CTA Operations and Scheduling

Pep Colome, on behalf of the IEEC-CSIC team
(colome@ieec.cat)
Institute of Space Sciences

Planning & scheduling

- Goal: Solve constraint-satisfaction problem
- Technologies used: Metaheuristic Optimization (Genetic Algorithms, Multiobjective Evolutionary Algorithms) and Constraint-Based Reasoning (constraint propagation)
- Applicability
  - Mission planning optimization
  - Task (observations) sharing and cooperation between observatories
  - Embedded replanning for long distance or long autonomy operations

Mission planning optimization

- Projects

carmenes

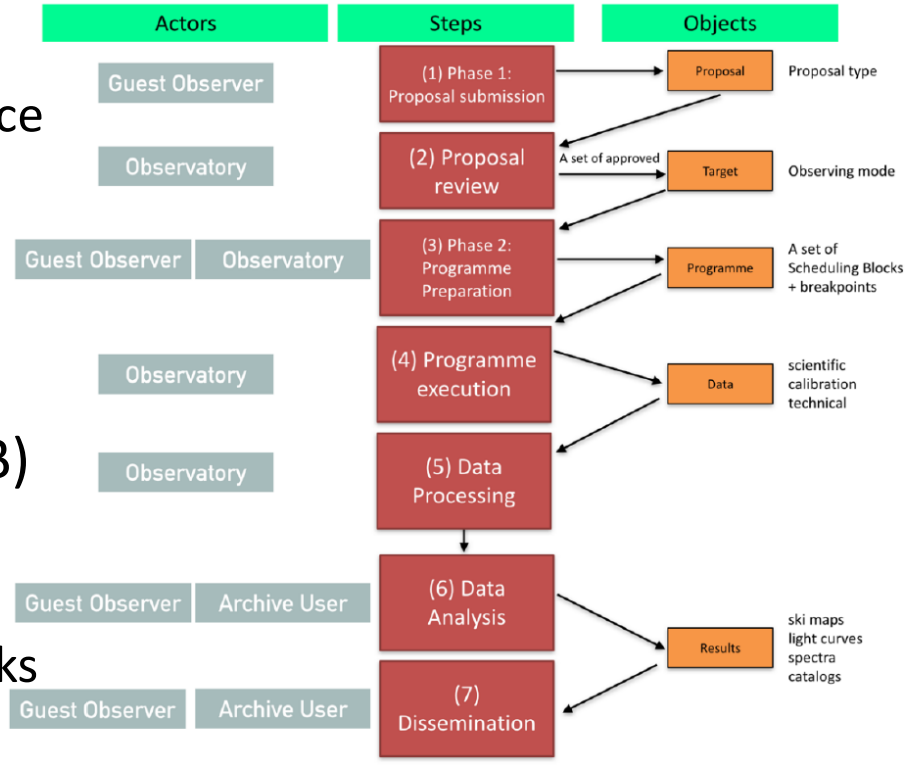
cta
cherenkov telescope array

Scheduler for CTA

- CTA Scheduler (SCTA) prototype
- SCTA is a software designed to schedule astronomical observations based on Artificial Intelligence (Metaheuristic Optimization: GA, MOEA)
- Provide an automatic schedule of observations to each subarray: fulfill the conditions that must be satisfied (hard constraints); and highly optimize specific objectives (soft constraints)
- We can obtain a near-optimal solution (i.e., scheduling solution that highly optimizes the objectives and fulfills all the hard-constraints)
- SCTA allows Multi-facility scheduling and it is highly configurable: Different sites / Weather Conditions / Sub-Arrays / Cadence & Observation Strategies / Proprietary Time & Observation constrains
- SCTA works in 3 levels: Long-term, Mid-term and Short-term
- Current version implemented in C++

Problem Conditions

- Operation tasks
  - Science, calibration, maintenance
- Observation types (incl.ToOs)
- Observation modes
  - Sub-arrays, compact
  - Convergent/divergent modes
- Observing time distribution (SB)
- Two sites (North/South)
  - 30-100 Telescopes/site
  - Independent & coordinated tasks



CTA observation modes

- Convergent mode (very deep field)

CTA observation modes

Divergent mode

CTA observation modes

Monitoring
4 telescopes

Monitoring
4 telescope

Deep field
~1/2 of telescopes

Monitoring
4 Telescopes

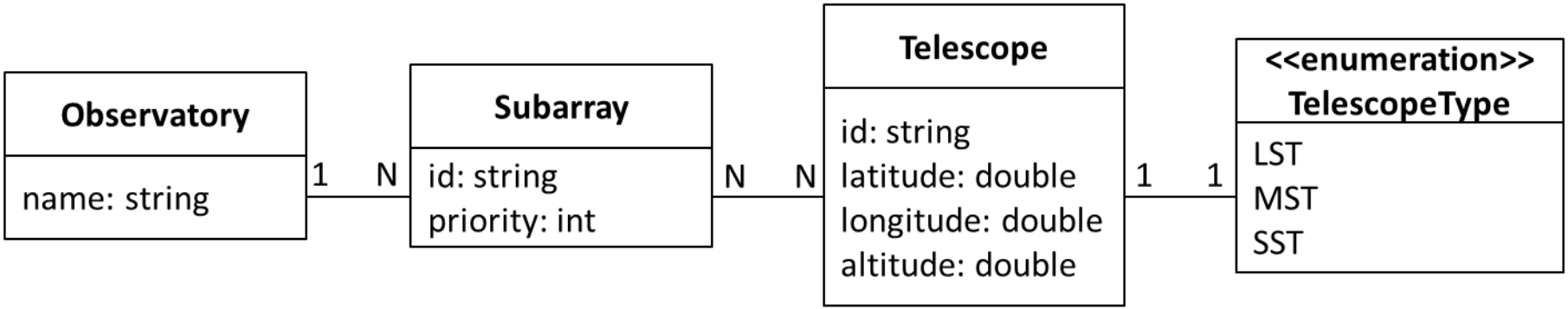
Deep field
~1/3 of telescopes

Monitoring
1 telescope

Divergent & convergent mode in
SUB-ARRAY configuration

Problem Conditions

- Observatory
  - Several subarrays
    - Each subarray contains a number of telescopes (TLCs) of same or different types
    - TLCs can be shared between subarrays (those subarrays will then exclude each other in simultaneous observation, i.e., Subarray1: All TLCs vs Subarray2: LSTs + MSTs)



Observation Constraints

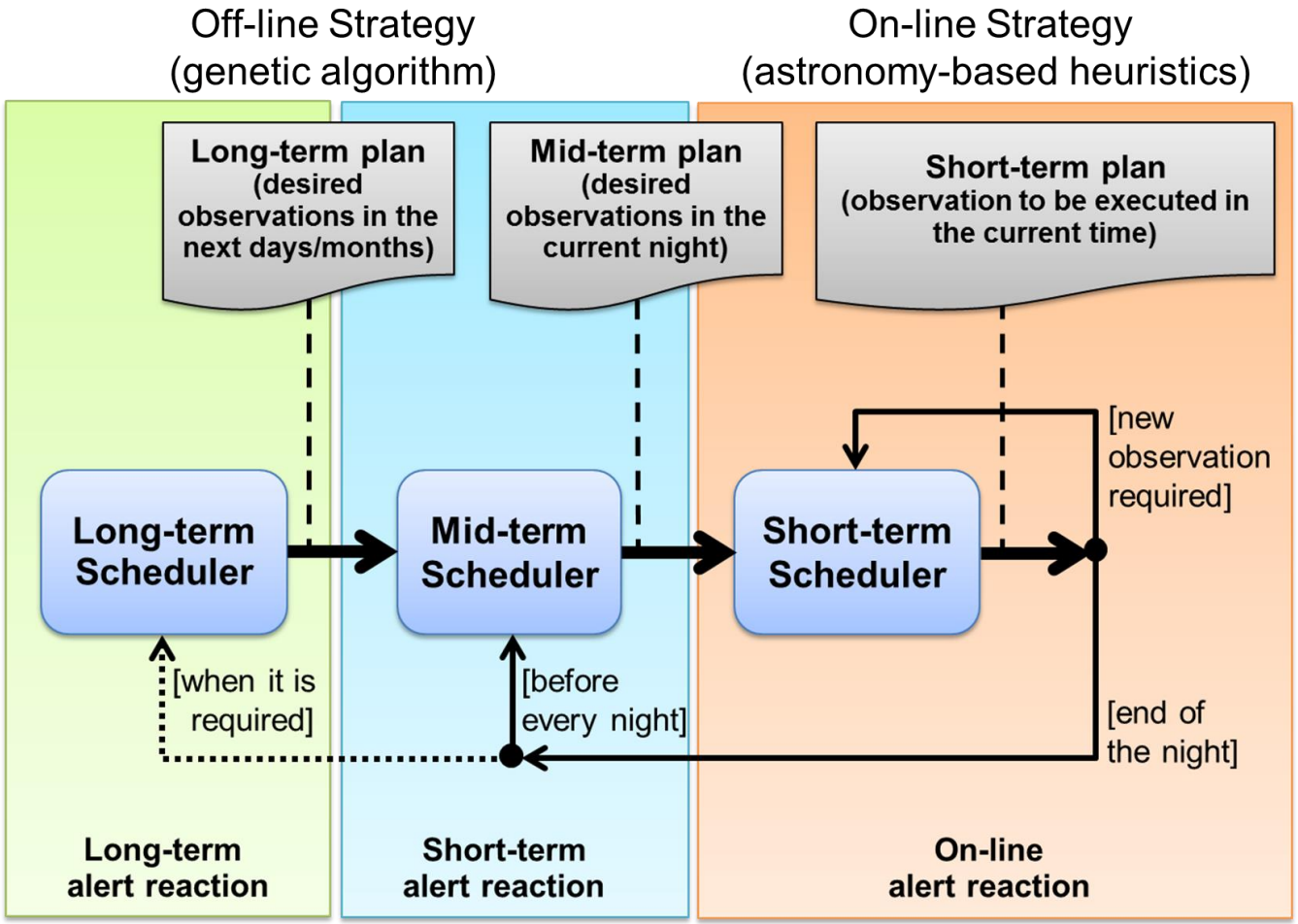
- Hard Constraints
  - Visibility constraints
    - Dark hours (global) → solar horizon (-18º), Moon phase
    - Maximum Zenith Angle (target)
  - Resource constraints
    - Subarrays that share telescopes cannot observe at the same time
    - Each target observed by the assigned subarray
- Soft Constraints
  - Maximize observation time of each night
  - Maximize completion of proposals
  - Minimize slew time of each night (time blocks will increase due to consecutive observations)

Optimization Strategies

- Long-term and Mid-term schedulers
  - Genetic Algorithm (GA)
    - Single objective
      - Maximize the observation time
  - Multiobjective Evolutionary Algorithm (MOEA)
    - Two objectives
      - Maximize the observation time or the proposals completion
      - Minimize slew time

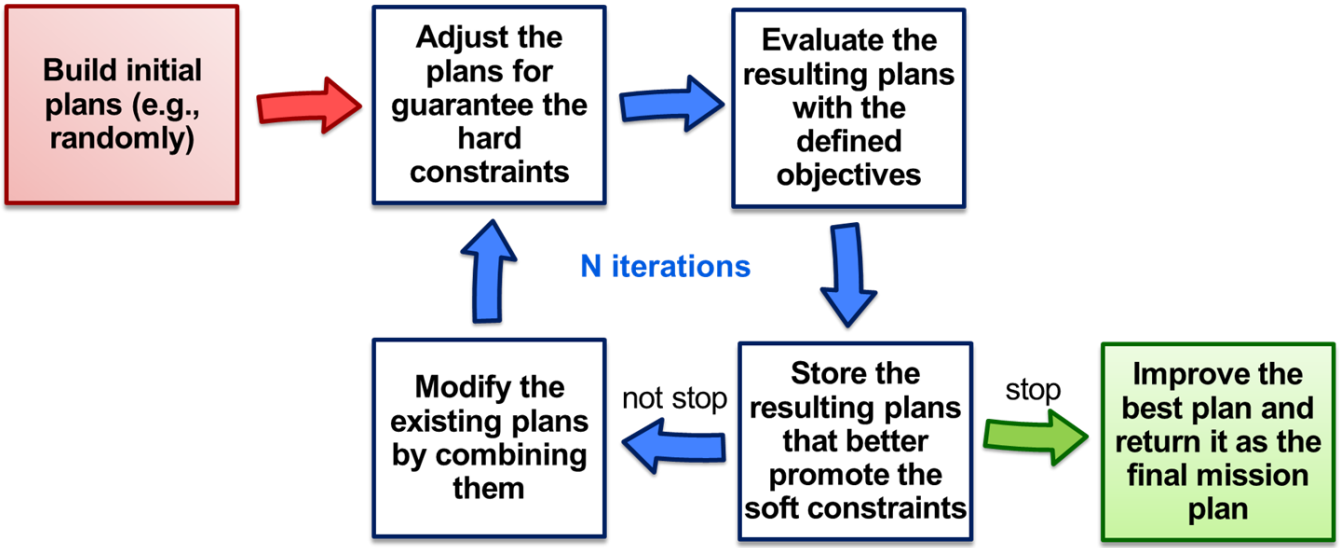
Optimization Strategies

- Short-term scheduler
  - Features
    - Executed on-line (i.e., in real time)
    - Provide to array central control the next task (i.e., scheduling block) to be executed
    - React to unexpected and unpredictable situations
      - ToO, weather, telescope condition…
    - Respond in a few seconds
  - Strategy used
    - Adapt the plan previously computed by the mid-term scheduler
      - Without performing a global search (i.e., expensive optimization processes) with the aim of providing a quick response
      - Local search based on astronomical heuristics (i.e., decision rules)
    - Provide scheduling blocks with a reasonable trade-off between quality (i.e., suitability) and response time


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)
Long-term Scheduler
Mid-term Scheduler
Short-term Scheduler
[new observation required]
[when it is required]
[before every night]
[end of the night]
Long-term alert reaction
Short-term alert reaction
On-line alert reaction

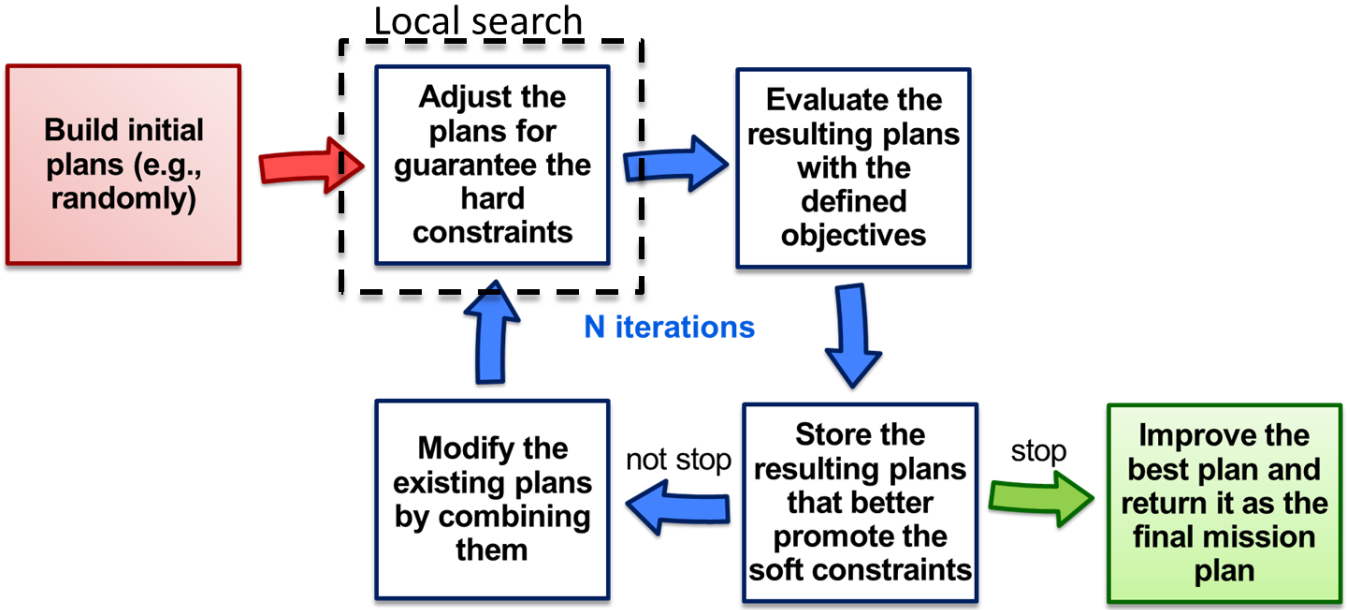
Mission Planning Tool

- Optimization process based on Genetic Algorithms



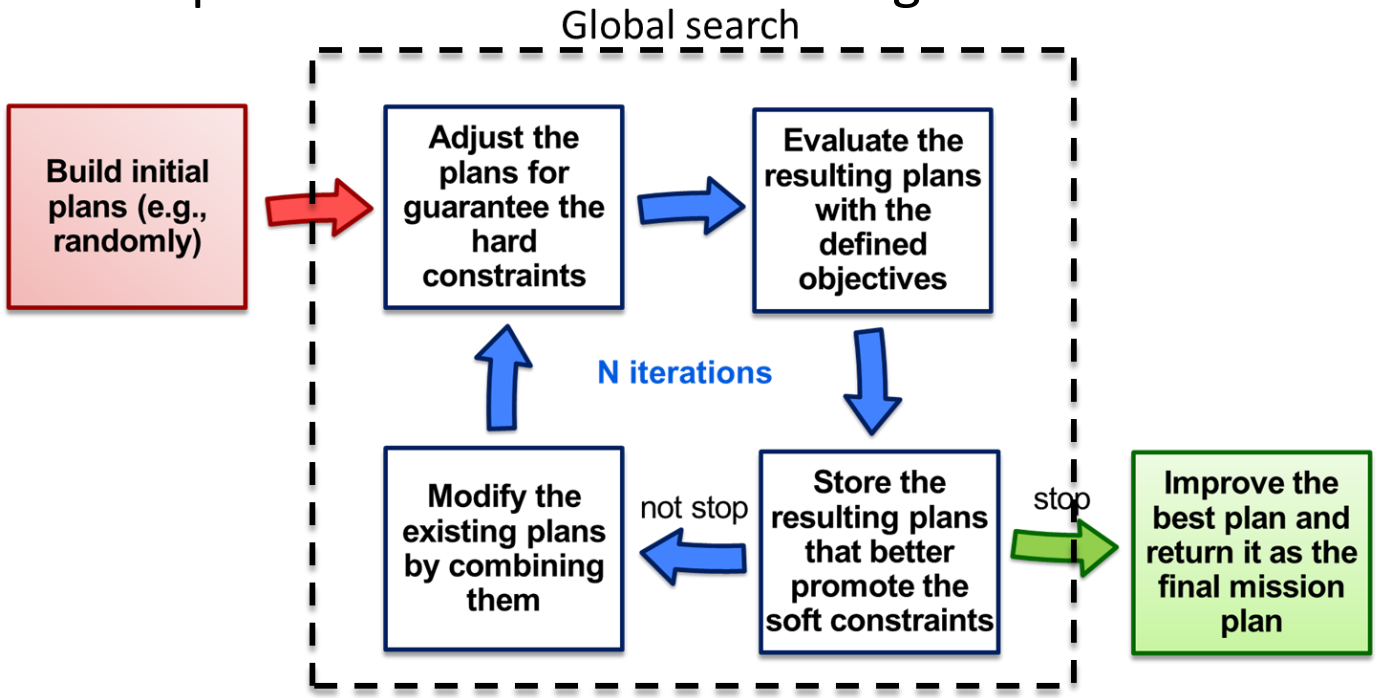
Mission Planning Tool

- Optimization process based on Genetic Algorithms



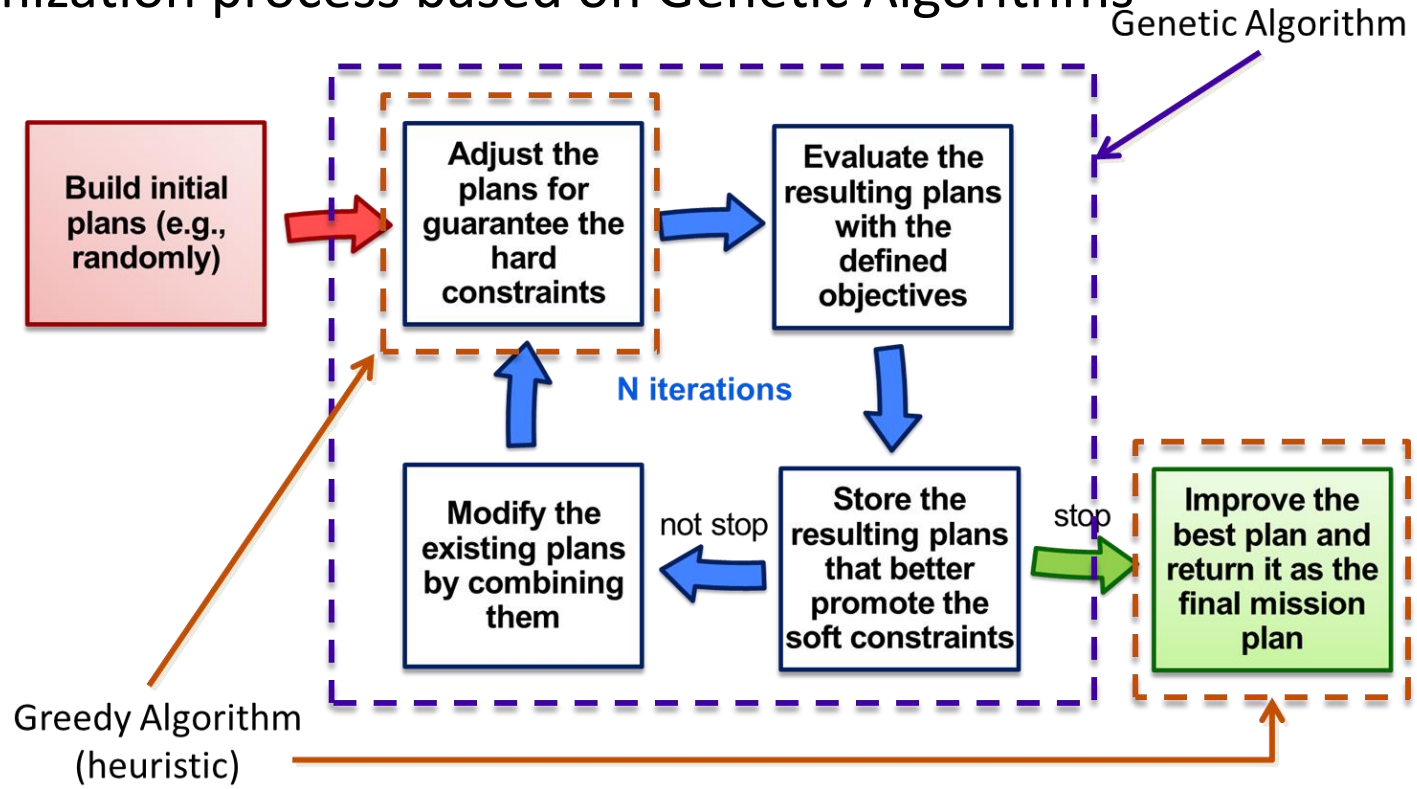
Mission Planning Tool

- Optimization process based on Genetic Algorithms



Mission Planning Tool

- Optimization process based on Genetic Algorithms



Simulation parameters

- Parameters of each target
  - Coordinates
  - Observation time to be achieved
  - Maximum Zenith Angle
  - Subarray assigned
- Observation blocks
  - Duration can be configured for each target
  - Fixed pointing
- Slew time between observations of different targets
  - Overhead time of 2 minutes + 1 second per degree
- Mid-term Scheduler and Short-term Scheduler
  - Real-time response to bad weather conditions / ToO / etc.

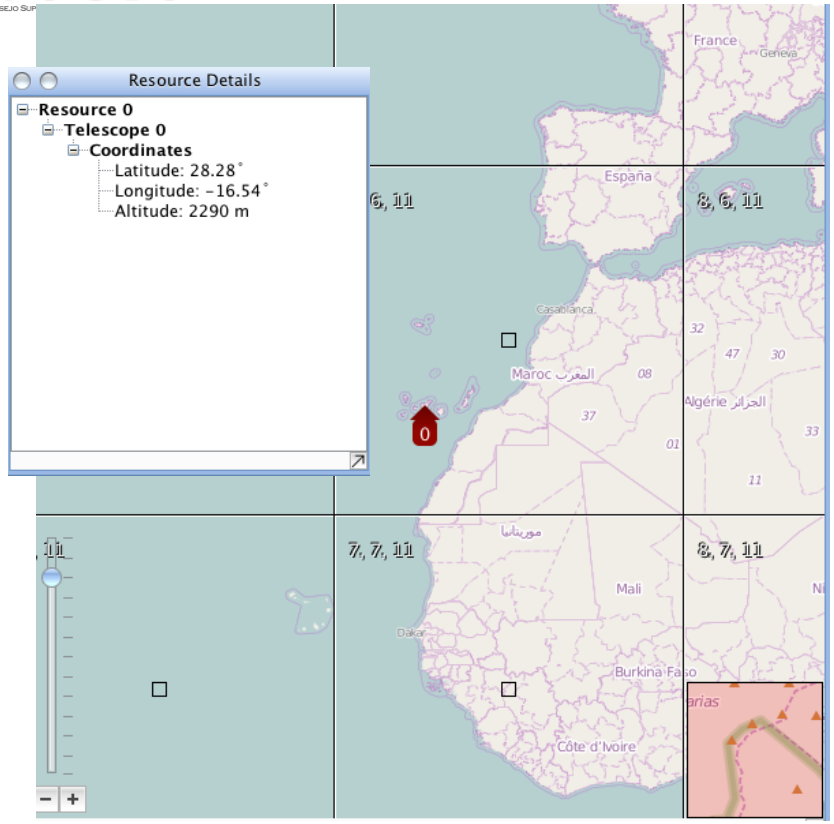
Simulation constraints

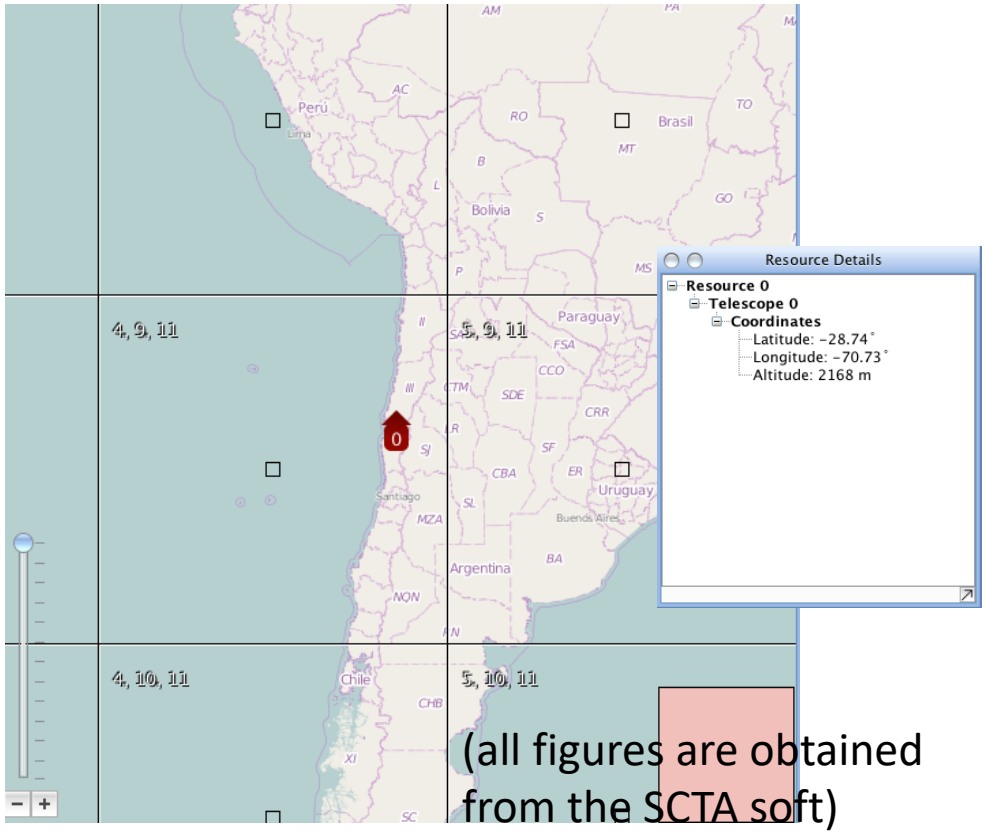
- Hard Constraints
  - Visibility constraints
    - Dark hours (global) → solar horizon (-20º), Moon phase
    - Maximum Zenith Angle (target definition)
  - Resource constraints
    - Subarrays that share telescopes cannot observe at the same time
    - Each target observed by the assigned subarray
- Soft Constraints
  - Maximize proposal completeness
  - Maximize observation time of each night
  - Minimize slew time of each night (time blocks will increase due to consecutive observations)

Simulation conditions

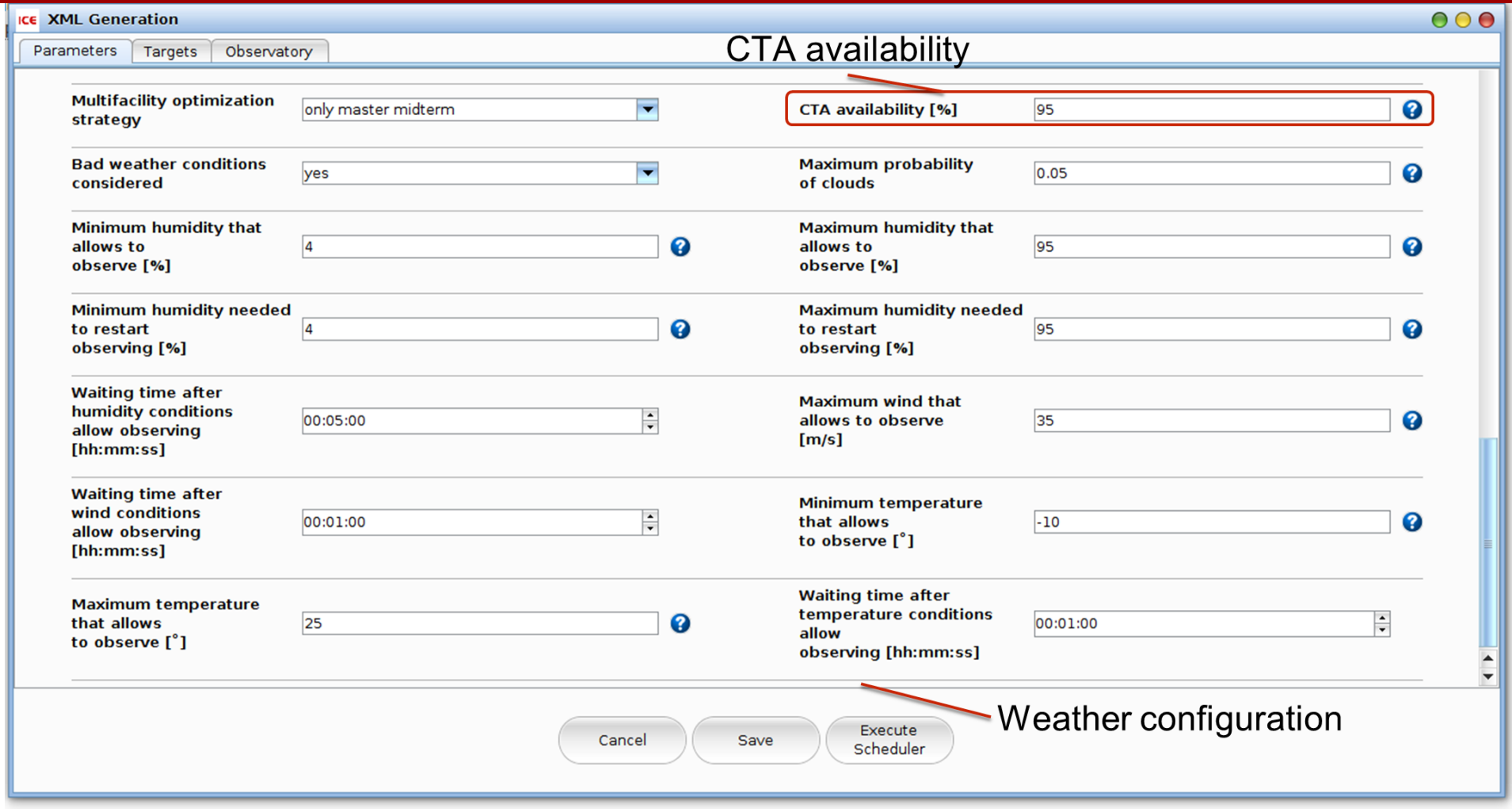
- Real weather conditions based on archival data using 2 years monitoring. Conditions to allow observations (configurable):
  - wind < 36 km/h
  - humidity between 4% and 95%
  - cloudless
  - temperature between -10 and 25 C
- Observations with partial Moon light are not considered in the time computation.
- Time distribution
  - T_S = 2062.25 h
  - $T_{Moonless}$ ~ 1676 h
  - $T_{UsableMoonless}$ ~ 1284 h (after weather selection)
  - $T_{Available}$ ~ 1220 h (CTA availability, according to reqs: 95% for science, 5% others)
- We simulated three programmes and surveys in 1 and 3 years full proprietary time.
- 1 subarrays and 3 types of telescopes (LST, MST, SST) - Configurable!

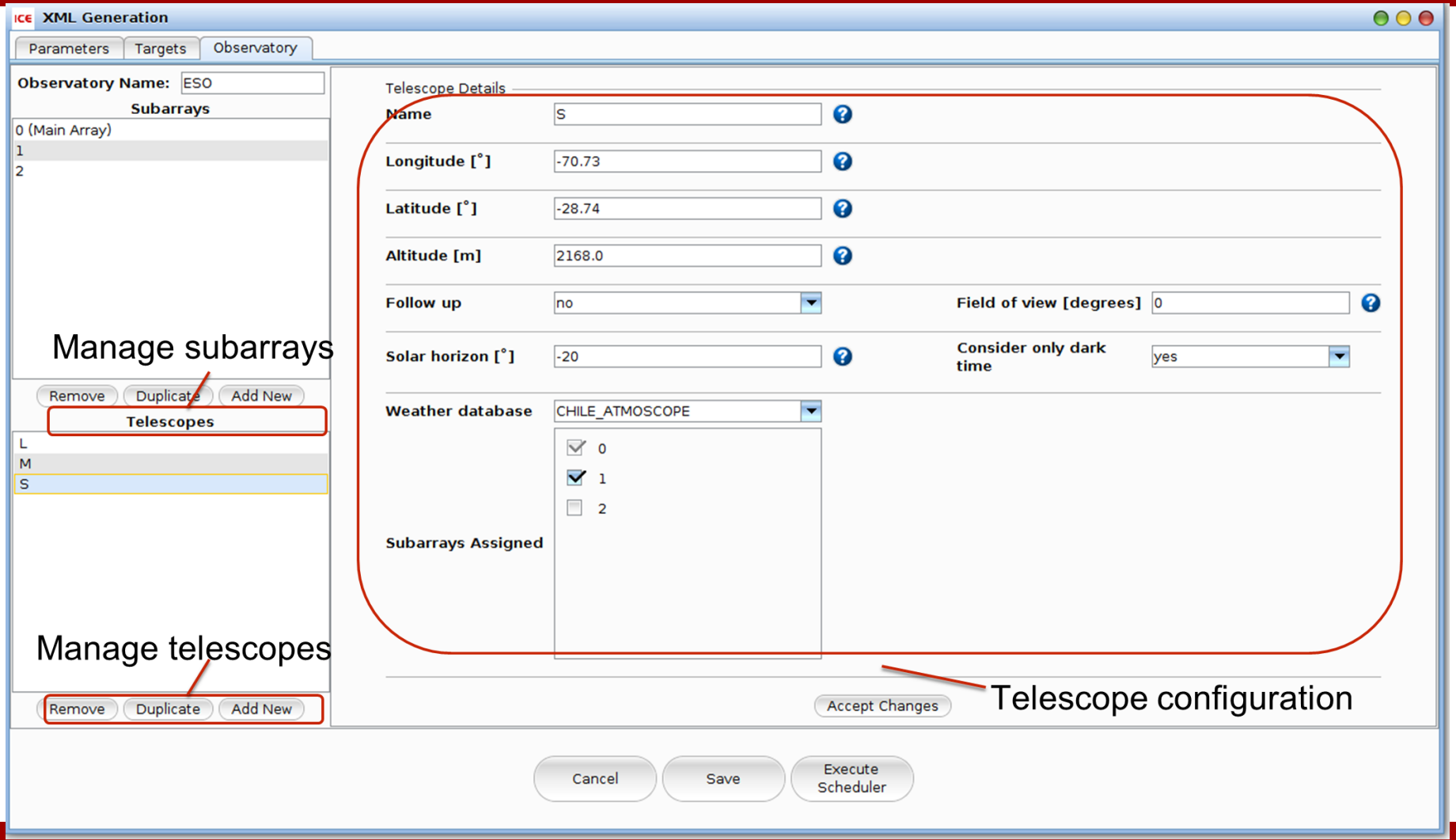
Two sites: Paranal in the South and La Palma in the North





(all figures are obtained from the SCTA soft)


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

Simulation Configurations

- Scenario
  - CTA South: 464 targets (3692.11 hours)
  - 1 year scheduling and 3 years scheduling
  - 4 subarrays and 3 types of telescopes (LST, MST, SST)
    - Targets assigned to subarrays according their type

Target Type	#Targets	Subarrays Assigned
SURVEY 1	170	0 (LST + MST + SST)
SURVEY 2	231	1 (LST + MST)
SURVEY 3	20	2 (MST + SST)
SURVEY 4	5	2 (MST + SST)
SURVEY 5	38	3 (LST)

Comparison of Strategies

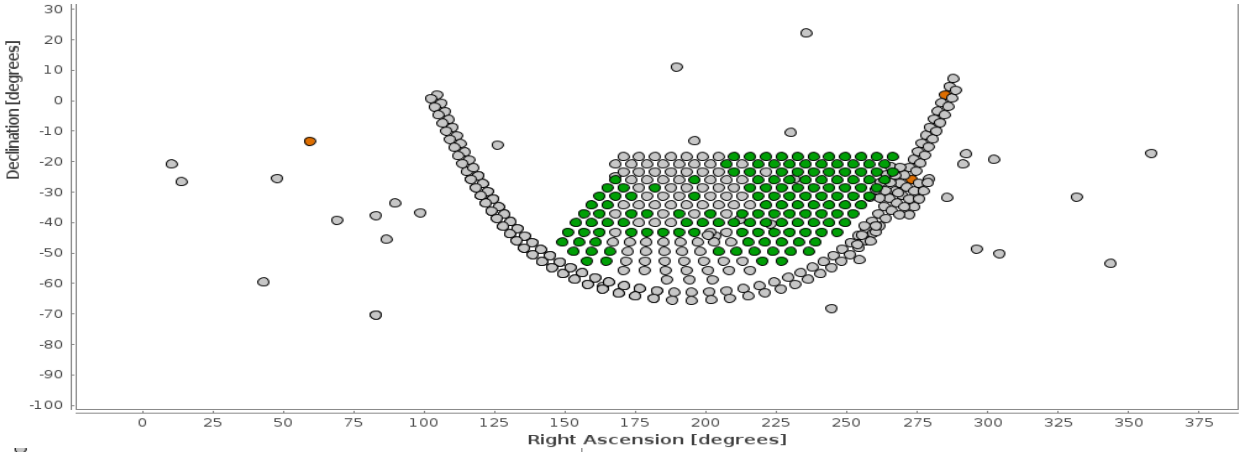
- Results (according all subarrays)
  - Observation time metric
    - GA: 3609 observations (1168 hours)
    - MOEA: 4271 observations (1359.68 hours)
  - Slew time metric
    - GA: 8.32% of the working time* (104.7 hours)
    - MOEA: 2.62% of the working time* (34.26 hours)

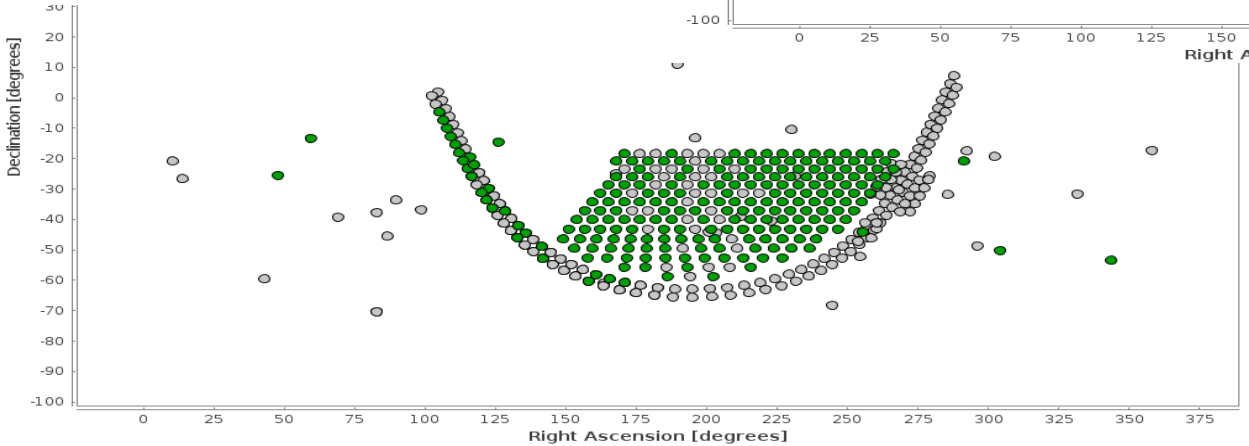
* Working time: slew time + observation time

- Execution time
  - Around 5 hours to simulate the 1 year scenario

Comparison of Strategies

- Target Status
  - GA





  - MOEA

Comparison of Strategies

- Proposal point of view
  - MOEA allows to complete more objects than GA because it performs more observations

Target Type	#Targets	GA #Planned (#Completed)	MOEA #Planned (#Completed)
SURVEY 1	170	167 (0)	170 (27)
SURVEY 2	231	231 (140)	231 (195)
SURVEY 3	20	20 (0)	20 (0)
SURVEY 4	5	5 (0)	5 (1)
SURVEY 5	38	37 (0)	38 (6)

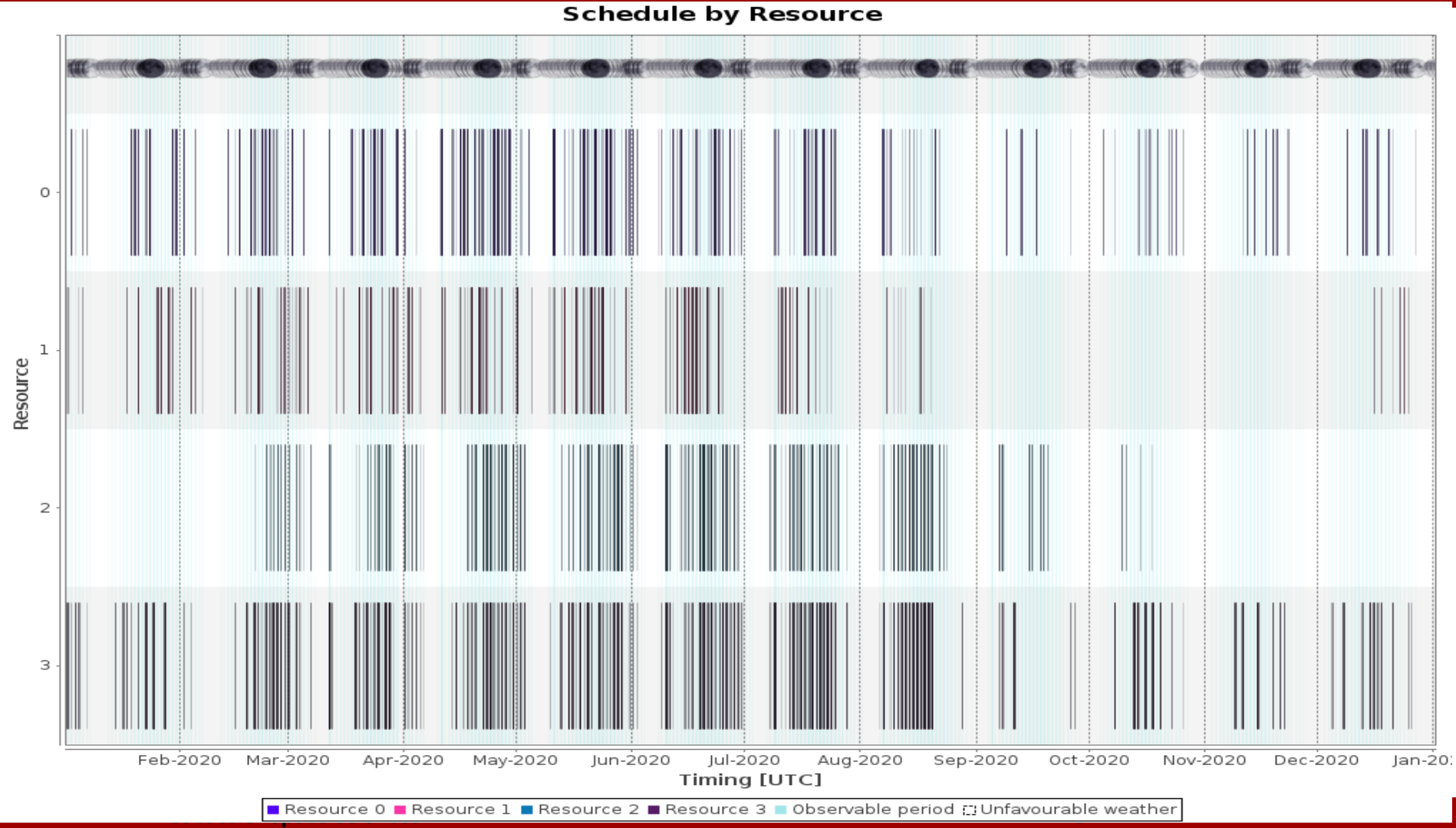
Optimization strategies

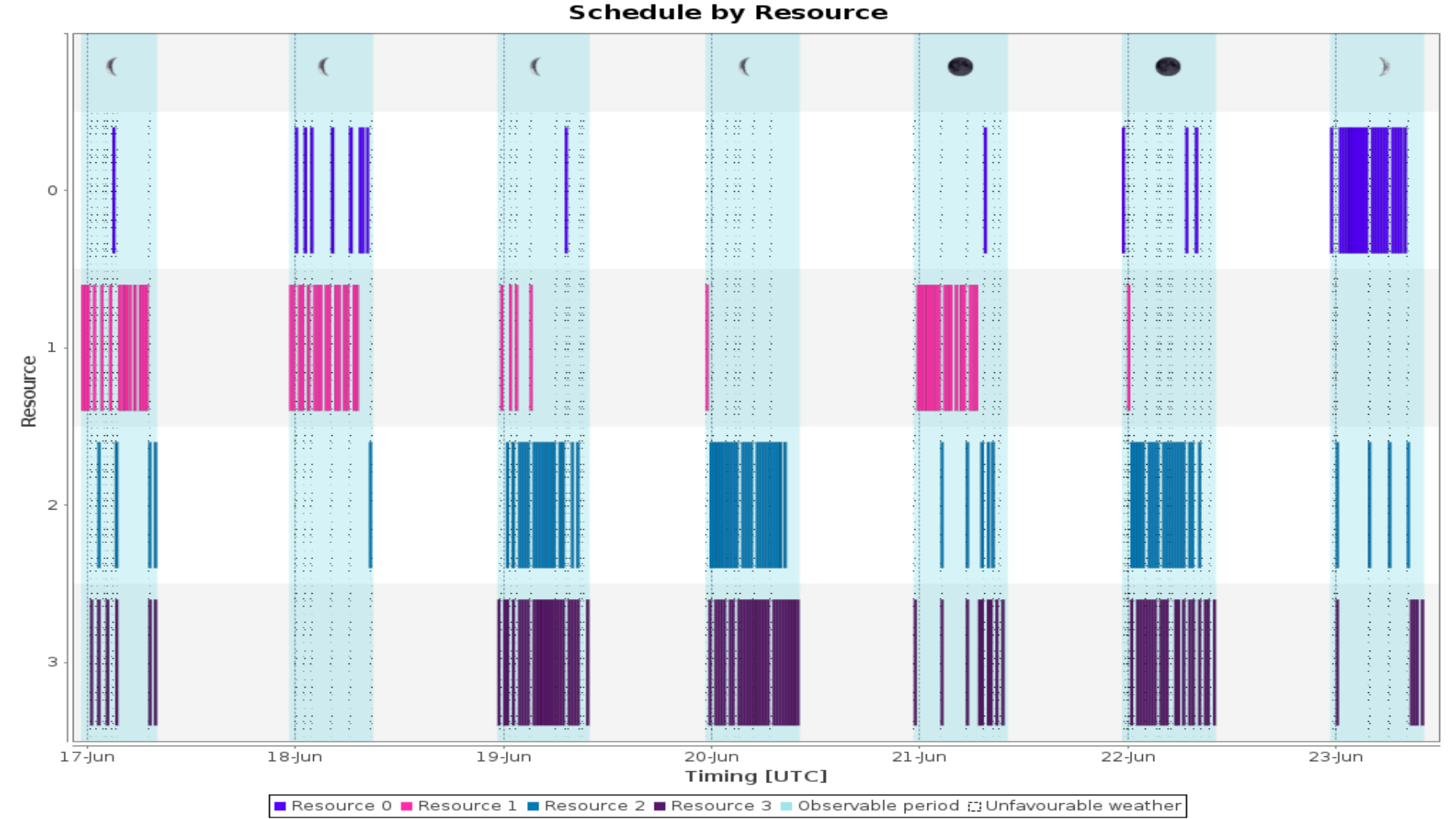
– GA

Subarrays	Required Time (h)	#Observations	Working Time (h)	Slew (% of WT)
0 (LST + MST + SST)	1557.75	865	313.88	8.14
1 (LST + MST)	200.01	602	220.28	8.90
2 (MST + SST)	550.00	719	261.81	8.46
3 (LST)	1384.35	1423	514.33	7.78

– MOEA

Subarrays	Required Time (h)	#Observations	Working Time (h)	Slew (% of WT)
0 (LST + MST + SST)	1557.75	1108	376.86	2.00
1 (LST + MST)	200.01	660	230.13	4.40
2 (MST + SST)	550.00	800	271.45	1.76
3 (LST)	1384.35	1703	581.14	2.32


Schedule by Resource
Resource
0
1
2
3
Feb-2020
Mar-2020
Apr-2020
May-2020
Jun-2020
Jul-2020
Aug-2020
Sep-2020
Oct-2020
Nov-2020
Dec-2020
Timing [UTC]
Resource 0
Resource 1
Resource 2
Resource 3
Observable period
Unfavourable weather


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

MOEA –3 years

- 3 years: 2993.71 hours available (≈1000 hours/year)

Target Type	#Targets	#Planned (#Completed)
SURVEY 1	170	170 (38)
SURVEY 2	231	231 (231)
SURVEY 3	20	20 (20)
SURVEY 4	5	5 (5)
SURVEY 5	38	38 (31)

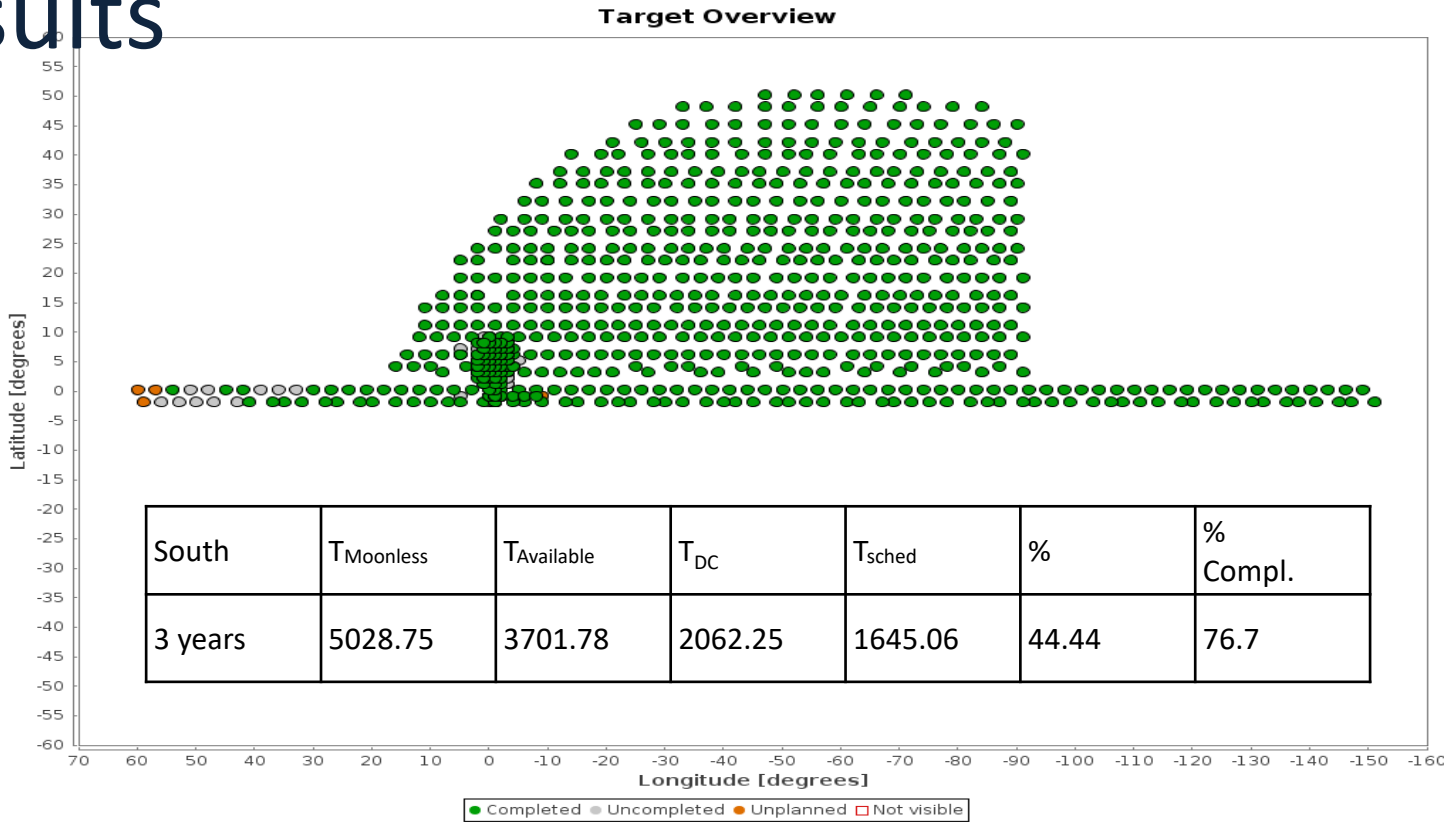
Subarrays	Required Time (h)	#Observations	Working Time (h)	Slew (% of WT)
0 (LST + MST + SST)	1557.75	2012	685.76	2.20
1 (LST + MST)	200.01	697	243.80	4.70
2 (MST + SST)	550.00	1653	559.65	1.55
3 (LST)	1384.35	2913	992.24	2.14

Results

Completed

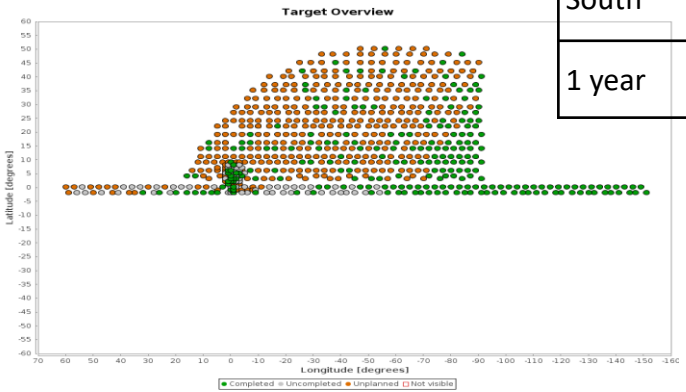
Uncompleted

Unplanned

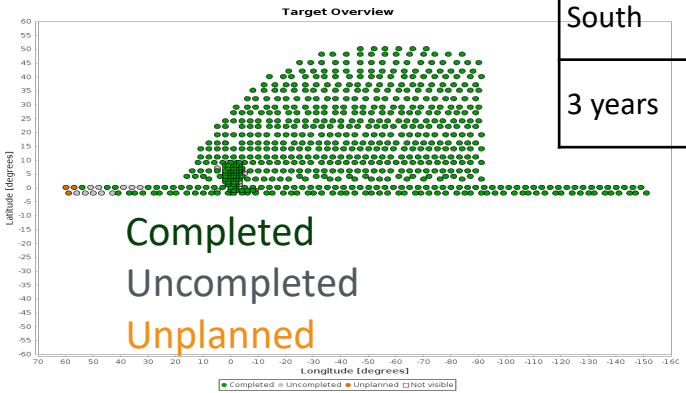


South	$T_{Moonless}$	$T_{Available}$	T_{DC}	T_{sched}	%	% Compl.
3 years	5028.75	3701.78	2062.25	1645.06	44.44	76.7

Results

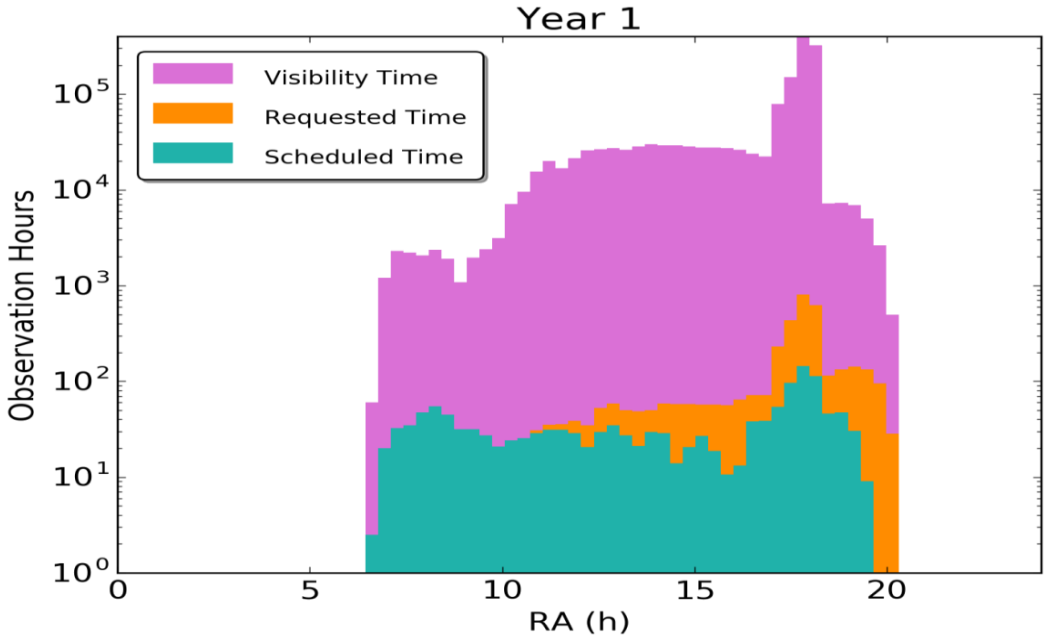


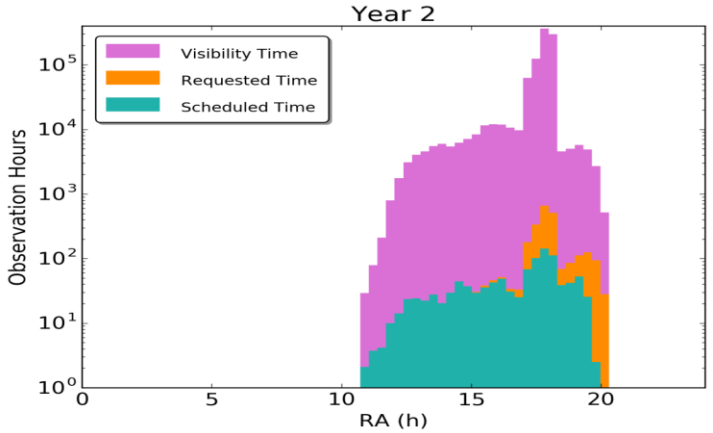
South	$T_{Moonless}$	$T_{Available}$	T_{DC}	T_{sched}	%	% Compl.
1 year	1679.52	1219.70	2062.25	739.03	60.62	34.7

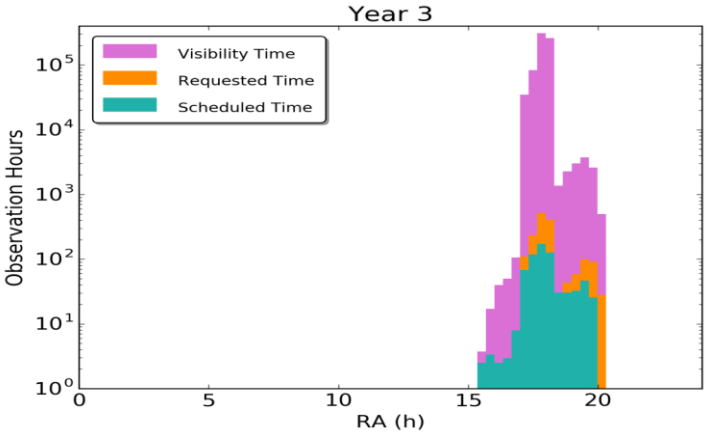


South	$T_{Moonless}$	$T_{Available}$	T_{DC}	T_{sched}	%	% Compl.
3 years	5028.75	3701.78	2062.25	1645.06	44.44	76.7

Results - 3 years







Results - 3 years visibility