Oró Telescope (TJO). Furthermore, we describe the recent upgrades made to the scheduler, combining the strenghts of both dispatch and optimal scheduling algorithms. This new approach ensures a global and adaptable scheduling strategy, enabling the use of the TJO telescope for the observation of target-of-opportunity events in combination with long term monitoring programs.

## 2. THE MONTSEC OBSERVATORY

The TJO telescope is mounted at the Montsec Observatory[3] (OdM), located at an altitude of 1570 m in Sant Esteve de la Sarga, 50 km north of the city of Lleida (Catalonia, Northeastern Spain). This site was carefully selected for its exceptional conditions for astronomical observation. First of all, it is in a region certified as an UNESCO Starlight Reserve[4], and explicitly protected from light pollution by a law of the Catalan Parliament. The night sky brightness at the site reaches values as low as 22.0 mag arcsec$^{-2}$ at the zenith, and between 21.520.6 mag arcsec$^{-2}$ at a height of 45° above the horizon, both in the Johnson $V$ band (Colomé et al. 2008). Secondly, the weather conditions are quite good during the year, allowing operations in around 70% of all the night time. Finally, it has a very low astronomical seeing, with a median value of 0.82" and better than 0.7" during 32% of the night time

[3]https://www.montsec.ieec.cat/

[4]https://en.fundacionstarlight.org/contenido/46-list-starlight-reserves.html

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(Colomé et al. 2010), as reported by five months of measurements using a Robotic Differential Image Motion Monitor (DIMM Sarazin & Roddier 1990).

The observatory has multiple facilities that are devoted to different areas, such as:

- Research: two telescopes offered to the scientific community, the TJO (0.8 m) and the TFRM[5] (0.5 m), and an All-Sky Camera for fireball and meteor detection.
- Teleport: S-band and UHF/VHF facilities for communication with satellites.
- Services to the community: a weather monitoring station of the Catalan Meteorological Service, an atmospheric pollution and quality monitoring station, firefighter surveillance cameras, and radiolinks to provide internet access to hydroelectric generating systems and nearby towns.

## 3. THE TJO TELESCOPE

The main facility at the OdM is the Joan Oró telescope (TJO), which has been operated by the Institute for Space Studies of Catalonia[6] (IEEC) since its construction in 2004. It is a Ritchey-Chrétien telescope with an aperture of 80 centimeters and a focal ratio of F/9.8, and is fully robotic, with no human intervention required apart from supervision and maintenance.

The TJO is equipped with two simultaneous instruments. The main instrument is the Large Area Imager for Astronomy (LAIA), an Andor iKon XL imaging camera with a 4096×4096 back-illuminated sensor, a pixel size of 0.4 arcsec, and a field of view of 30 arcmin. LAIA is mounted together with a rotating filter wheel that contains 5 standard Johnson-Cousins photometric filters ($U$, $B$, $V$, $R$, and $I$), 4 Sloan Digital Sky Survey photometric filters ($g$, $r$, $i$, and $z$), and a narrowband filter centered at the H$\alpha$ line.

The other instrument mounted at the TJO is the Astronomical mid-REsolution Spectrograph (ARES), an optical spectrograph with a resolution of $R$=12'000 divided in two spectral windows, one centered at the magnesium triplet (495 to 529 nm) and another centered at the H$\alpha$ alpha line (634 to 678 nm).

The primary functions of the TJO include satellite surveillance and tracking (SST) activities and scientific research, offering observation time to the scientific community via a Time Allocating Committee (TAC) in two yearly semestral calls for proposals. As for the research areas, the TJO is a multi-purpose telescope, with proposals aimed at stellar variability (e.g. Ribas et al. 2018), stellar activity (e.g. Baroch et al. 2020), transiting exoplanets (e.g. Herrero et al. 2011), Gaia follow-up (e.g. Wyrzykowski et al. 2020), transient sources (e.g. Morales-Garoffolo et al. 2014), or Solar System objects (e.g. Trigo-Rodríguez et al. 2008), among others.

The TJO has been working on a completely unattended control since 2013, requiring minimal human supervision. In order to achieve this level of autonomy, it requires having a reliable, secure, and efficient system that is able to plan, execute, and reduce astronomical data completely unattended.

The current system present at the TJO, the Robotic Observatory Control System (ROCS), is divided in two main nodes: one off-site and another on-site, as depicted in Fig. 2. Each of the nodes is equipped with its own database containing identical information, which is synchronized on a routine basis.

The offsite node, located at the IEEC offices in Barcelona, is in charge of the storage and distribution of data. The main system there is the Management for Users in ROCS (MUR), which is the interface where the users can submit proposals, define the observations, and access and download the observed data. Additionally, as part of an agreement with the Spanish Virtual Observatory (SVO), all the data outside the ownership period (1 year) are made publicly accesible through the SVO webpage[7], where more than 300'000 images spanning 10 years are available to the community.

The onsite node is located at the OdM, and it is in control of unattended operations. The main system in this node is the Observatory Control System (OCS), which is responsible for issuing commands to the dome, telescope, and the instrument (via the Telescope Control System, TCS, and the Instrument Control System, ICS) based on the night plan issued by the scheduler and on the weather conditions. Additionally, the system contains a collection of pipelines (The IEEC Calibration and Analysis Tool, ICAT) used to perform data reduction and quality control. Finally, this node also contains the Intelligent Scheduler for ROCS (ISROCS), which is the autonomous scheduler used to create the night plans.

[5] `https://www.racab.cat/es/observatori-fabra/tfrm`
[6] `https://www.ieec.cat/`
[7] `https://sdc.cab.inta-csic.es/joro`

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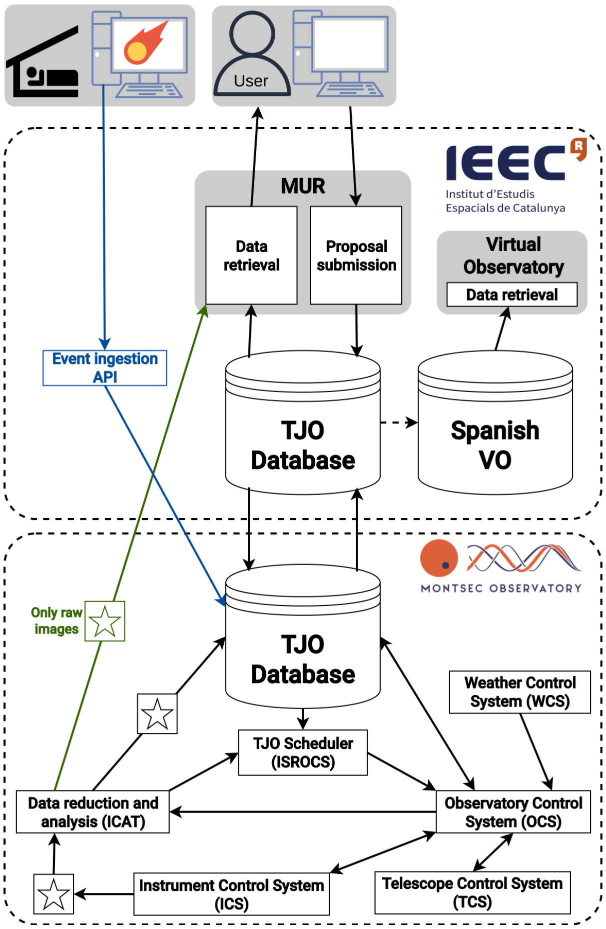


Fig. 2. Schematic diagram of the architecture of the Robotic Observatory Control System (ROCS) of the TJO. The blue and green arrows and icons correspond to new upgrades to the system to allow the ingestion of transient events.

## 4. ISROCS

The main function of the scheduler is to compute an efficient schedule of astronomical observation tasks that optimizes the available time, which has a direct impact on the scientific return. The scheduler used for the TJO, ISROCS, is a custom layer on top of the Scheduling Telescopes as Autonomous Robotic Systems (STARS, Colomé et al. 2020), which is the scheduler presently in use or soon to be adopted by several ground and space-based observatories, such as CARMENES, CTA, PLATO, and ARIEL, and is being used by the TJO since 2020.

At the TJO, ISROCS is responsible for accessing to the observation tasks that the users have defined in MUR, computing the visibility windows of these tasks based on the observing constraints specified by the users, such as the maximum solar elevation and airmass, the minimum distance to the moon, or the time-delay between to observations of the same object, among others. Then, all the tasks that comply with the observing constraints for the current night are sent to STARS, which uses an optimal scheduling algorithm that tries to maximize the figure-of-merit of the entire schedule, defined as:

$$\mathcal{F} = \sum_i f_i \sigma(t_i), \tag{1}$$

where $\sigma(t_i)$ is a correction factor that depends on the time $t$ at which the target $i$ has been scheduled and is used to penalize tasks scheduled at relatively high airmass values, and $f$ is the figure-of-merit of each individual observation task, given by:

$$f = \begin{cases} p\Delta t \left(1 + \frac{G-R}{\alpha}\right) & \text{if } G \geq R \\ p\Delta t \left(1 - \frac{G-R}{\alpha}\right)^{-1} & \text{if } G < R \end{cases}. \tag{2}$$

In this equation, $\Delta t$ is the duration in seconds of the observation, $p$ is the priority assigned to the proposal as defined by the TAC, $G$ is the fraction between amount of time already observed and the total time granted to the proposal, and $R$ is the fraction of semester passed. Finally, $\alpha$ is a configurable parameter that is used to control the weight of the different parameters in the function. In that way, for example, the tasks of a proposal that has not been observed yet at the end of the semester will have a higher figure-of-merit than a proposal that has been normally observed.

Finally, once the schedule that optimizes the figure-of-merit is found by STARS, ISROCS sends the night plan with the tasks to be observed during the night to the OCS, which will trigger the observations at the specified time.

## 5. OBSERVING TRANSIENT EVENTS AT THE TJO

As outlined in Sect. 1, one of the major limitations of using an optimal scheduling algorithm, as the one used at the TJO, is its inability to rapidly react to urgent observation of transient events. These unpredictable and short-lived astronomical phenomena, such as stellar flares, near earth objects, supernovae, gamma ray bursts, microlensing events, and more, require instantaneous follow-up observations.

Recognizing the critical need for swift responses to observe these events, we have performed significant enhancements across all subsystems involved in the scheduling system of the TJO. With these improvements, we achieved a reaction time for photometric observations of around 1-2 minutes since the

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alerts are issued, corresponding to the time required to move the dome and point the telescope. The key updates include:

- **Dynamic nighttime scheduling:** ISROCS can now dynamically generate new schedules during the night, using real-time information about the progress of ongoing observations, such that completed or partially observed tasks are not included in the new plan. Nighttime scheduling is triggered only in two scenarios: firstly, after returning from bad weather conditions, enabling the rescheduling of high-priority observations that could not be observed before due to adverse weather conditions. Secondly, in response to the addition of new tasks to our database, providing a prompt option for urgent observations.

- **API for programmatic observations:** The creation of a new API enables users subscribed to transient event alert distribution services to programmatically submit observation requests. Users can use their codes that are continuously monitoring these alerts to automatically trigger new photometric observations at the TJO. When the observation is received, it is immediately scheduled at the earliest time allowed by the observing constraints, and sent to the OCS to start the observation. In parallel, a new night plan is requested to ISROCS, which will schedule the remaining tasks around the newly received observation with a reaction time of under 2 minutes.

- **Immediate raw image access:** Users now have the option to download raw images in real-time as they are being observed. This immediate access to raw data gives the user the ability to respond effectively to evolving astronomical phenomena. This feature is particularly valuable in scenarios such as imminent impactor observations, allowing users to analyze data immediately and adjust observing strategies as needed.

## 6. SUMMARY

In this proceedings, we provide an overview of the scheduling system employed by the TJO telescope at the OdM, and introduce significant enhancements aimed at enabling photometric observations of transient events. These new upgrades strategically align the TJO with the current trend toward rapid-response observational capabilities.

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## REFERENCES

Bakos, G. Á., Lázár, J., Papp, I., Sári, P., & Green, E. M. 2002, PASP, 114, 974
Baroch, D., Morales, J. C., Ribas, I., et al. 2020, A&A, 641, A69
Bellm, E. C., Kulkarni, S. R., Barlow, T., et al. 2019, PASP, 131, 068003
Colomé, J., Nakhjiri, N., García-Piquer, Á., Morales, J. C., & Vilardell, F. 2020, ASPC, 527, 313
Colomé, J., Ribas, I., Fernández, D., et al. 2008, Conf. SPIE, 70192K
Colomé, J., Ribas, I., Francisco, X., et al. 2010, AdAst, 2010, 183016
Colomé, J., Sanz, J., Vilardell, F., Ribas, I., & Gil, P. 2012, Conf. SPIE, 845127
Denny, R. B. 2004, SASS, 23, 35
Granzer, T. 2004, AN, 325, 513
Herrero, E., Morales, J. C., Ribas, I., & Naves, R. 2011, A&A, 526, L10
Morales-Garoffolo, A., Elias-Rosa, N., Benetti, S., et al. 2014, MNRAS, 445, 1647
Ribas, I., Tuomi, M., Reiners, A., et al. 2018, Natur, 563, 365
Sarazin, M. & Roddier, F. 1990, A&A, 227, 294
Steele, I. A. & Carter, D. 1997, Proc SPIE, 3112, 222
Trigo-Rodríguez, J. M., García-Melendo, E., Davidsson, B. J. R., et al. 2008, A&A, 485, 599
Wyrzykowski, Ł., Mróz, P., Rybicki, K. A., et al. 2020, A&A, 633, A98