Telescope and space mission scheduling towards a multi-observatory framework

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J. Colomé (IEEC), Á. García-Piquer (IEEC), E. de Ona Wilhelmi (IEEC), D. F. Torres (IEEC), A. Bridger (STFC), J. Lightfoot (STFC), E. Díez (GTD), J. C. Morales (IEEC), I. Ribas (IEEC), F. Vilardell (IEEC)

Outline

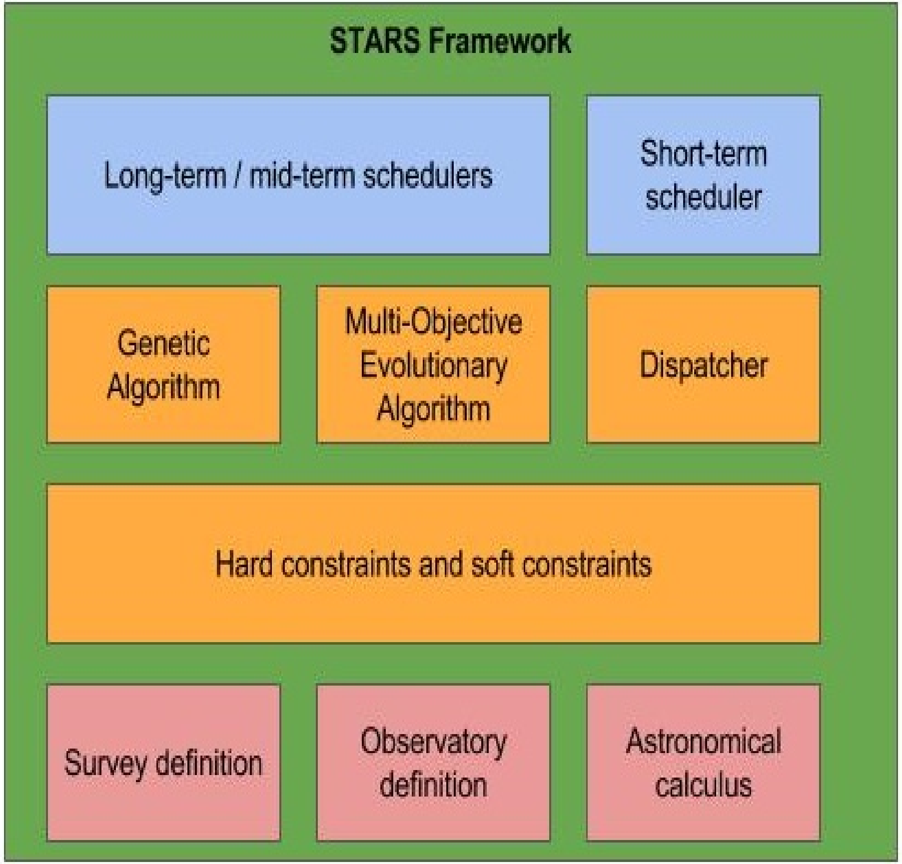
- **STARS framework**
  - Features
  - Perfomance metrics
  - Hard and soft constraints
  - Optimization algorithms
  - Optimization strategies
- Scheduling Applications
  - Single telescope: ARIEL-ESA, CARMENES, TJO
  - Observatory with multiple sites and sub-arrays: CTA
  - Multi-observatory: CTA&SKA, CTAN&S+GW

CLEOPATRA

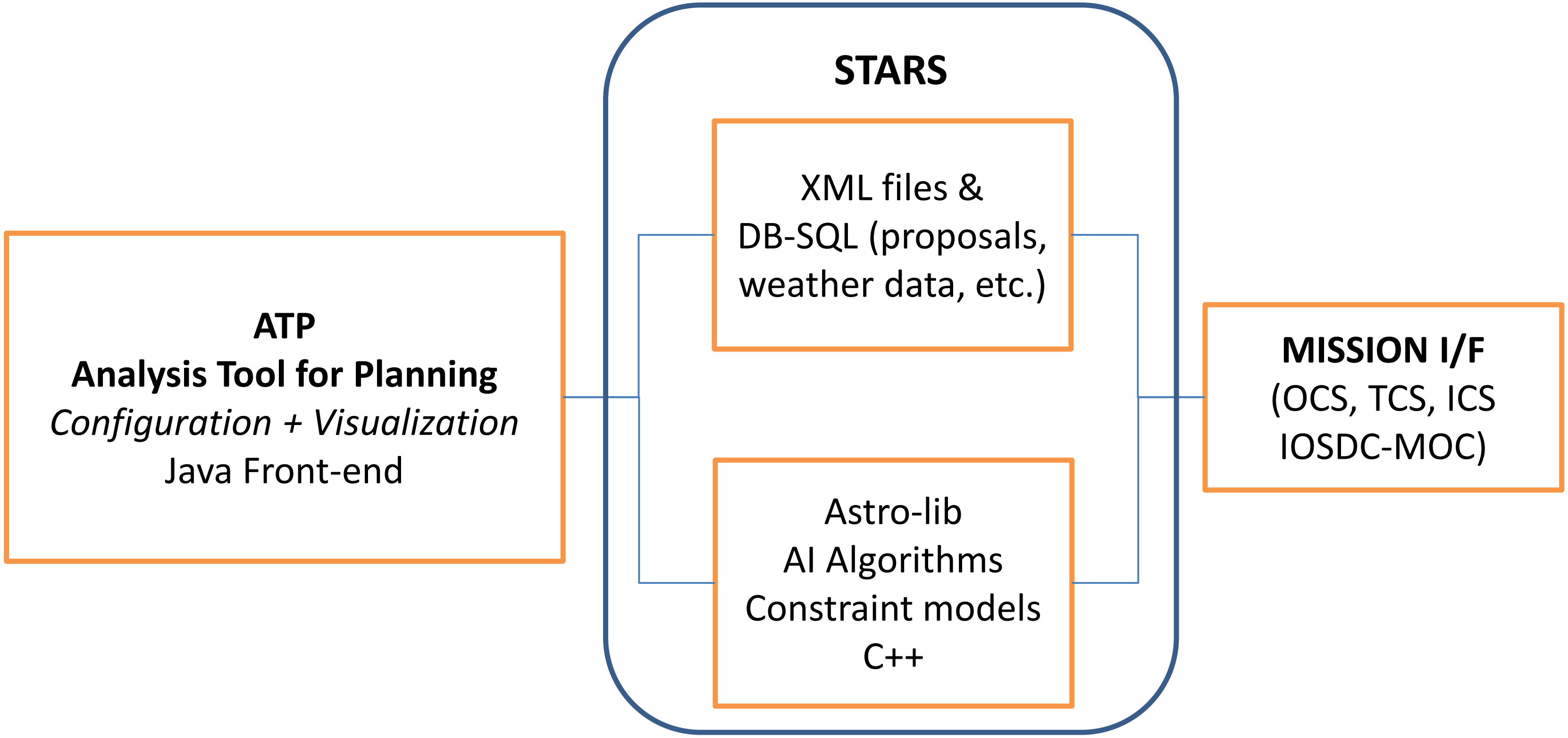
Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-Time Alerts (CLEOPATRA)

Features

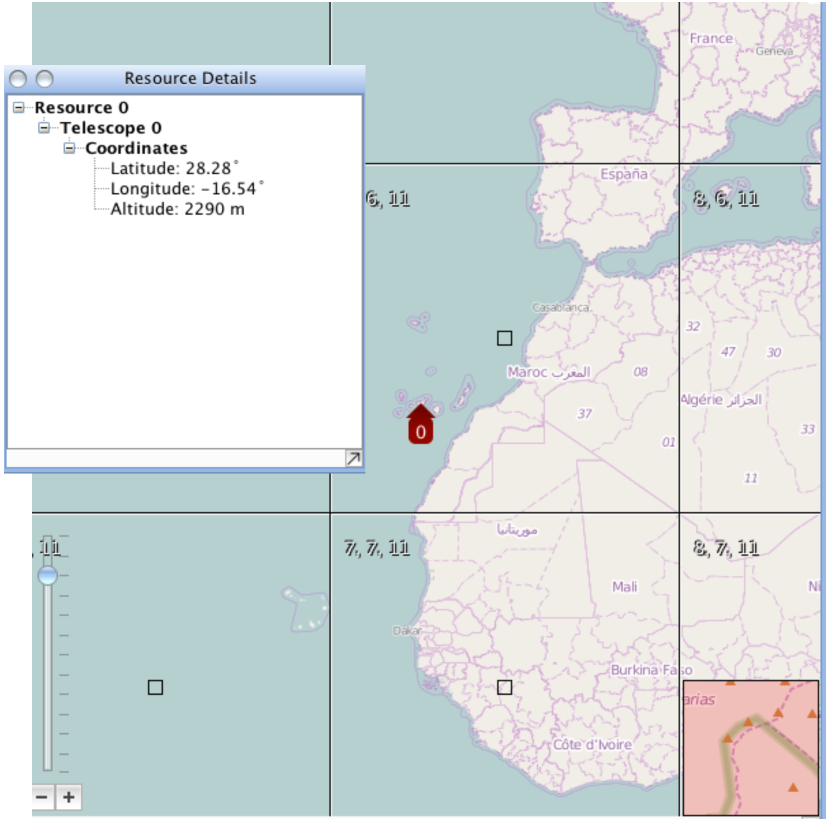
- Scheduling Technologies for Autonomous Robotic Systems
- Applied in several space and ground observatories
- Libraries
  - Definition of the survey: objects to be observed, features of the objects
  - Definition of the observatory: location, number of telescopes, type of telescopes
  - Astronomical calculations: object coordinates, object elevation, Sun and Moon position, Moon phase
  - Long- and mid-term schedulers based on Evolutionary Algorithms, and for a short-term scheduler a dispatcher using astronomy-based heuristics

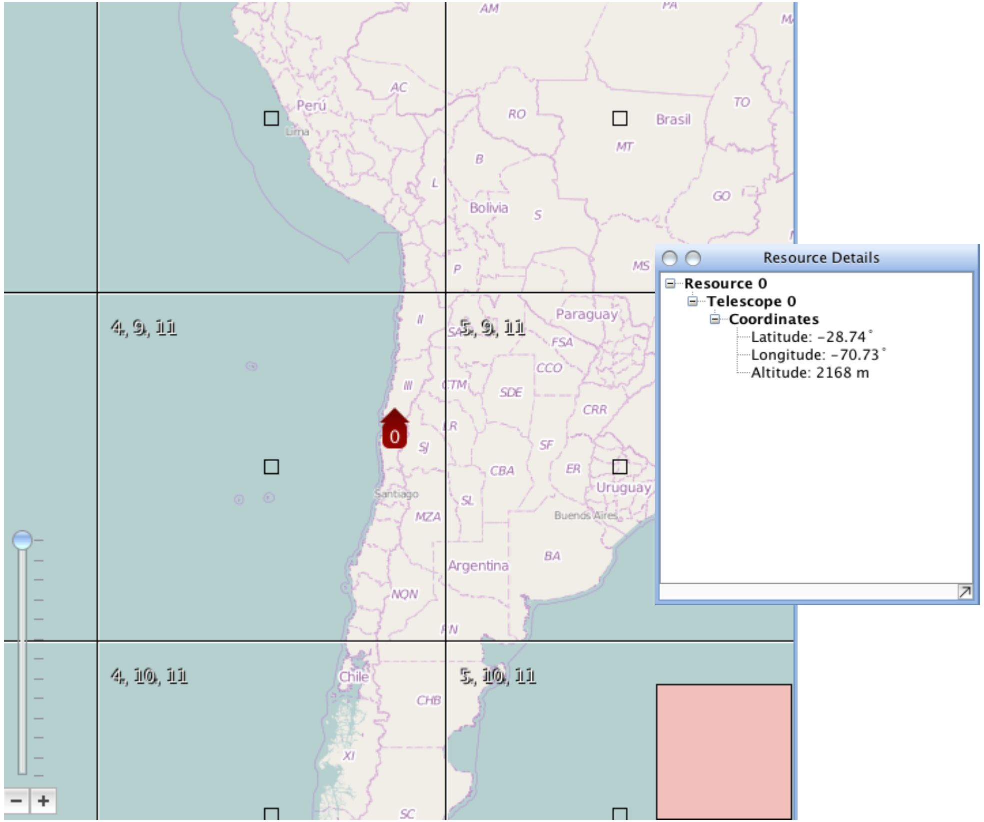


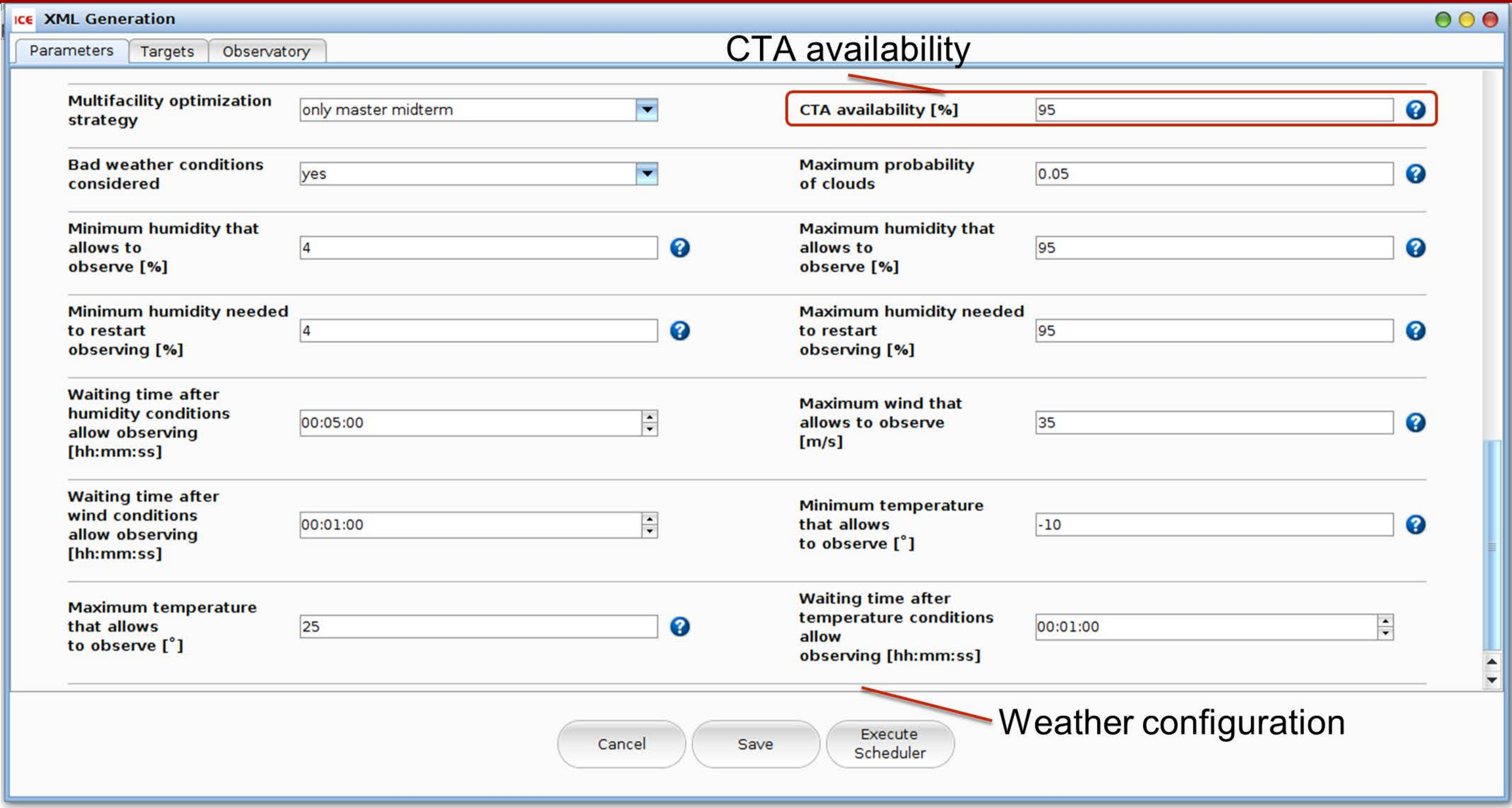
Features

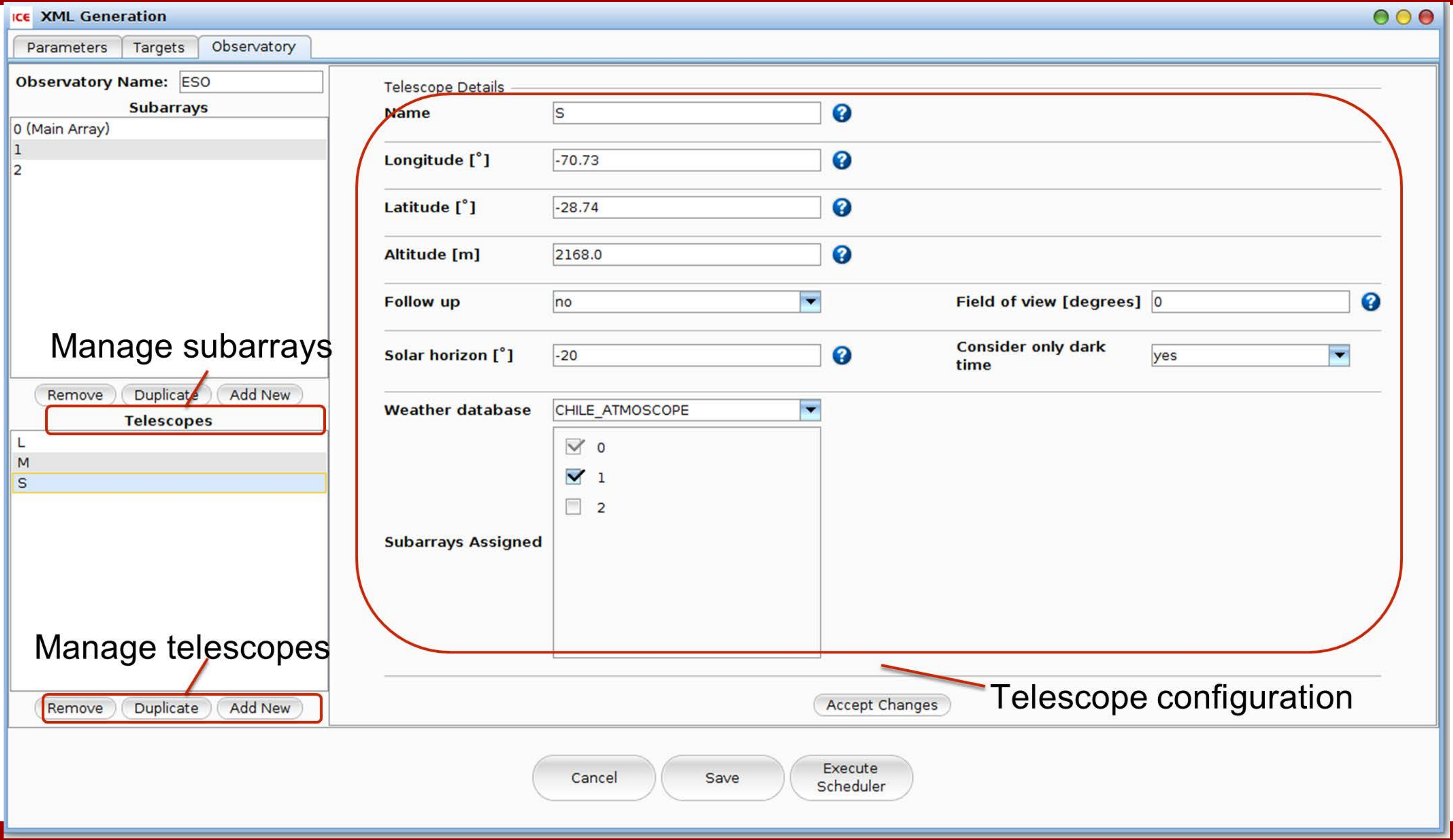

STARS
XML files &
DB-SQL (proposals,
weather data, etc.)
ATP
Analysis Tool for Planning
Configuration + Visualization
Java Front-end
MISSION I/F
(OCS, TCS, ICS
IOSDC-MOC)
Astro-lib
AI Algorithms
Constraint models
C++

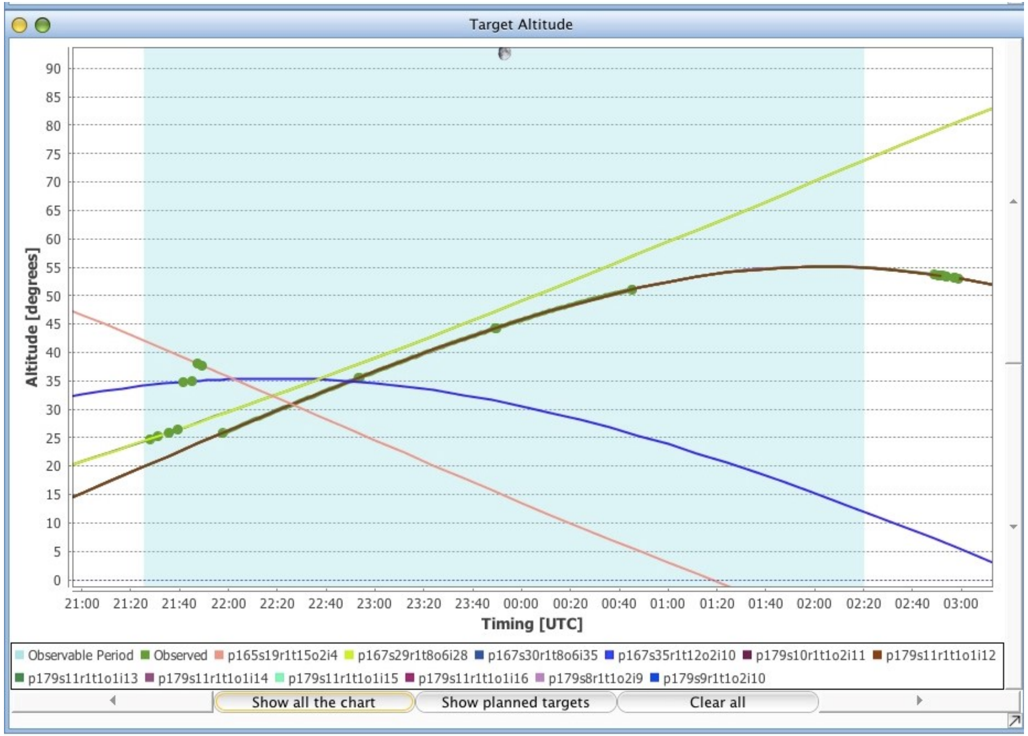
Two sites: Paranal in the South and La Palma in the North

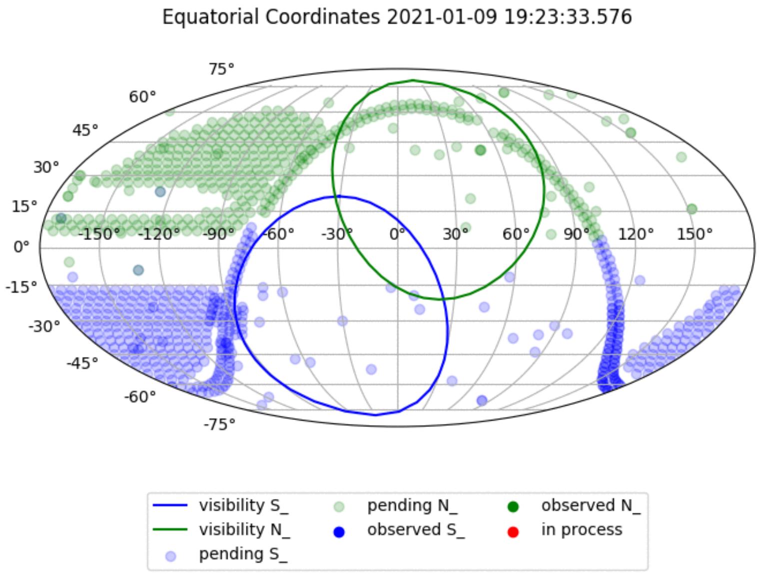


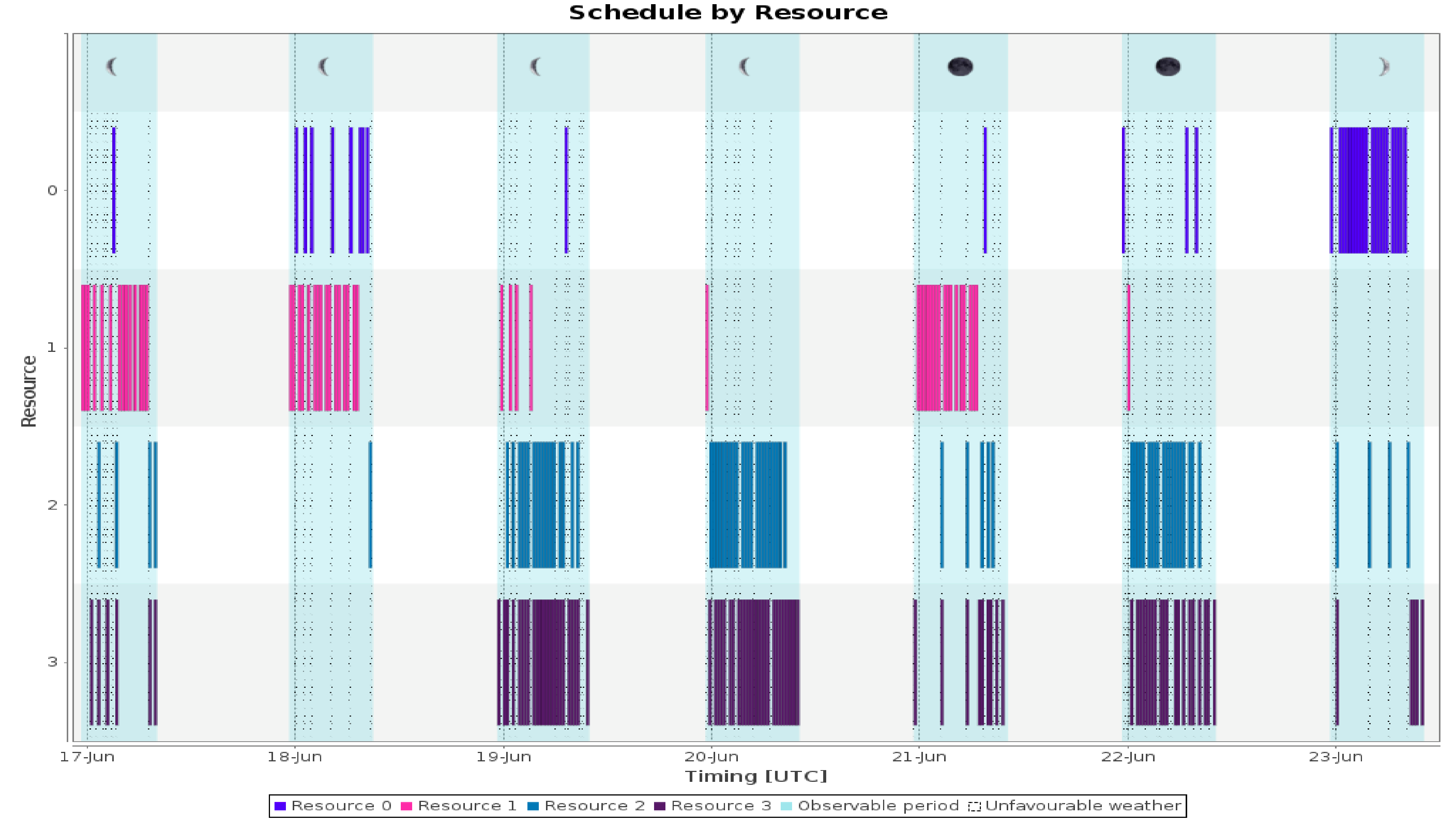



XML Generation
Parameters
Targets
Observatory
CTA availability
Multifacility optimization strategy
only master midterm
CTA availability [%]
95
Bad weather conditions considered
yes
Maximum probability of clouds
0.05
Minimum humidity that allows to observe [%]
4
Maximum humidity that allows to observe [%]
95
Minimum humidity needed to restart observing [%]
4
Maximum humidity needed to restart observing [%]
95
Waiting time after humidity conditions allow observing [hh:mm:ss]
00:05:00
Maximum wind that allows to observe [m/s]
35
Waiting time after wind conditions allow observing [hh:mm:ss]
00:01:00
Minimum temperature that allows to observe [°]
-10
Maximum temperature that allows to observe [°]
25
Waiting time after temperature conditions allow observing [hh:mm:ss]
00:01:00
Cancel
Save
Execute Scheduler
Weather configuration


XML Generation
Parameters
Targets
Observatory
Observatory Name:
ESO
Subarrays
0 (Main Array)
1
2
Manage subarrays
Remove
Duplicate
Add New
Telescopes
L
M
S
Manage telescopes
Remove
Duplicate
Add New
Telescope Details
Name
S
Longitude [°]
-70.73
Latitude [°]
-28.74
Altitude [m]
2168.0
Follow up
no
Field of view [degrees]
0
Solar horizon [°]
-20
Consider only dark time
yes
Weather database
CHILE_ATMOSCOPE
0
1
2
Subarrays Assigned
Accept Changes
Telescope configuration
Cancel
Save
Execute Scheduler


Target Altitude
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Altitude [degrees]
21:00 21:20 21:40 22:00 22:20 22:40 23:00 23:20 23:40 00:00 00:20 00:40 01:00 01:20 01:40 02:00 02:20 02:40 03:00
Timing [UTC]
Observable Period
Observed
p165s19r1t15o2i4
p167s29r1t8o6i28
p167s30r1t8o6i35
p167s35r1t12o2i10
p179s10r1t1o2i11
p179s11r1t1o1i12
p179s11r1t1o1i13
p179s11r1t1o1i14
p179s11r1t1o1i15
p179s11r1t1o1i16
p179s8r1t1o2i9
p179s9r1t1o2i10
Show all the chart
Show planned targets
Clear all


Equatorial Coordinates 2021-01-09 19:23:33.576
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150°
visibility S_
visibility N_
pending S_
pending N_
observed S_
observed N_
in process

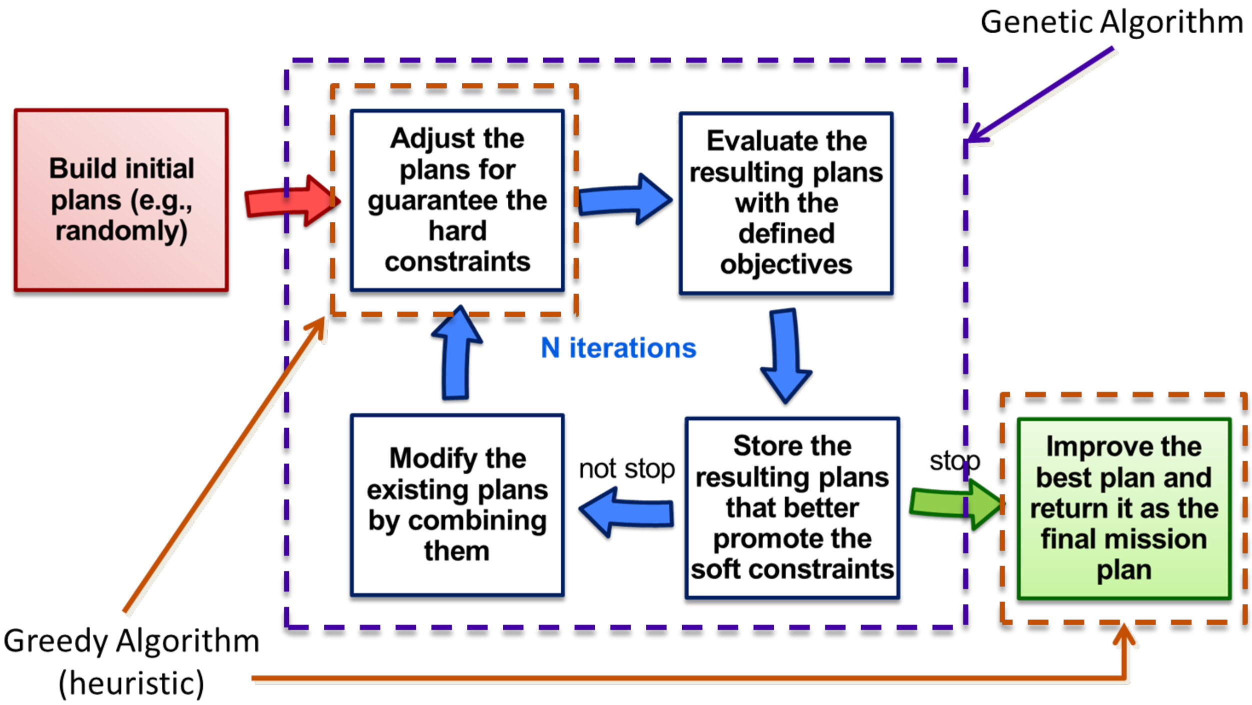

Schedule by Resource
Resource
0
1
2
3
17-Jun
18-Jun
19-Jun
20-Jun
21-Jun
22-Jun
23-Jun
Timing [UTC]
Resource 0
Resource 1
Resource 2
Resource 3
Observable period
Unfavourable weather

Performance metrics

- Observing time optimization
  - The **time** in the schedule during which the **telescope** is **observing** objects should be maximized
- Optimization of scientific return
  - The **observation of completed targets** should be maximized in order to increase the scientific efficiency of the mission
  - **Observation of the priority targets** should be promoted
  - **Observation deviation** to ensure that all targets with the same priority will have a proper share of assigned observing time
  - **Observing cadence** according to the observation strategy

Optimization algorithms

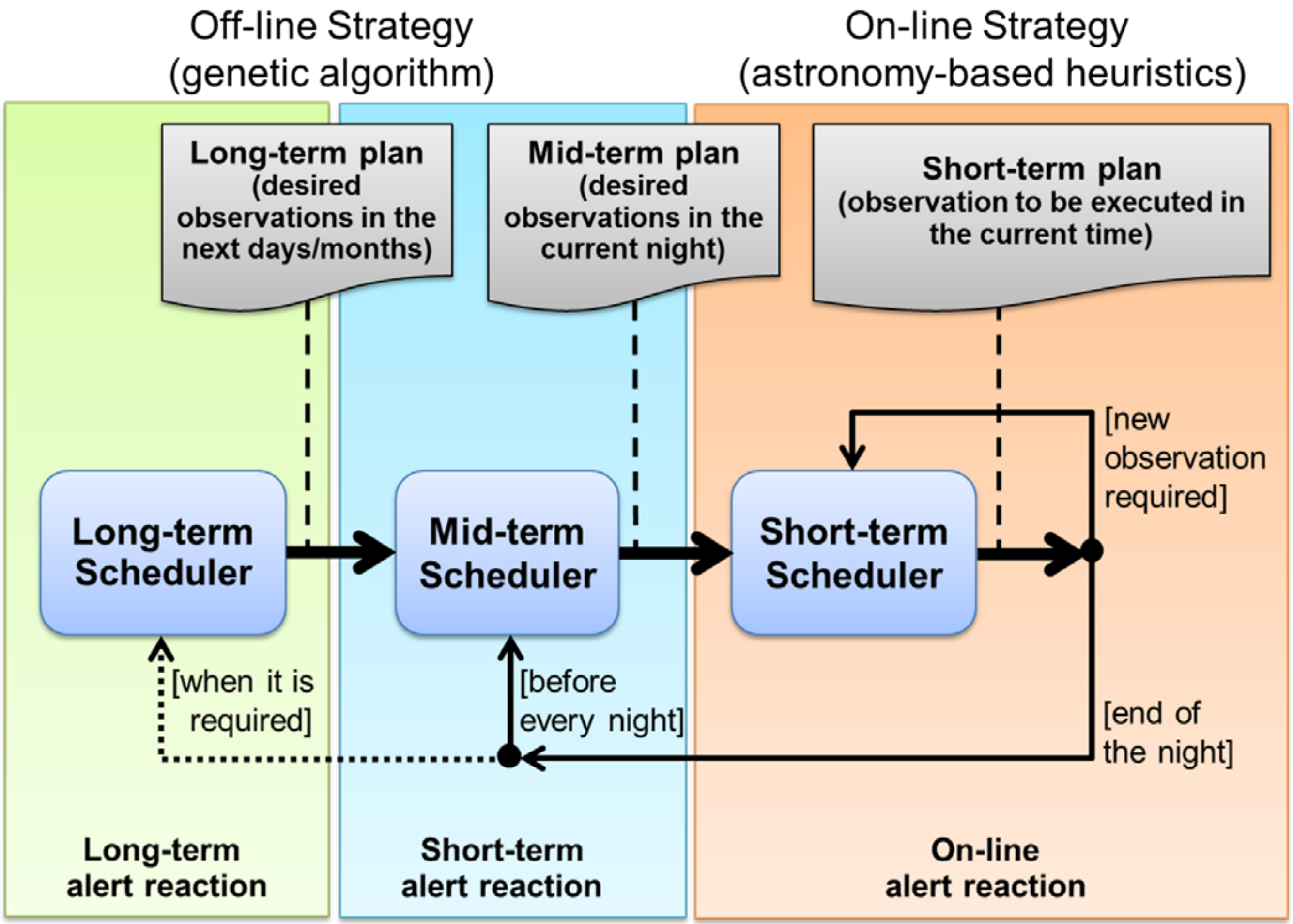
- Optimization process based on AI Algorithms



Optimization strategies

- Off-line ➔ Long-term and Mid-term schedulers
  - Time interval according to hard constraints that can be predicted
- On-line ➔ Short-term scheduler
  - It considers all constraints and adapts the mid-term plan to react to immediate circumstances

Constraint	Long-term	Mid-term	Short-term
Hard Constraints			
Night	X	X	X
Elevation	X	X	X
Moon influence	X	X	X
Visibility duration	X	X	X
Pointing	X	X	X
Overlapping		X	X
Overhead time		X	X
Environmental conditions			X
Soft Constraints			
Observing time		X	X
Observation deviation		X	X
Observing cadence	X		



Off-line Strategy
(genetic algorithm)
On-line Strategy
(astronomy-based heuristics)
Long-term plan
(desired observations in the next days/months)
Mid-term plan
(desired observations in the current night)
Short-term plan
(observation to be executed in the current time)
[new observation required]
Long-term Scheduler
Mid-term Scheduler
Short-term Scheduler
[when it is required]
[before every night]
[end of the night]
Long-term alert reaction
Short-term alert reaction
On-line alert reaction

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  - Observatory with multiple sites and sub-arrays: CTA
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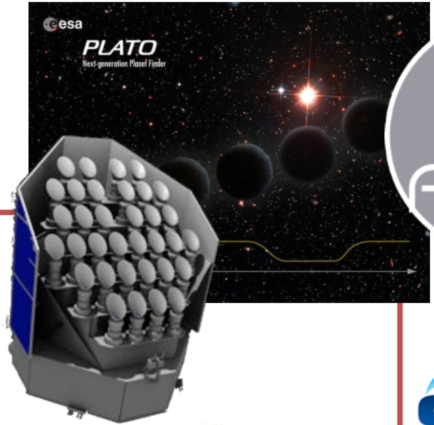
esa



ARIEL

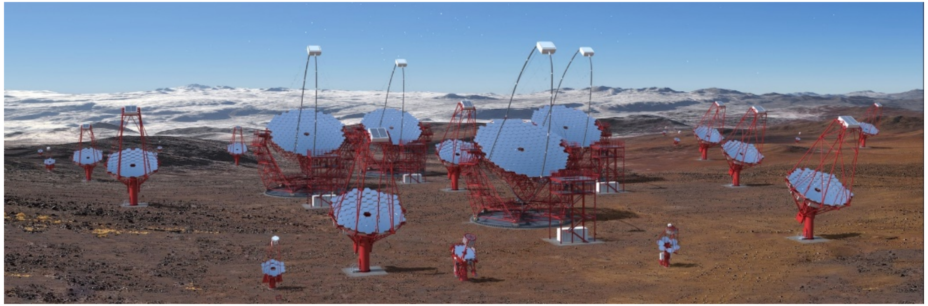
SKA
SQUARE KILOMETRE ARRAY

cta
cherenkov telescope array

carmenes

Cherenkov Telescope Array

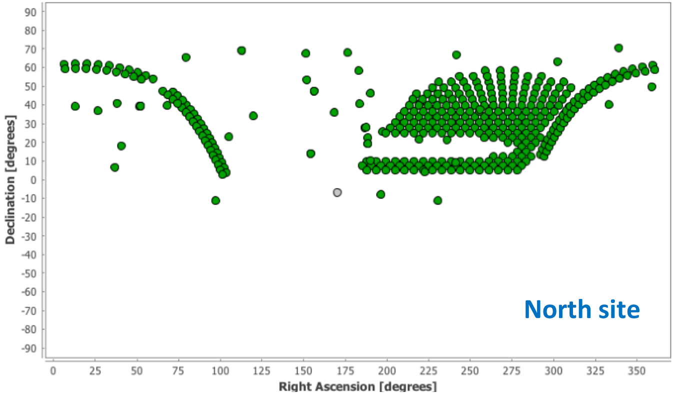
- CTA scheduling conditions
  - Operation tasks
    - Science, calibration, maintenance
  - Observation modes
    - Sub-arrays, compact
    - Convergent/divergent modes
  - Observing time distribution (SB)
  - Two sites (CTAN@ORM / CTAS@Paranal)
    - 20-100 Telescopes/site
    - Independent & coordinated tasks

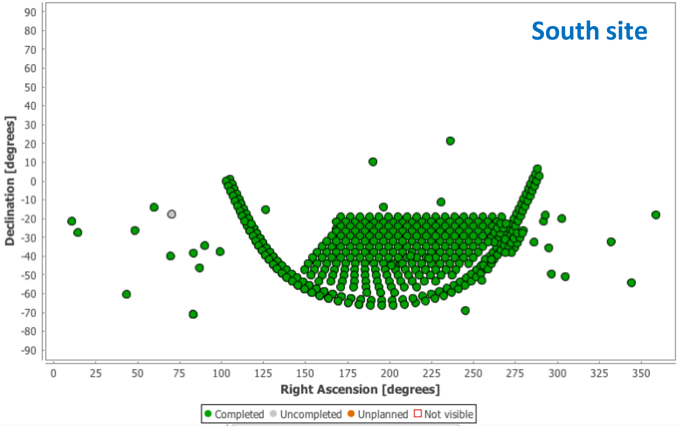


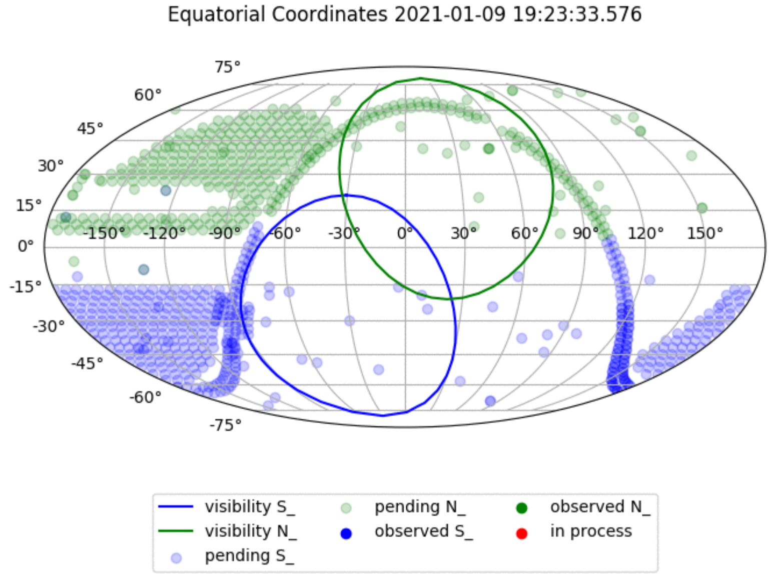
CTAS&CTAN rendering, Gabriel Pérez Díaz, IAC, SMM

CTA KSP simulations - 10 yr

- Two configurations (1/1/2021 to 1/1/2031):
  - Full Array – North & South (coordinated observations)
  - Sub Arrays – only in the South



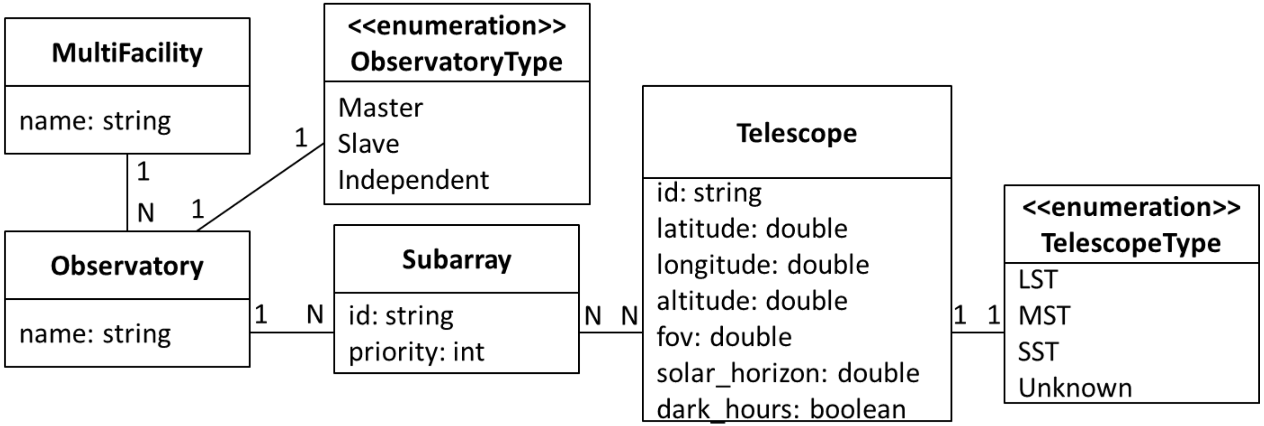




Visibility plots-10 yrs
- Completed
- Uncompleted
- Unplanned

Multi-observatory scheduling

- Science cases: **transient events** (GRBs, GWs, etc.), **surveys**
- Problem conditions
  - Each observatory contains various subarrays
  - Each observatory has a role: leader, follower or independent
- **Additional Objective ➔ Maximize the simultaneity of observations** (maximize coincident observations or minimize the distance between them)

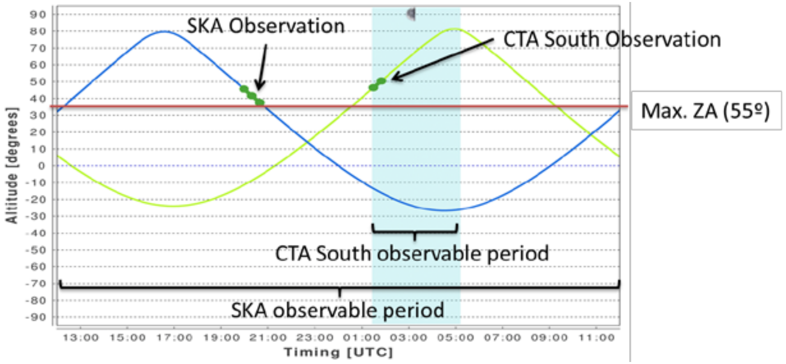


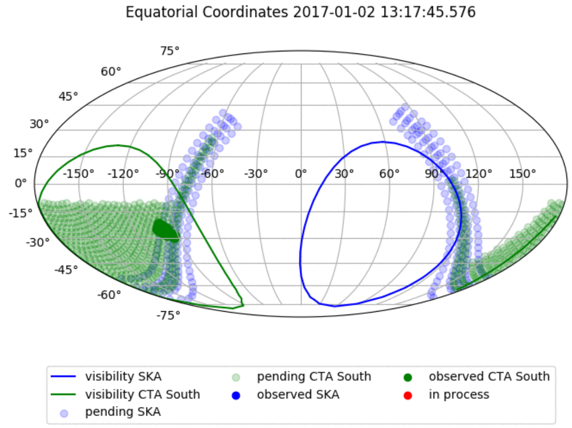
Multi-observatory scheduling

- Strategies
  - Subsidiary observations: leader - follower
  - Interactive approach: leader - leader
  - Multi-Messenger: random alerts (GW) observed by CTAN&CTAS
- Facilities
  - CTA (CTAN - La Palma, Canary Islands; CTAS – Chile)
  - SKA (Australia, South Africa) → GASKAP (Australia)
  - William Herschell (La Palma, Canary Islands)

Simulation configurations

- Science test case: CTA and SKA
  - CTA: North and South example surveys
  - SKA: GASKAP galactic survey (Dickey, 2013)
- Scenario (max Zenith: 55º)
  - Leader: site SKA-AU, GASKAP survey
  - Follower: site CTA South, CTA South survey example (FOV: 8 deg ∅)
- Leader and follower
  - Strategy 1: leader and follower subarrays are optimized simultaneously
  - Strategy 2: leader is optimized individually ➔ Followers do a follow-up





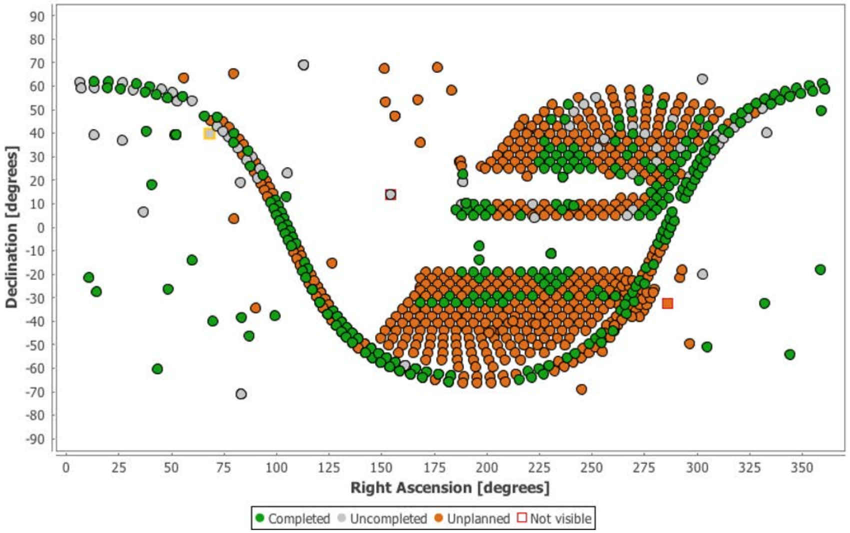
Simulation results

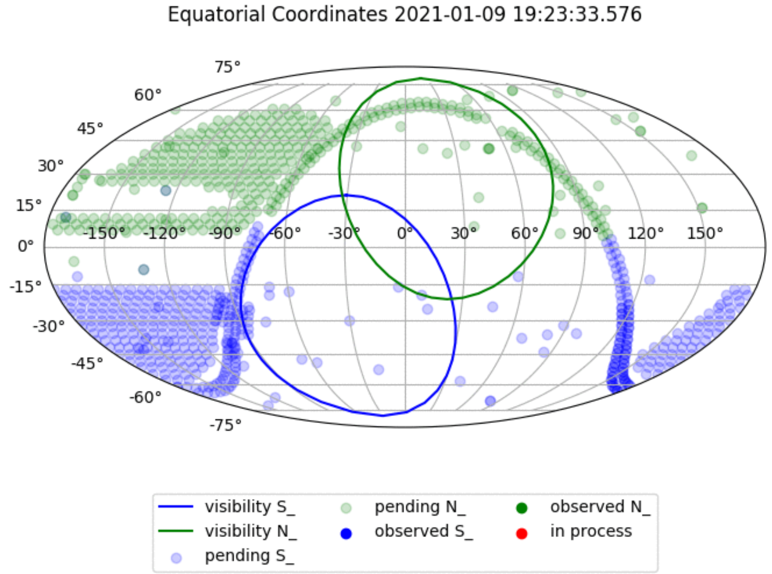
- No targets can be observed simultaneously in CTA South and SKA because of the maximum ZA (55º) ➔ Optimization reduces time between observations

	MO Strategy 1		Individually	
	SKA	CTA South	SKA	CTA South
Required Time (h)	13300	2062.25	13300	2062.25
Targets in the survey	275	1356	275	1356
Available Time (h)	6132	1149.78	6359.34	1193.52
Observing Time (h)	3968.67	713.33	3984.67	720.67
Slew Time (h)	255.64	72.02	88.75	27.3
#Observations	11906	2140	11954	2162
Targets observed (#Planned (#Completed))	235 (19)	652 (212)	236 (43)	483 (373)
Survey completion (%)	29.84	34.59	29.96	34.95

Simulation results

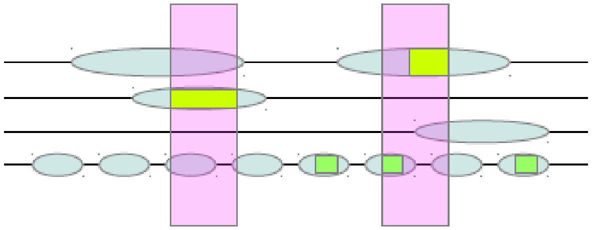
- Multi-Messenger
  - CTAN&S coordinated & GW transients follow-up
  - Configuration: 854 targets, required time 7200 h (incl. 2000 h for transients), 2500 h/yr of available time
  - 10 yr simulation (figure: results after 1st yr)





Conclusions

- STARS is a framework for **observatory time scheduling**
  - Algorithms used are: GA, MOEA and astronomical heuristics. Other global search algorithms can be applied following the same steps
  - Hard and soft constraints can be adapted and generalized to different cases
  - Tool to estimate the efficiency of the survey, and to study the impact of different parameters or which targets are most restrictive
- STARS is applied to different projects: CARMENES, TJO, CTA, ARIEL-ESA
  - **Simulations for Multi-observatory and Multi-Messenger applications: CTA&GASKAP, CTAN&S&GW follow-up**
- Future steps → **MM Coordination Platform**



Telescope and space mission scheduling towards a multi-observatory framework

Pep Colome (colome@ieec.cat)

Institut d'Estudis
Espacials de Catalunya