Development of a Dark and Quiet Skies (DQS) Module

Swiss SKA days 2023

WHAT IS THE SPACE SUSTAINABILITY RATING (SSR)?

Encouraging space actors to **design & implement sustainable & responsible space missions** for the long-term **sustainability of the space environment**

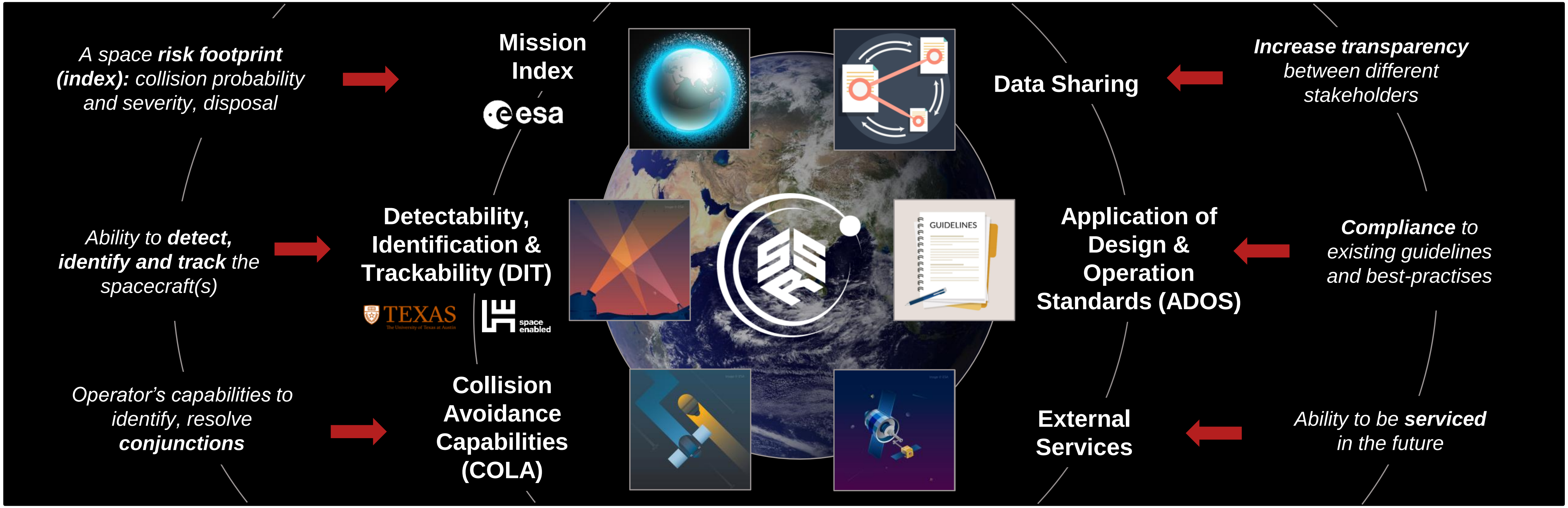
A METRIC FOR SPACE SUSTAINABILITY

Aggregation of mission parameters into a **rating label:**

- **Assessing** mission’s **impact** on the space environment;
- **Recognizing efforts** by satellite operators; and
- **Incentivizing** sustainable building and operation practises

Tier level	**Tier** Score
Platinum	Between 81% and 100%
Gold	Between 71% and 80%
Silver	Between 56% and 70%
Bronze	Between 40% and 55%

A SHORT OVERVIEW OF THE SSR MODULES



2022-2023: Development of a Dark and Quiet Skies module

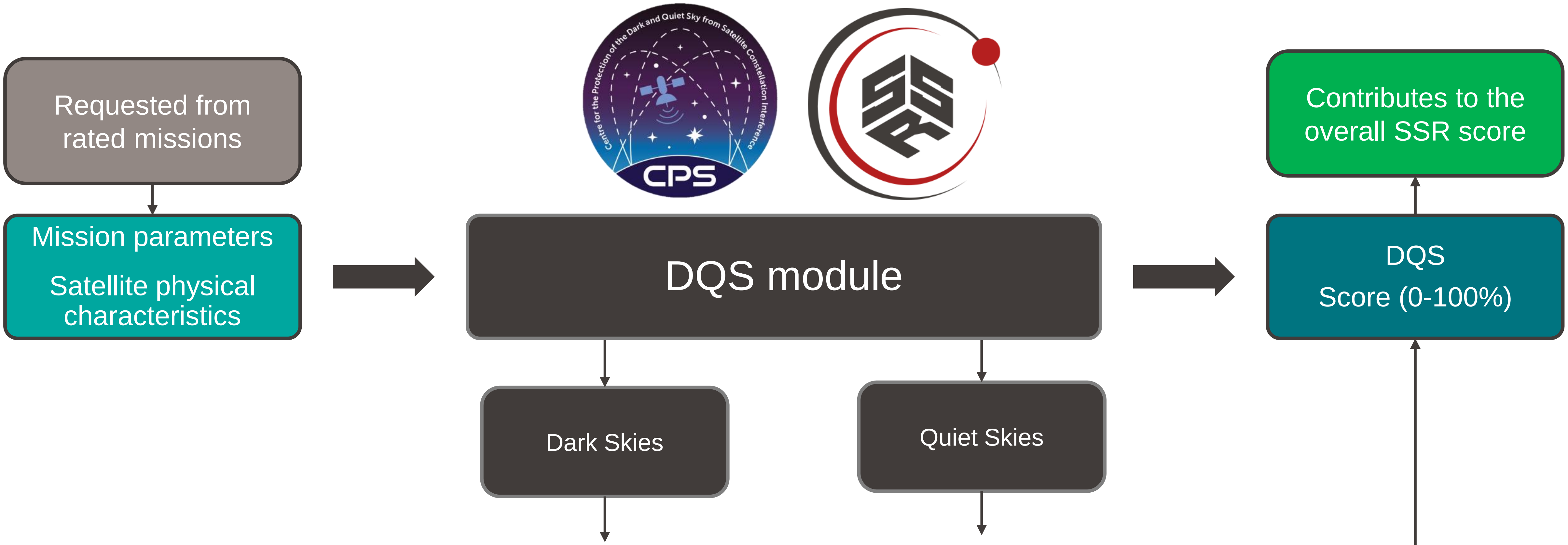
Participating in the IAU CPS Policy Hub (WP n°3)

- Phase I: July-August 2022
  - Internship: Literature review

- Phase II: September-December 2022
  - Semester projects: Preliminary module definition

- Phase III: February-June 2023
  - Semester Project and Master Thesis: Preliminary definition of module's sub-components (Dark Skies, Quiet Skies)
  - **Milestone:** First conference paper to be published at IAU Symposium 385 "Astronomy and Satellite Constellations: Pathways Forward". 2-6 October 2023.

Dark and Quiet Skies Module: in a nutshell



$$\gamma_{Dark} * Score_{Dark} + \gamma_{Quiet} * Score_{Quiet}$$

γ_{Dark} and γ_{Quiet} weights to be defined

HERITAGE FROM THE DETECTABILITY MODULE

- Python code framework:
  - Simulate ground stations, simulate satellite(s)
  - Satellite propagation for desired duration
  - Retrieve access periods (for optical or radio purposes)
  - For optical only: Compute the VM of the satellite(s) for different access periods above the defined ground station, retrieve the time stepped values
  - Some limitations! → computation time and satellite's albedo parameter

- Phase III scope:
  - **Dark Skies**: define a scoring function based on the existing python framework
  - **Quiet Skies**: define a RFI **quantification** methodology

Dark skies

- Goals of the Dark Skies module:
  - Enhance the Python framework;
  - Define a scoring function based on the existing python framework; and
  - Study the impact of mission parameters to provide recommendations to operators

- $Score_{Dark}$ in three parts:
  - $Score_{\mathrm{Design}}$: Impact at spacecraft level (i.e., Visual-magnitude wise)
  - $Score_{Aggregated}$: Aggregated impact at mission level (i.e., data-loss wise)
  - $Score_{Questionnaire}$ = Impact of other parameters (other non-quantitative criteria that can be used in a compliance/non compliance questionnaire)

$$Score_{Dark} = \gamma_1 S_{Design} + \gamma_2 S_{Aggregated} + \gamma_1 S_{Questionnaire}$$

γ_1, γ_2 and γ_3 are weights to be defined

Dark skies

- $\underline{Score_{Design}}$ definition:
  - mag_{min} = Minimum apparent magnitude (brightest)
  - mag_{avg} = Average apparent magnitude
  - mag_{diff} = Margin around the IAU recommendation for minimum visual magnitude*
  - ω_0 = “Reward” for being over (fainter) the IAU recommendation for minimum visual magnitude*
  - ω_1 = Weight of the minimum magnitude function
  - ω_2 = Weight of the average magnitude function
  - ω_3 = Steepness of the logarithm

$$Score_{Design} = w_0 f(mag_{min}) + w_1 g(mag_{min}) + w_2 g(mag_{avg})$$

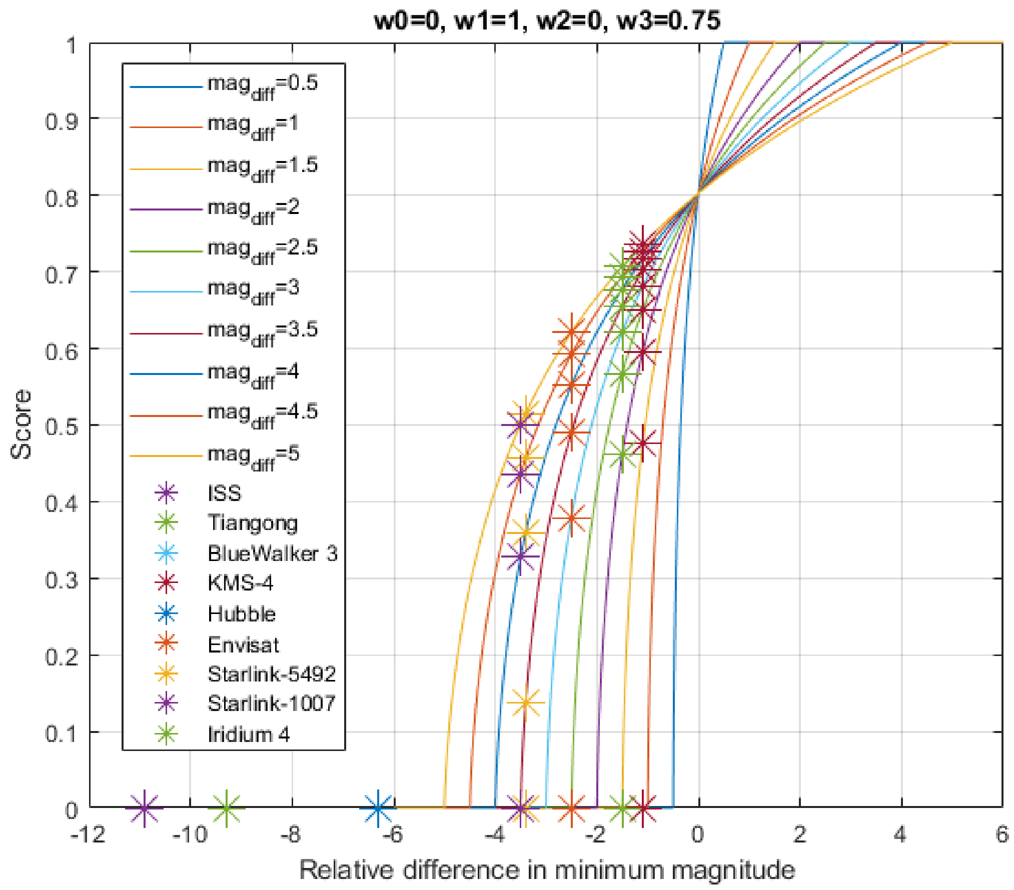
$$f(x) = \begin{cases} 0 \; for \; x < mag_{rec} \\ 1 \; for \; x \geq mag_{rec} \end{cases}$$

$$g(x) = \begin{cases} 0 \; for \; x < mag_{rec} - mag_{diff} \\ log_{10}(9 * (\frac{x - mag_{rec} + mag_{diff}}{2 * mag_{diff}})^{w_3} + 1) \; for \; |x - mag_{rec}| \leq mag_{diff} \\ 1 \; for \; x > mag_{rec} + mag_{diff} \end{cases}$$

* Sat_Con-5: $Min_{VM} \geqq 7 + 2.5 \log_{10}(h/550)$ https://www.iau.org/static/publications/uncopuos-stsc-crp-8jan2021.pdf

Dark skies

- Plot for different mag_{diff} for different spacecrafts*:
  - ISS
  - Tiangong
  - BlueWalker 3
  - KMS-4
  - Hubble
  - Envisat
  - 2 different generations of Starlink
  - Iridium 4



*Magnitudes from heavens-above.com as a preliminary test for the scoring function

Quiet skies

Goals:

1. **Quantify** the impacts, two scoring categories were pre-identified:
    - **Proportion of time above a** Radio Frequencies Interference threshold: Comparison of the satellite power flux density to the radio observatory (using it's the SEFD parameter over its integration time window)
    - **Number of frequency channels** (average) perturbed by satellites when above the interference threshold

2. Propose solutions to lower the satellite(s) impact on Earth ground stations <u>during the design phase</u>:
    - Depends on the mission characteristics (orbital plane, altitude, radio emission power, frequencies, shutdown systems presence, ...)

SEFD: System Equivalent Flux Density. Standard sensitivity / performance metric for a telescope

Quiet skies

- Created a fast and reliable and ergonomic framework where one can simulate the impact of one or several satellites with respect to a given set of radio ground stations.
- Adapted the code to be fully configurable by using a configuration file where all satellite and ground station parameters are entered and can be changed between 2 simulations

Next steps: Validate the program with realistic data for radio GS and satellites against a professional tool.

Use Case	Initial Code runtime [s]	New Code runtime [s]	Speed Up
First run	1260	30	4,200%
Consecutive runs with small modifications	1260	0.5	252,000%

Work has been done to make the program multi-threaded and multi-processed for run time reduction

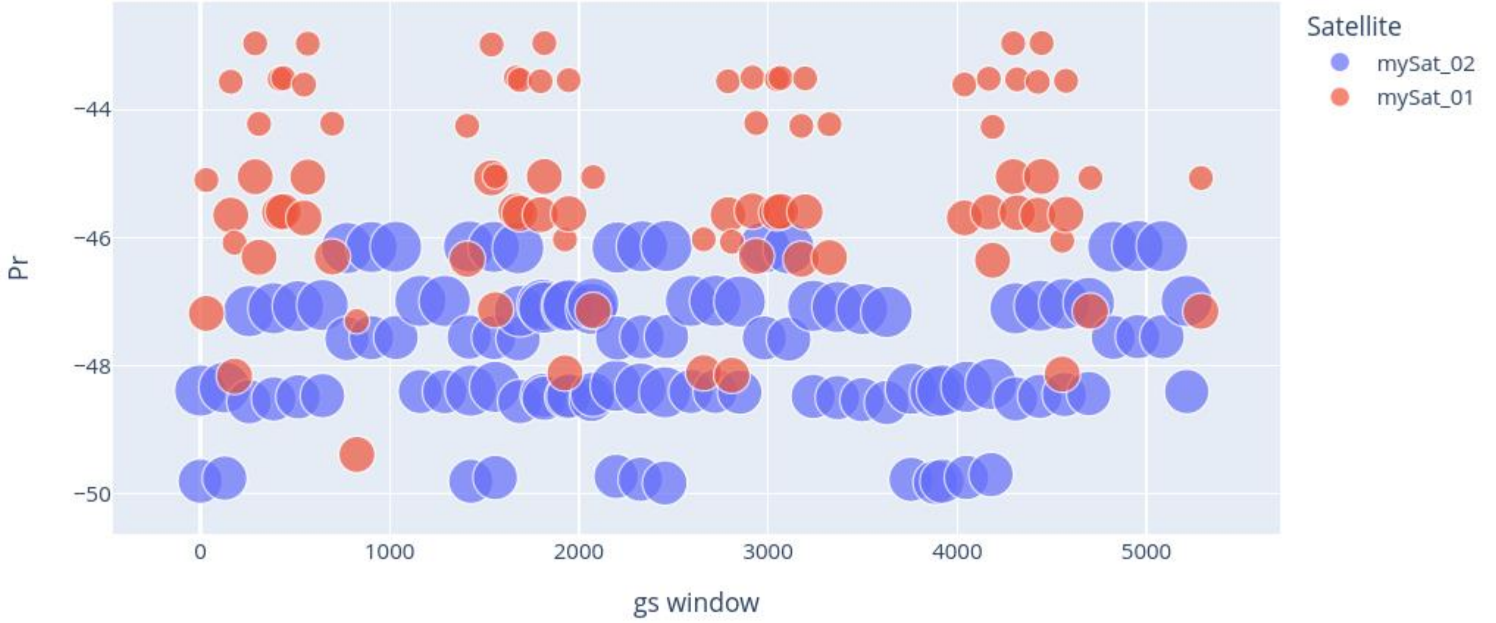

```yaml
global_sim:
  out_dirname: sim_out # if not present,
  start_date: 2020-10-06 16:00:00.000 #
  stop_date: 2021-02-06 15:59:59.999 # f
  time_resolution: 10 # in seconds
radio_stations: # if the radio telescope is a baseline, co
  SKA:
    location: { lat: -37.603, lon: 140.388, alt: 13.851 }
    field_of_view: 30 # [°]
    radio:
      Gr: 6 # [dBW] in function of theta
      Gr_max: 15 # [dBW]
      frequency_range: [[2.e+6, 2.1e+9], [3.e+9, 3.1e+9]]
      SEFD: 5.5e+6 # [Jy]
      channel_bandwidth: 50 # [kHz] should be smaller than
      integration_time: 2000 # [s] must be a multiple of t
  VLBA:
    location: { lat: 0.0, lon: 0.0, alt: 1.1 }
    field_of_view: 12.5
    radio:
      Gr: 0 # [dBW] in function of theta
      Gr_max: 10 # [dBW]
      frequency_range: [[2.e+6, 2.1e+9], [3.e+9, 3.1e+9]]
      SEFD: 8.e+5 # [Jy]
      channel_bandwidth: 2.e+3 # [Hz]
      integration_time: 1000
```

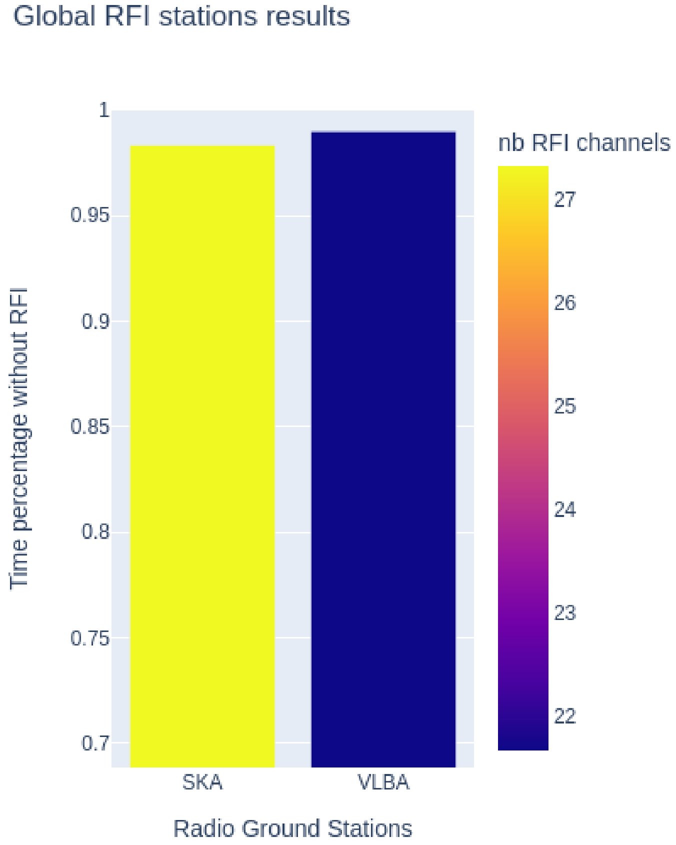

Configuration example for Radio telescopes (numbers taken arbitrarily)

Quiet skies

Results:

- The size of the dots represent the number of frequency channels undergoing RFI for a given satellite (designated by the dot color).
- Each dot represents a radio RFI for a whole integration time window (which might of different length from one radio telescope to another)





Disclaimer: data shown on the graphs come from fake/random satellite & radio telescope input parameters, and whose sole purpose is to show the plot rendering. Please, do not take these results as realistic.

CONCLUSION

- Preliminary definition of a framework to quantify satellite impacts, account for efforts by operators, and assign a score allowing to incentivize satellite operators to account for their impact on astronomy;

- Next steps includes further definition of modules sub-components and validation of the developed framework

- All this activity is unfunded and mainly performed by students: if you think that it is interesting and should be pushed further, **please get in contact**!

GET IN TOUCH

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