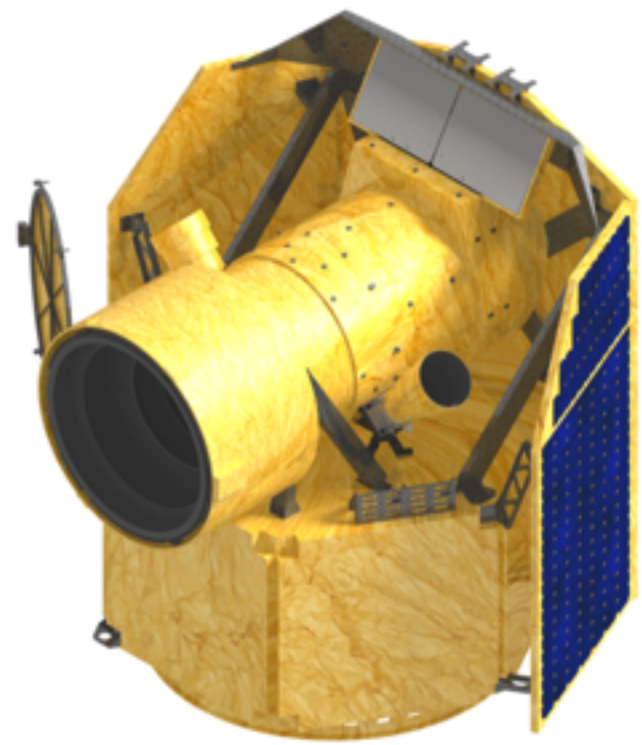


Mission Planning

and the Feasibility Checker

Nicolas Billot
CHEOPS Operations Scientist
University of Geneva

Mission Planning Overview

Mission Planning ⟷ Scheduling of spacecraft activities (mostly science observations) that satisfy various constraints

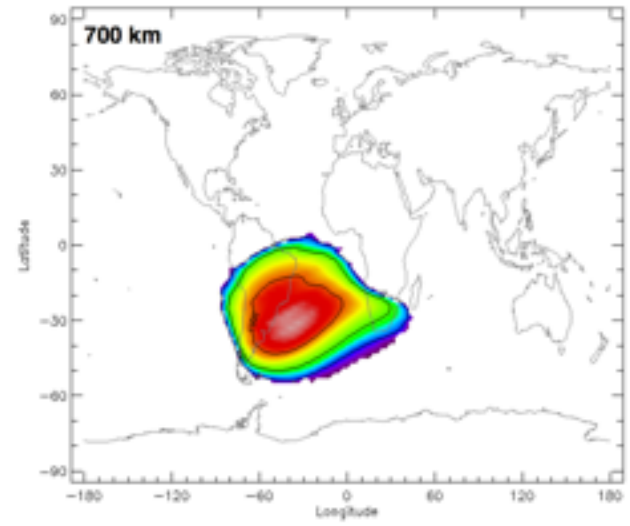
Of relevance to CHEOPS observers:

- Observing constraints (physical constraints)
  See D. Ehrenreich's presentation
- Scheduling constraints (competition with other observations)

Observing Constraints

- Low Earth orbit
  - Frequent crossing of the South Atlantic Anomaly (strong radiation zone)

South Atlantic Anomaly



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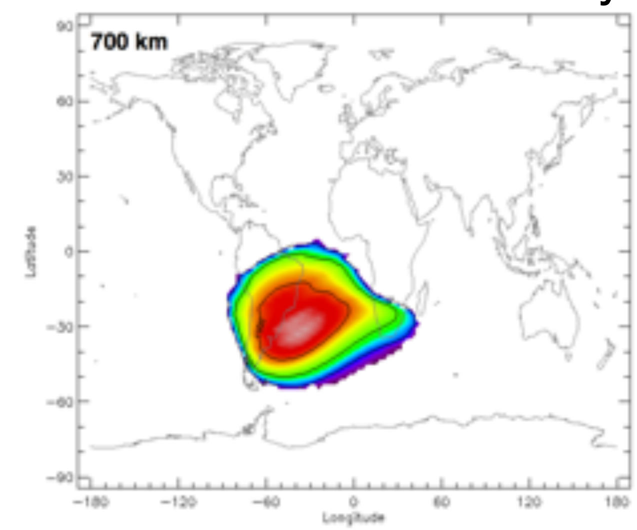
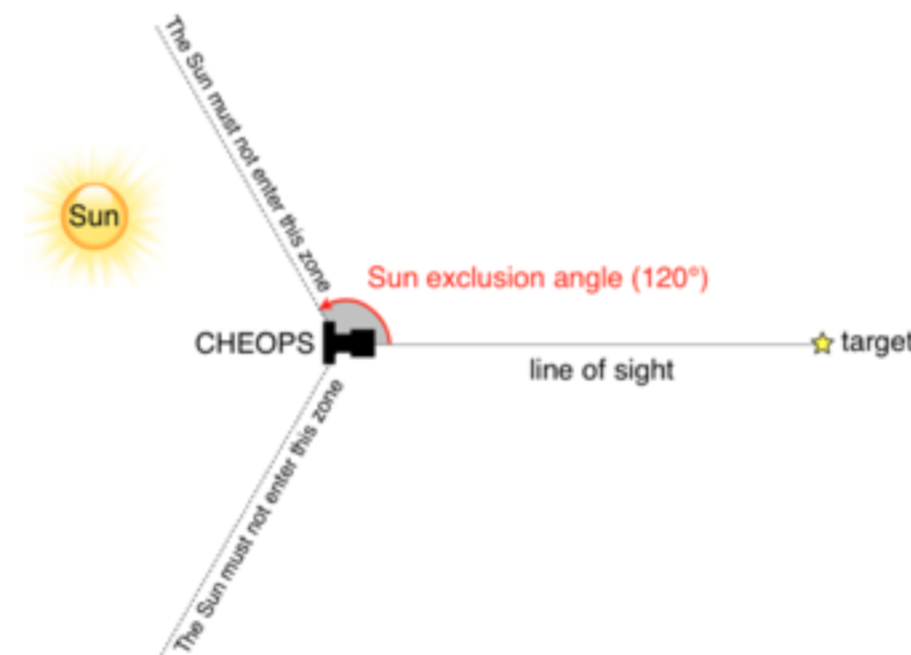
South Atlantic Anomaly



- Low level of stray light required for precision photometry:
  - Sun avoidance angle = 120 degrees



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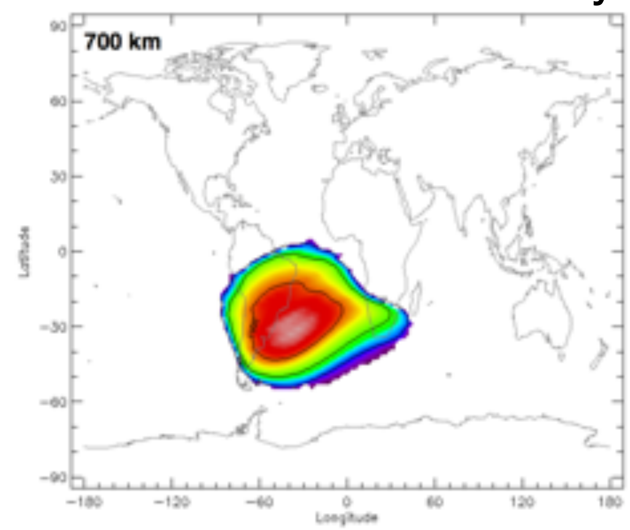
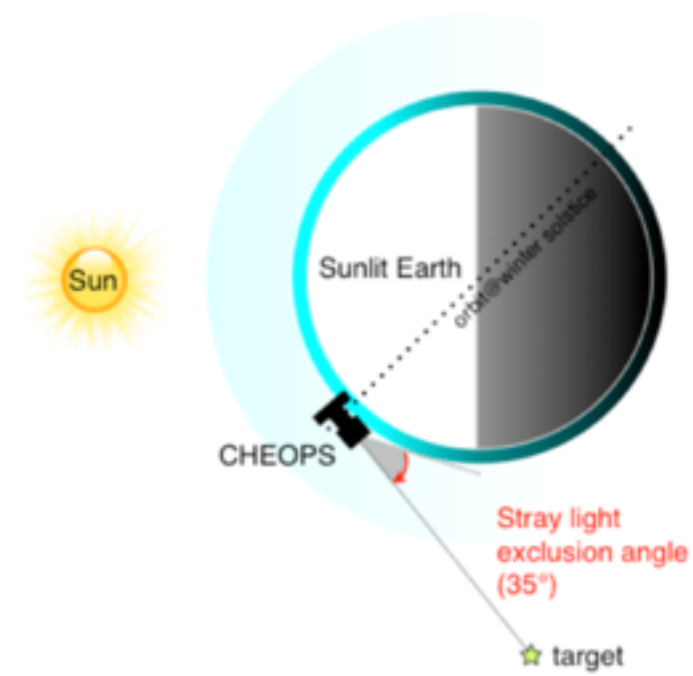
South Atlantic Anomaly



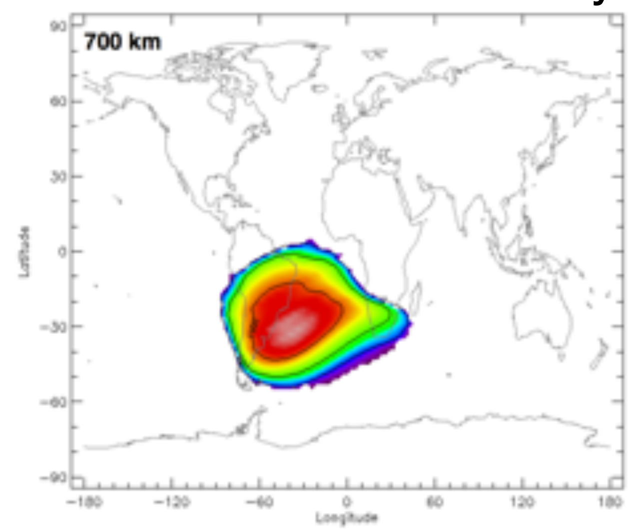
- Low level of stray light required for precision photometry:
  - Sun avoidance angle = 120 degrees
  - Earth illuminated limb exclusion angle = 35 degrees



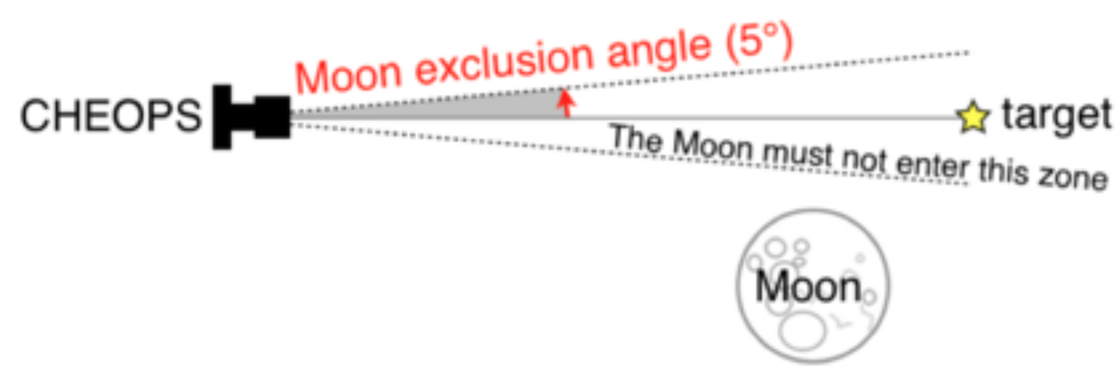
Observing Constraints

- Low Earth orbit
  - Frequent crossing of the South Atlantic Anomaly (strong radiation zone)

South Atlantic Anomaly



- Low level of stray light required for precision photometry:
  - Sun avoidance angle = 120 degrees
  - Earth illuminated limb exclusion angle = 35 degrees
  - Moon exclusion angle = 5 degrees



Scheduling Constraints

- Competition with other science observations
  - Time-constraints associated with transiting planets
  - Science priority (see next slide)
  - GTO/GO/DDT balance (see K. Isaak's presentation)
  - Over-subscription (required for higher scheduling efficiency)

Scheduling Constraints

- Competition with other science observations
  - Time-constraints associated with transiting planets
  - Science priority (see next slide)
  - GTO/GO/DDT balance (see K. Isaak's presentation)
  - Over-subscription (required for higher scheduling efficiency)
- Accommodate for non-science activities
  - Monitoring & Characterisation (see A. Deline's + R. Alonso's presentation)
  - Platform requests (spacecraft maintenance, expected to be rare)
  - Collision Avoidance manoeuvres (spacecraft orbit adjustment, expected to be rare)

Science Priorities

Three-level priority scheme:

A : high priority science (high profile / urgent)

Undersubscription to limit scheduling conflicts / visits overlaps

=> expected high completion rate (tentatively above 80%)

B : Main science observations

Expected completion rate above 50% (depending on oversubscription)

C : Filler observations

Mostly non-time-constrained **short** observations

Expected low completion rate (below 30%, depending on oversubscription)

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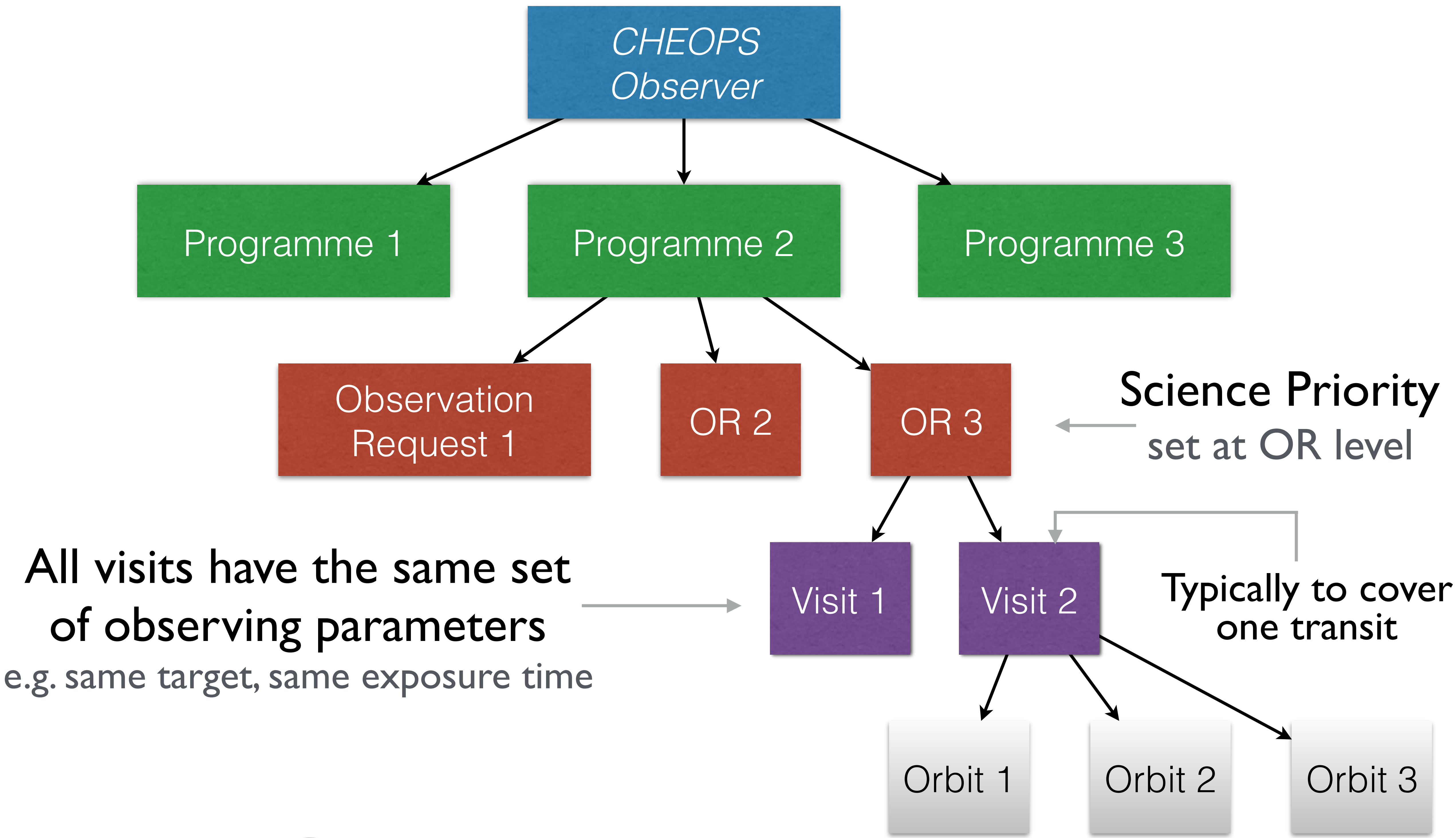
Programme - Observations Hierarchy



Schedule Optimisation

The observing schedule will be generated to maximise:

- **Science return**
  - Schedule as many visits as possible (satisfying observers' constraints)
  - Ensure timely completion of high priority observations
- **Telescope time**
  - Promote observations with highest observing efficiencies
  - Filler observations

A so-called *merit function* is defined in that sense, and it will be optimised with "*smart*" (genetic) algorithms.

Merit function computation includes:

- Science Priority
- GO/DDT-to-GTO ratio
- Overall timeline filling factor
- Observing efficiency of individual visits
- Completion of individual observation requests

Mission Planning Simulations

Mission Planning prototype developed for test purposes

Relevant parameters were explored for their impact on scheduling performances

Feasibility

Relevant at individual visit level

Schedulability

Relevant for competition during schedule optimisation

- Number of visits
- Observing efficiency
- Critical phase ranges
- Visit duration
- Start-phase slack
- GO/GTO
- Relative fraction of A-to-B observations
  (aiming at 80+% completion rate for A-grades)
- Oversubscription of A+B
- Number/duration of filler observations

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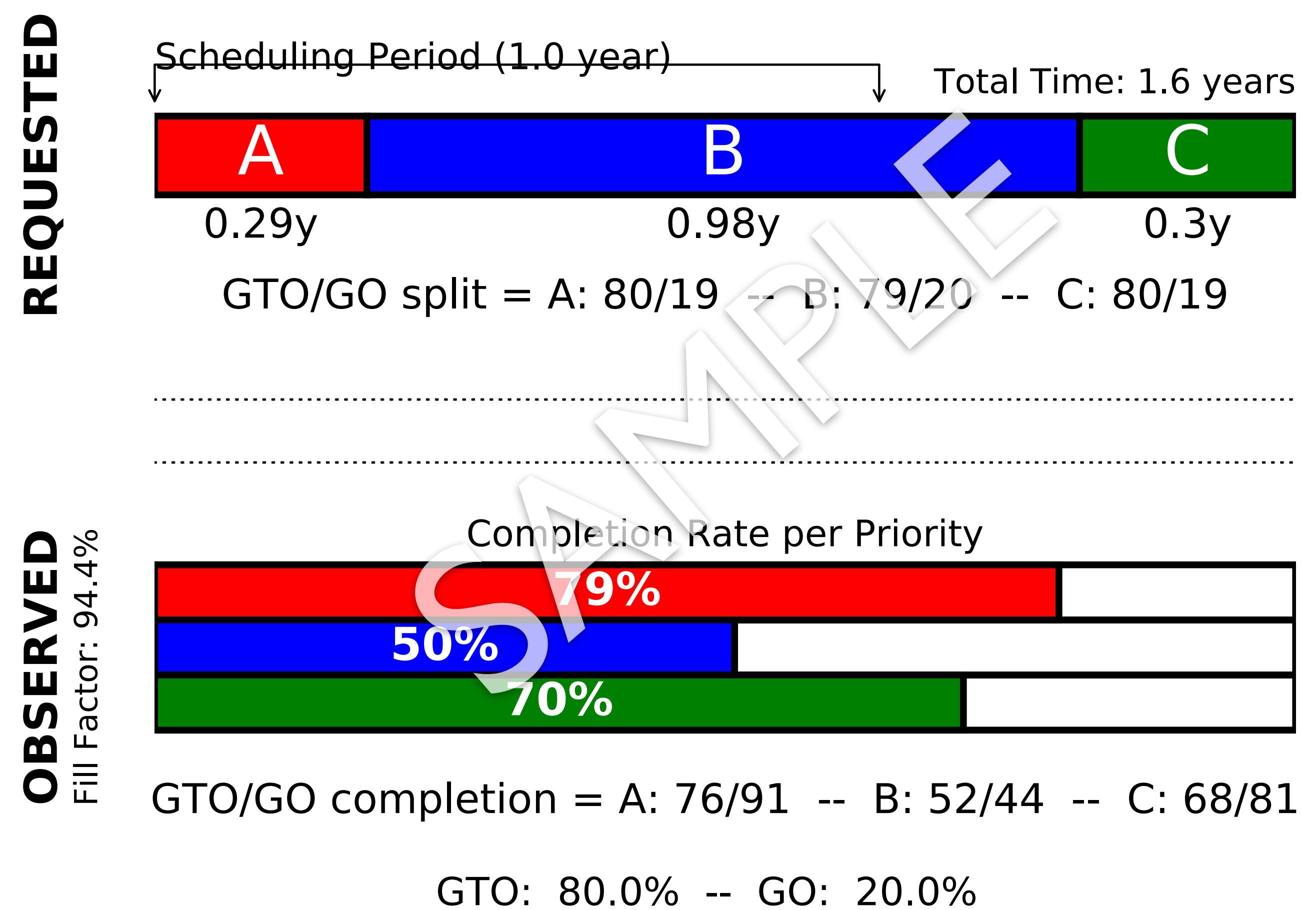
Mission Planning Simulations

Test dataset:

1.6 years of *synthetic* observation requests with realistic priority and GO/GTO distributions.

→ Generate a 1-year optimised schedule with the Mission Planning prototype



Mission Planning prototype performs as expected:

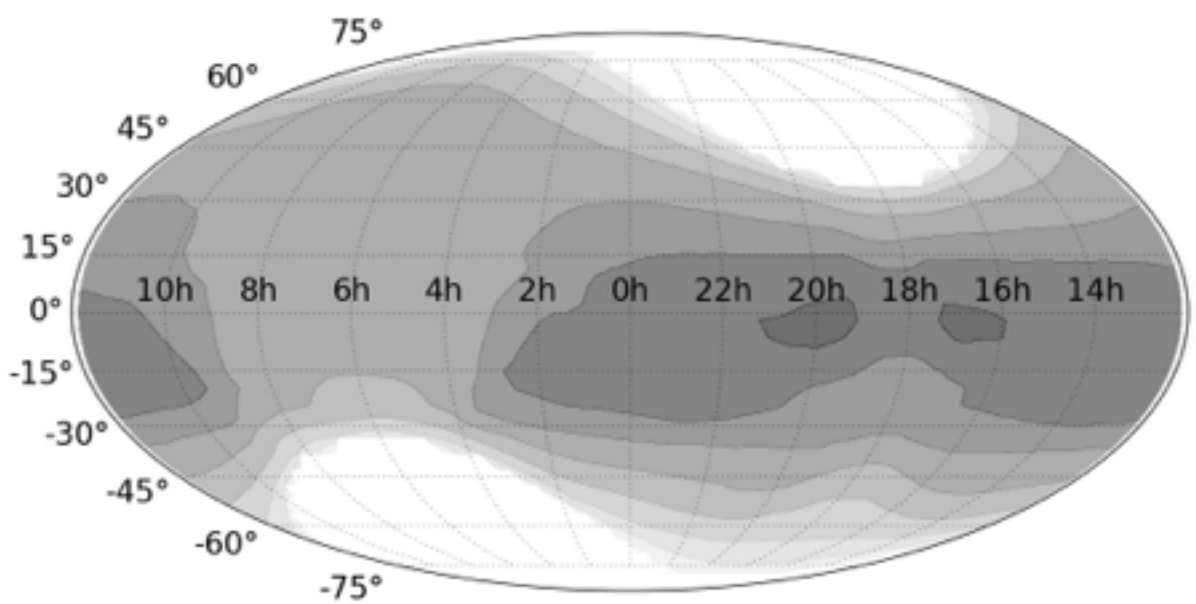
- High filling factors achieved
- High completion rate for A-rated observations
- GTO-to-GO ratio is respected

Mission Planning for Observers

Before applying for CHEOPS time:

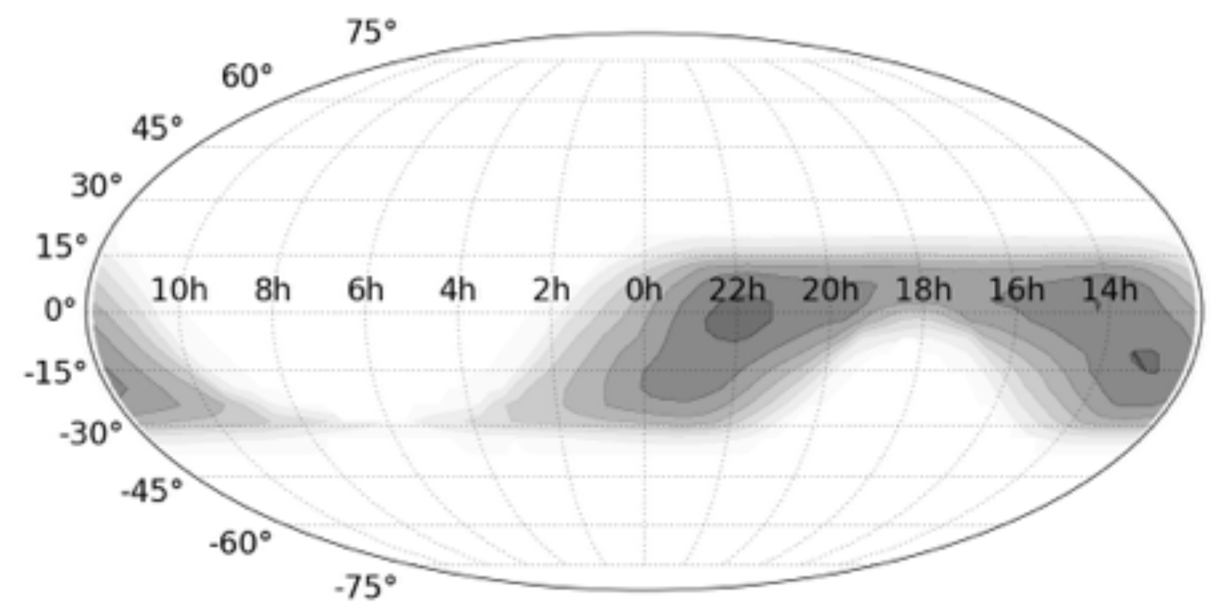
Is the target visible at all?

→ Check out the CHEOPS visibility maps



Most unconstrained / favourable case

Allows for high levels of stray light
(adequate for bright stars)
Over 50% of uninterrupted observation per orbit



Most restrictive / unfavourable case

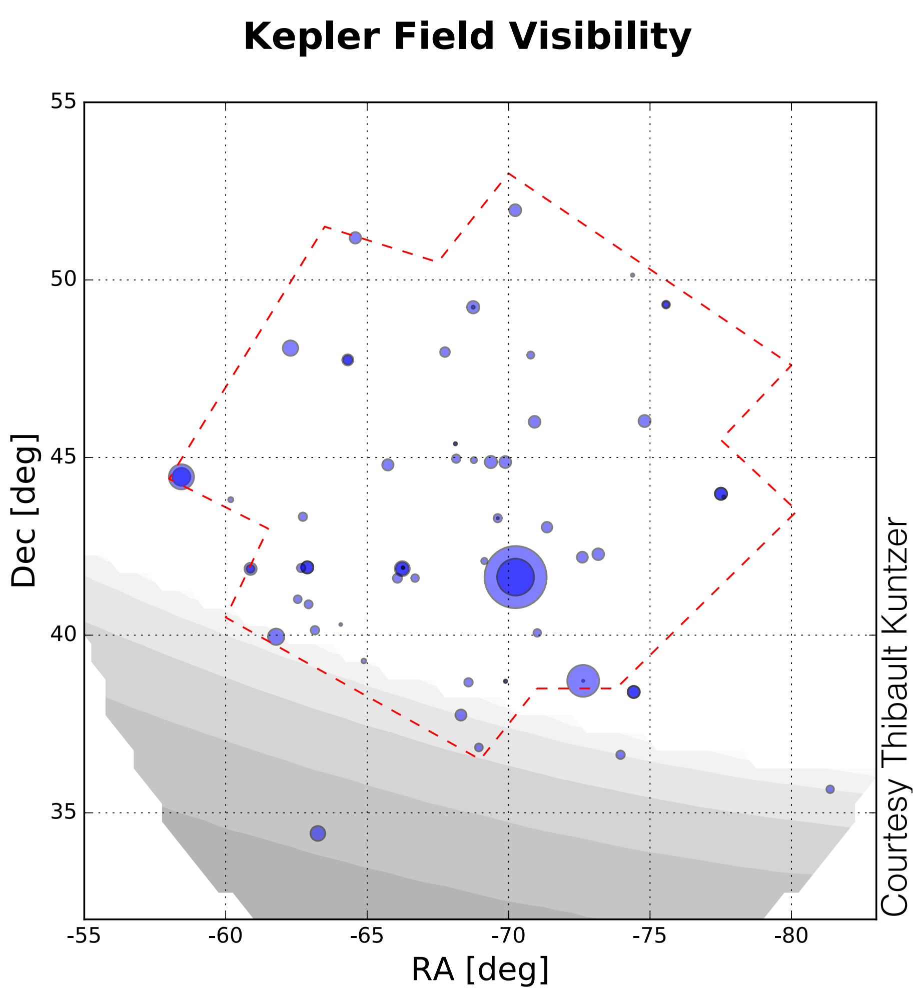
Allows for lower levels of stray light
(required for faint stars)
Over 80% of uninterrupted observation per orbit

Mission Planning for Observers

Before applying for CHEOPS time:

Is the target visible at all?

→ Check out the CHEOPS visibility maps



Most targets from the Kepler field are **not** visible by CHEOPS due to the Sun exclusion angle

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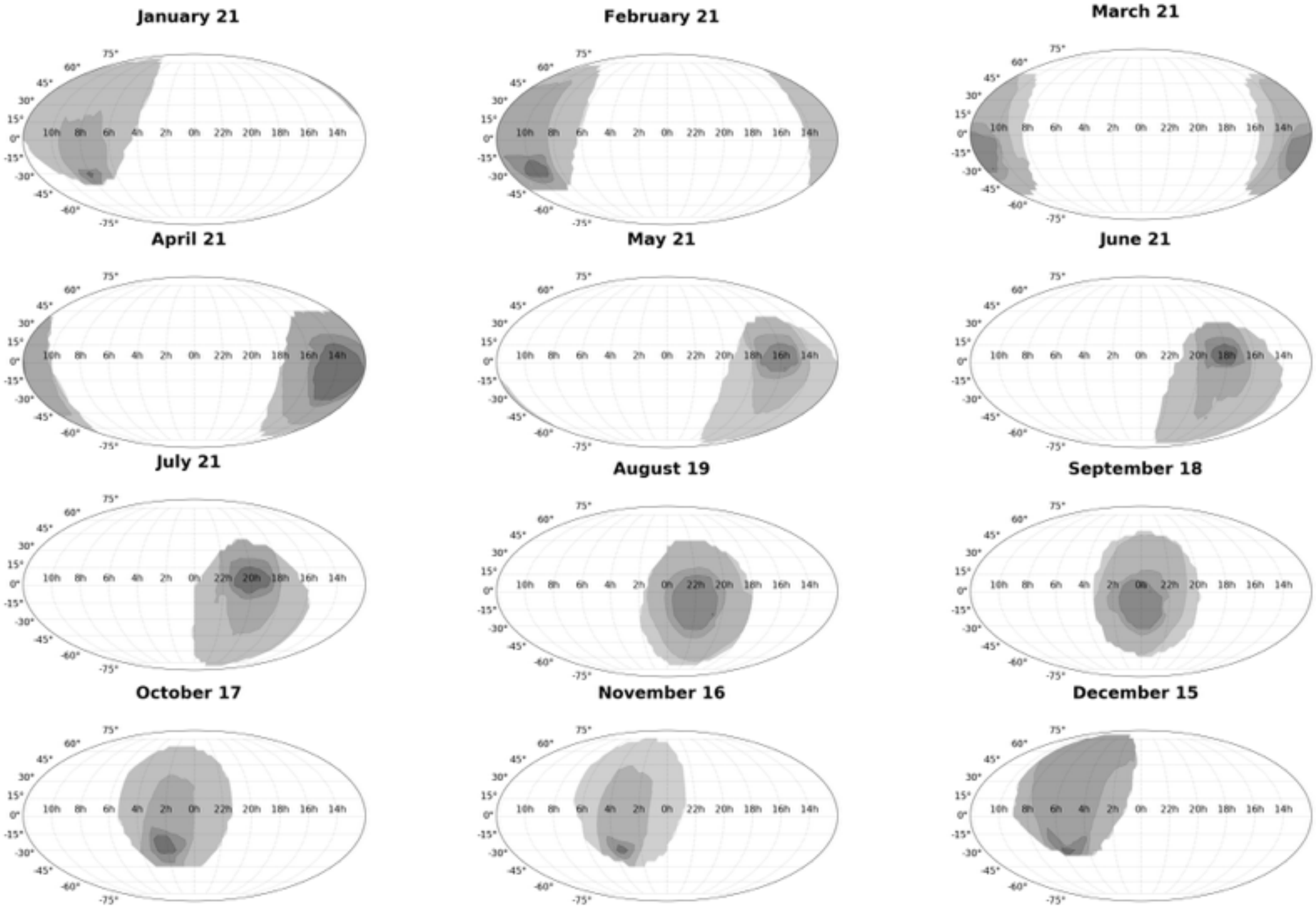
Mission Planning for Observers

Monthly sky visibility maps

When can my source be observed by CHEOPS?



Feasibility Checker (FC)

Tool to generate possible visits satisfying user-defined constraints

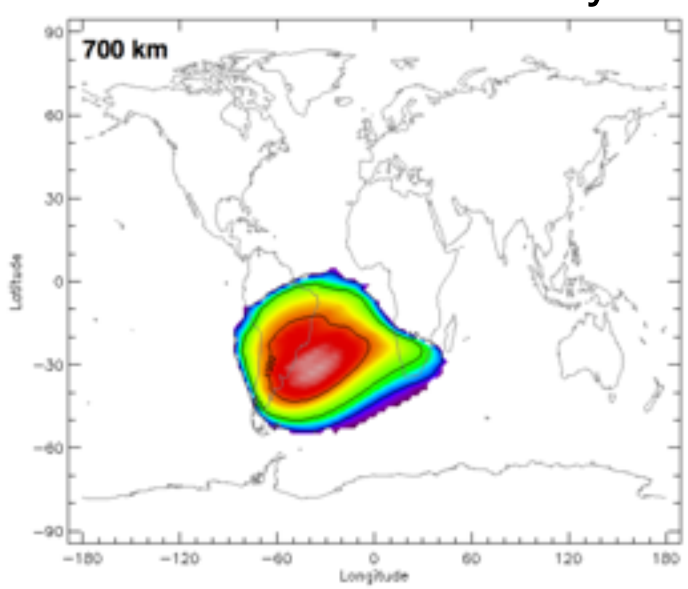
- Most functionalities already implemented
- Available to the community from 1st Announcement of Opportunity on
- FC used to check if an observation is feasible (≠ **will be scheduled**)
- FC results should be considered as **indicative only** (not binding)
- FC provides clues to evaluate if an observation is easy to schedule
  - Two major observation constraints can be checked with the FC:
    - visibility windows
    - "*reasonable*" observing efficiency (on-source time, excluding interruptions)

Feasibility Checker (FC)

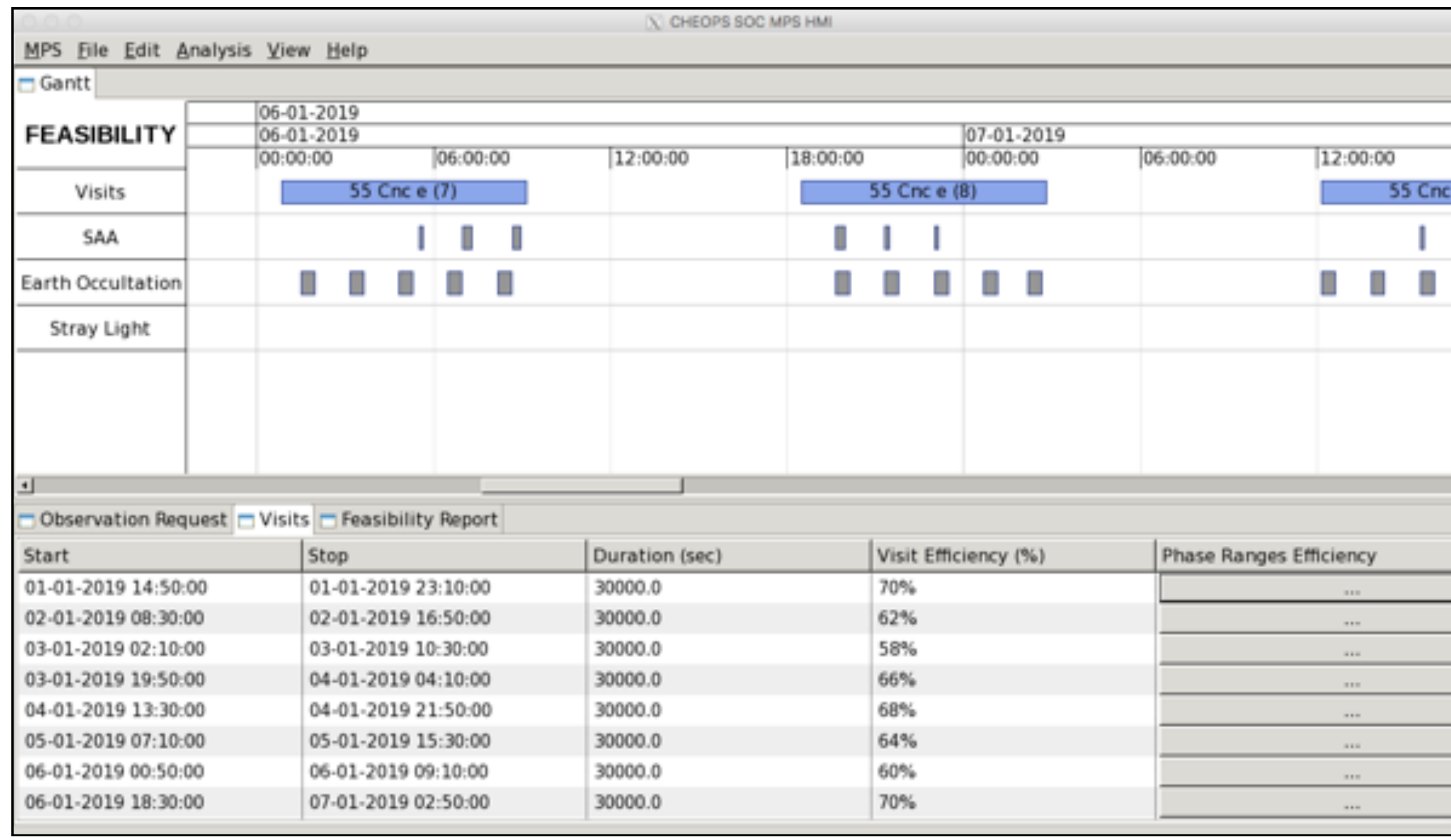
The Feasibility Checker is a powerful tool

- Born as a by-product of the Mission Planning System used for operations

South Atlantic Anomaly



Earth occultations



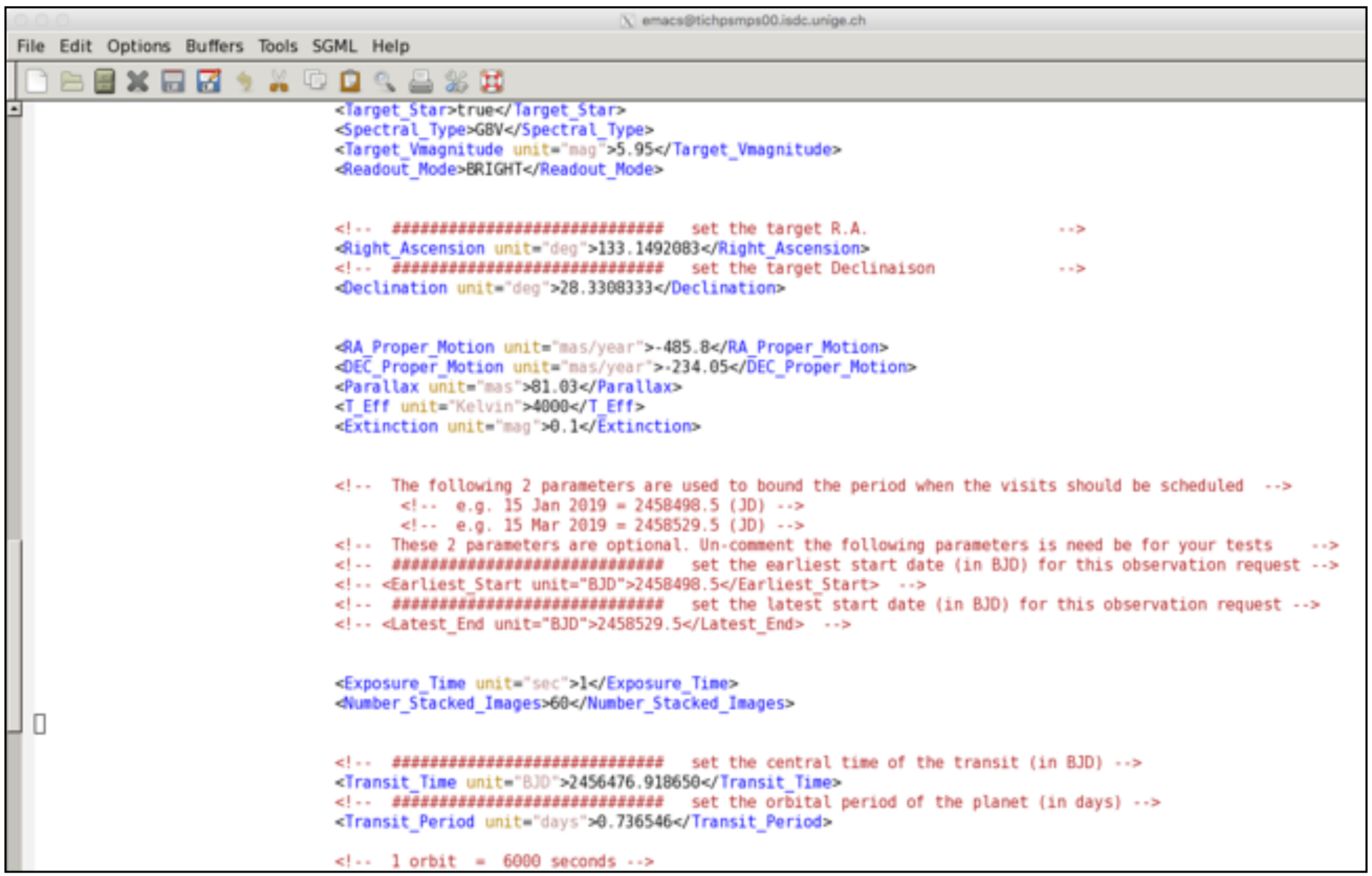
Start	Stop	Duration (sec)	Visit Efficiency (%)	Phase Ranges Efficiency
01-01-2019 14:50:00	01-01-2019 23:10:00	30000.0	70%	...
02-01-2019 08:30:00	02-01-2019 16:50:00	30000.0	62%	...
03-01-2019 02:10:00	03-01-2019 10:30:00	30000.0	58%	...
03-01-2019 19:50:00	04-01-2019 04:10:00	30000.0	66%	...
04-01-2019 13:30:00	04-01-2019 21:50:00	30000.0	68%	...
05-01-2019 07:10:00	05-01-2019 15:30:00	30000.0	64%	...
06-01-2019 00:50:00	06-01-2019 09:10:00	30000.0	60%	...
06-01-2019 18:30:00	07-01-2019 02:50:00	30000.0	70%	...

Start Stop Duration Efficiency Efficiency Phase Ranges

Feasibility Checker (FC)

The Feasibility Checker is a powerful tool

- Born as a by-product of the Mission Planning System used for operations
- But… it inherited the rigidity of a mission-critical system…

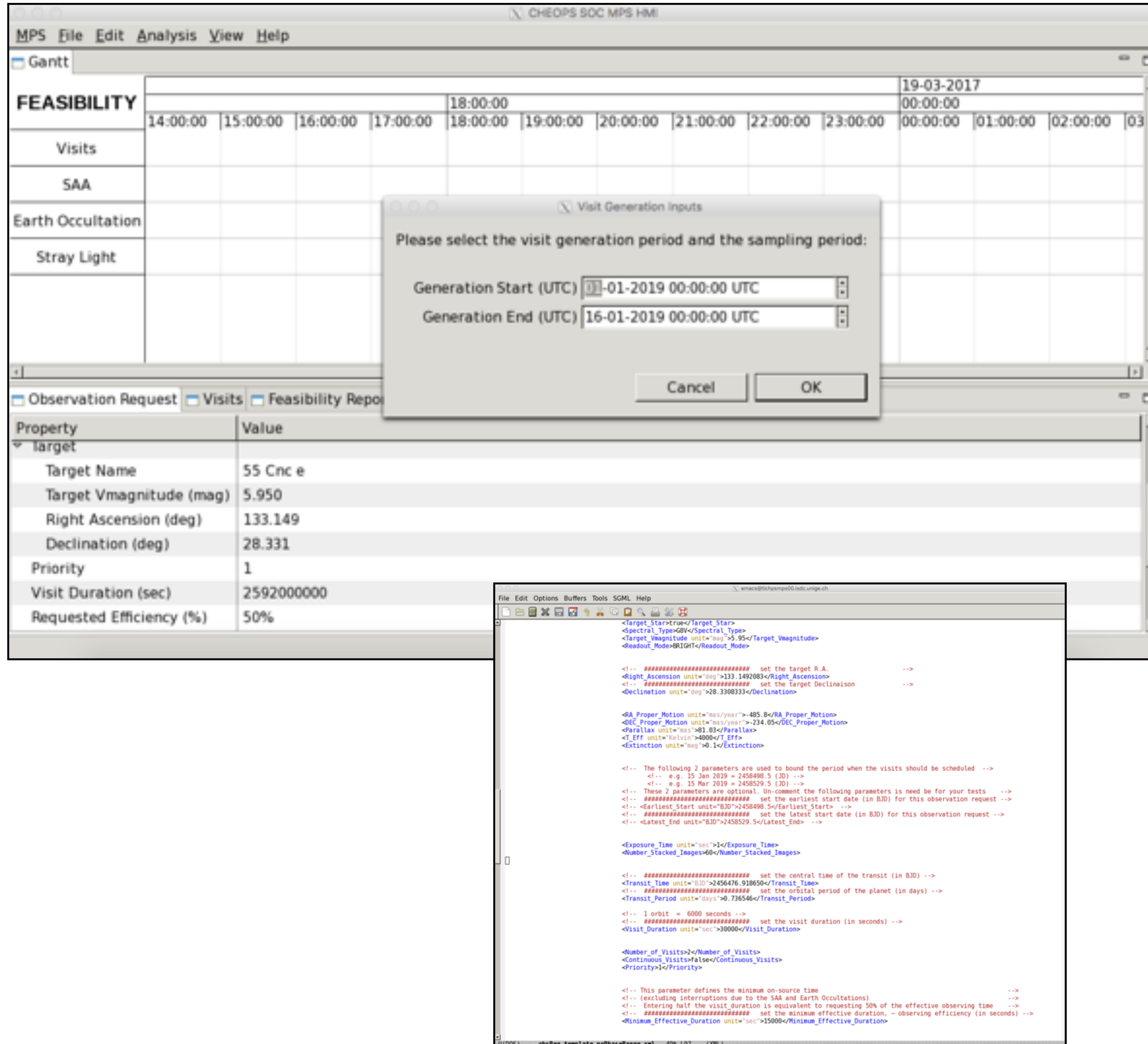



```
<Target_Star>true</Target_Star>
<Spectral_Type>G8V</Spectral_Type>
<Target_Vmagnitude unit="mag">5.95</Target_Vmagnitude>
<Readout_Mode>BRIGHT</Readout_Mode>

<!--  ##############################   set the target R.A.               -->
<Right_Ascension unit="deg">133.1492083</Right_Ascension>
<!--  ##############################   set the target Declinaison        -->
<Declination unit="deg">28.3308333</Declination>

<RA_Proper_Motion unit="mas/year">-485.8</RA_Proper_Motion>
<DEC_Proper_Motion unit="mas/year">-234.05</DEC_Proper_Motion>
<Parallax unit="mas">81.03</Parallax>
<T_Eff unit="Kelvin">4000</T_Eff>
<Extinction unit="mag">0.1</Extinction>

<!--  The following 2 parameters are used to bound the period when the visits should be scheduled  -->
      <!--  e.g. 15 Jan 2019 = 2458498.5 (JD) -->
      <!--  e.g. 15 Mar 2019 = 2458529.5 (JD) -->
<!--  These 2 parameters are optional. Un-comment the following parameters is need be for your tests    -->
<!--  ##############################   set the earliest start date (in BJD) for this observation request -->
<!-- <Earliest_Start unit="BJD">2458498.5</Earliest_Start>  -->
<!--  ##############################   set the latest start date (in BJD) for this observation request -->
<!-- <Latest_End unit="BJD">2458529.5</Latest_End>  -->

<Exposure_Time unit="sec">1</Exposure_Time>
<Number_Stacked_Images>60</Number_Stacked_Images>

<!--  ##############################   set the central time of the transit (in BJD) -->
<Transit_Time unit="BJD">2456476.918650</Transit_Time>
<!--  ##############################   set the orbital period of the planet (in days) -->
<Transit_Period unit="days">0.736546</Transit_Period>

<!--  1 orbit  =  6000 seconds -->
```

Feasibility Checker (FC)

Test Case on 55 Cnc:

- Short visit around transit of 55 Cnc e
- Any time in January 2019
- Requested visit duration of 4 orbits
- Requested min. efficiency of 75%



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Feasibility Checker (FC)

Test Case on 55 Cnc:

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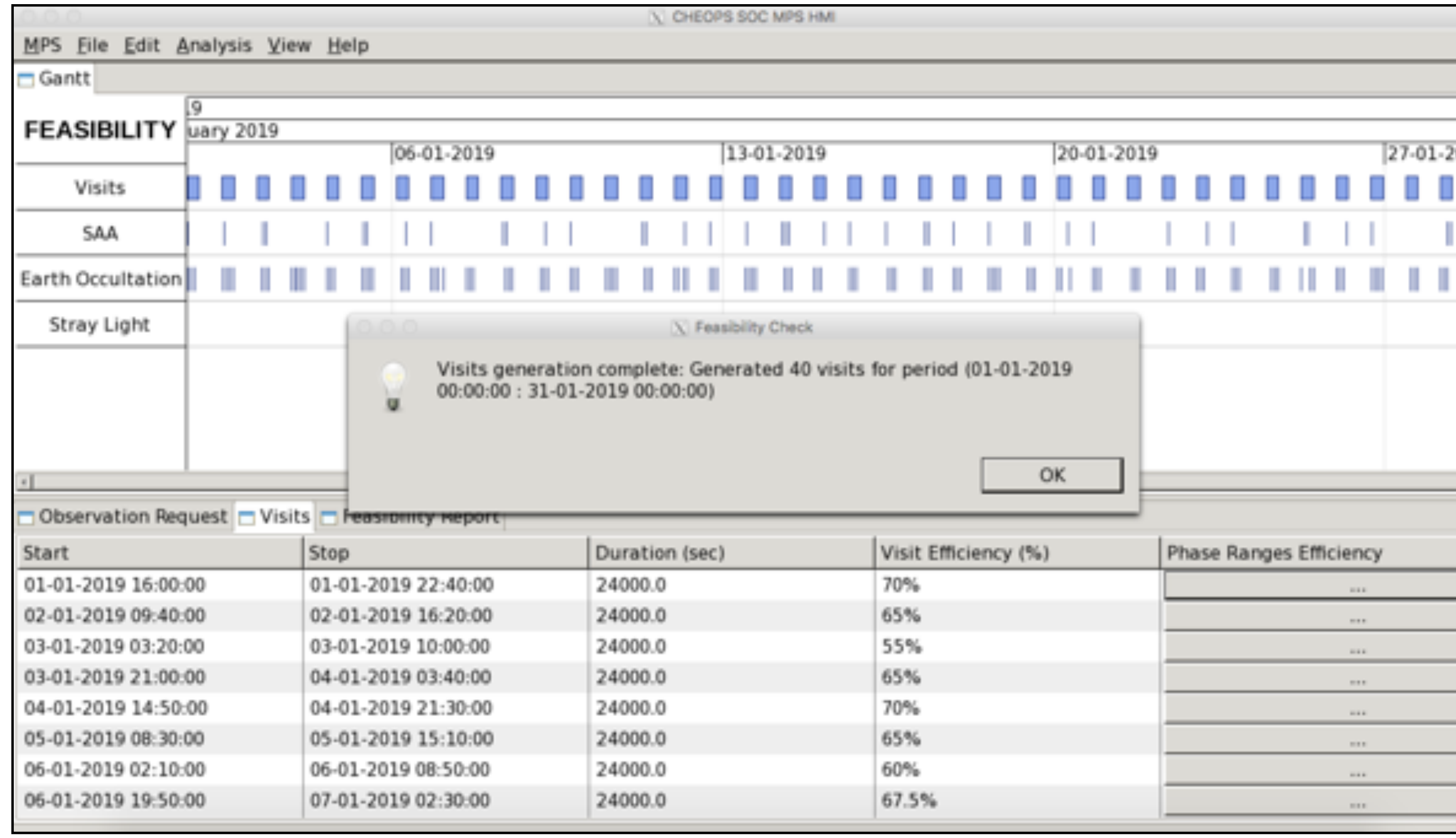
=> 40 possible visits in January



Feasibility Checker (FC)

Test Case on 55 Cnc:

- Short visit around transit of 55 Cnc e
- Any time in January 2019
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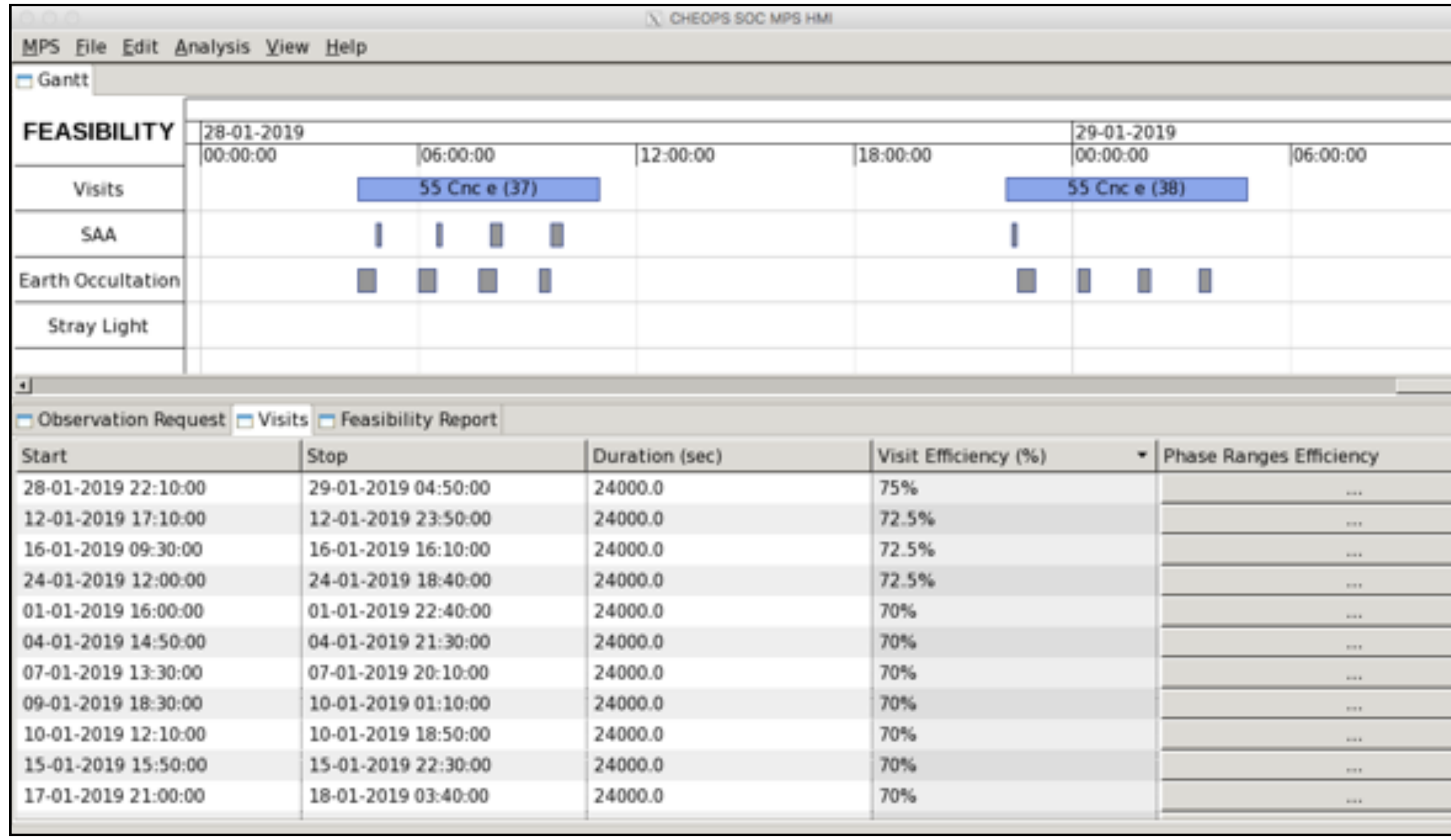
=> 40 possible visits in January

Explore the result

Efficiencies in the range 55 - 75%

=> Only 1 visit is valid



Start	Stop	Duration (sec)	Visit Efficiency (%)	Phase Ranges Efficiency
28-01-2019 22:10:00	29-01-2019 04:50:00	24000.0	75%	...
12-01-2019 17:10:00	12-01-2019 23:50:00	24000.0	72.5%	...
16-01-2019 09:30:00	16-01-2019 16:10:00	24000.0	72.5%	...
24-01-2019 12:00:00	24-01-2019 18:40:00	24000.0	72.5%	...
01-01-2019 16:00:00	01-01-2019 22:40:00	24000.0	70%	...
04-01-2019 14:50:00	04-01-2019 21:30:00	24000.0	70%	...
07-01-2019 13:30:00	07-01-2019 20:10:00	24000.0	70%	...
09-01-2019 18:30:00	10-01-2019 01:10:00	24000.0	70%	...
10-01-2019 12:10:00	10-01-2019 18:50:00	24000.0	70%	...
15-01-2019 15:50:00	15-01-2019 22:30:00	24000.0	70%	...
17-01-2019 21:00:00	18-01-2019 03:40:00	24000.0	70%	...

Likelihood of scheduling 1 visit $\propto$ Number of possible visits

Feasibility Checker (FC)

Lessons learned with the FC:

- Observing efficiency is a critical parameter
  - Too restrictive = no data
  - Too loose = incomplete data
- Summer targets (R.A. ~ 13-23h) allow for higher observing efficiencies (fewer/shorter interruptions from Earth illuminated limb constraints)
- High-declination targets suffer from frequent Earth occultations and shorter visibility windows
- Check how many visits are possible yearly (estimate ease of scheduling)

More for you to learn on the FC at the hands-on session

Tomorrow (July 27th) 8:45 — 9:30