# Earth Observation Scheduling MILP Formulation

## Sets and Indices

* **S**: Set of satellites. Each satellite can perform observations and downlinks.
* **T**: Set of targets. These are points or areas of interest to be observed.
* **G**: Set of ground stations. Each satellite can send data to ground stations during downlink windows.
* **K**: Set of observation time slots. Discrete time periods when observations can occur.
* **L**: Set of downlink time slots. Discrete time periods when downlinks can occur.
* **C**: Set of combined time slots (all observation and downlink slots), i.e. . This combined set is used for tracking satellite memory and power over time.

## Parameters

* **Data production per observation** ( GB): The amount of data generated by any observation.
* **Maximum downlink per window** ( GB): The upper bound on data that can be sent in a single downlink slot.
* **Max observations per satellite per day** ( ): Each satellite is limited to at most 5 observations in the scheduling horizon (interpreted here as one day).
* **Power capacity** ( Wh): Maximum battery capacity of each satellite.
* **Power per observation** ( Wh): Energy consumed to perform one observation.
* **Power per downlink** ( Wh per GB): Energy consumed to downlink one gigabyte of data.
* **Charge rate** ( Wh per slot): Amount of energy the satellite recharges in one slot when in sunlight.
* **Memory capacity** ( for each satellite ): Maximum onboard memory of satellite (given by input).
* **Target values** ( , for each target ): Each target has an urgency and importance factor; their product is used to value observing that target once.
* **Visibility windows** ( ): Equals 1 if satellite can observe target at time slot (based on orbital geometry), 0 otherwise.
* **Downlink windows** ( ): Equals 1 if satellite can downlink to ground station at time slot .
* **Recharge windows** ( ): Equals 1 if satellite is in sunlight (and thus can recharge) during slot .

## Decision Variables

* : Equals 1 if satellite **observes** target during time slot , 0 otherwise. This binary variable schedules each possible observation.
* : Equals 1 if satellite **downlinks** data to ground station during time slot , 0 otherwise. This binary variable schedules each possible downlink.
* : Continuous variable for the amount of data (in GB) downlinked from satellite to ground station at slot . This represents how much data is actually sent, up to the capacity of the link.
* : Onboard memory (in GB) stored on satellite at the end of time slot . This tracks accumulated observation data minus what has been downlinked.
* : Battery power (in Wh) available on satellite at the end of time slot . This tracks power consumption and recharging over time.

Each decision variable captures a control action (observe, downlink) or a state (memory, power) over time.

## Objective Function

Maximize the total mission value, composed of:  
- **Observation value**: Each scheduled observation of target contributes to the objective. Formally,

The combined objective is:

## Constraints

* **Visibility (VTW) constraint:**
* This ensures a satellite can only observe a target at times when it is visible (line-of-sight exists). If , then must be 0.
* **Observation limit per satellite:**
* Each satellite can make at most a fixed number of observations in the schedule.
* **Single observation per target:**
* Ensures each target is observed at most once (no duplicate observations by different satellites).
* **Memory balance (dynamics):** For each satellite and each time slot in chronological order, memory is updated by adding data from new observations and subtracting data downlinked:
* **Initial slot** :
* (This implicitly assumes initial memory was 0 at the very start.)
* **Subsequent slots** : If is the previous slot,

This ensures memory tracks all collected data minus what has been transmitted. The logic is to accurately account for data storage on-board.

* **Memory capacity:**
* The onboard memory cannot exceed the satellite’s capacity. This prevents scheduling more observations than can be stored.
* **Power (energy) balance:** Similar to memory, power evolves over time:
* **Power capacity bounds:**
* Ensures the satellite’s battery level is never negative and never exceeds its maximum capacity. This, together with the balance equations, prevents scheduling activities when insufficient power is available.
* **Downlink window constraint:**
* A downlink can only be scheduled if that satellite-to-ground-station link is available at time .
* **Data-downlink linking:**
* If (no downlink scheduled), then must be 0. If , then the data sent can be up to the maximum . This ties the continuous downlink amount to the binary decision.
* **Ground station conflict:**
* At most one satellite can use a given ground station at any time slot . This prevents collisions in ground station usage.
* **Satellite downlink exclusivity:**
* Each satellite can downlink to at most one ground station at a time. This means a satellite cannot simultaneously transmit to multiple stations in the same slot.