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SCIENCE AND OPERATIONS CENTER

Technical Report
Comparative study of the efficiency of various JWST coronagraph observation strategies.

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Comparative study of the efficiency of various JWST coronagraphic observations strategies

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**STScI JWST Document Change Record**

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Abstract

JWST coronagraph observations are built upon a “basic coronagraph sequence”, which consists of exposures on the science target at two spacecraft roll angles plus an exposure on a reference target. When observing the same source using different filters or coronagraphic masks, the ordering of the exposures has an important impact on efficiency. Indeed, an “optimal wavefront stability” strategy for which the observations are consecutive in each filter to minimize any potential for wavefront changes, increases the number of slews and rolls for the telescope. On the other hand, an “optimal efficiency” strategy, for which observations for a given target and roll angle are consecutive to minimize the number of rolls and slews, might feature larger wavefront variations. The purpose of this report is to assess the variations in efficiency of these two strategies. We compare the two strategies for several representative use cases using different numbers of coronagraphs and filters, using NIRCam and MIRI coronagraphs together on the same target, etc. We find that the “optimal efficiency” strategy can save as much as a few hours of overhead per science target in cases where 4-6 filters are desired on the target. Recent estimates for the temporal stability of JWST suggest the observatory may be quite stable on the short timescales (less than a day) envisioned for most coronagraphic observations, in which case the increased overheads do not appear to be justified by improved performance. We therefore recommend adopting the “optimal efficiency” approach when scheduling coronagraphic programs obtaining multiple filters on the same target.

1.1 Scope

The development of the systems supporting coronagraphic operations at the Science and Operations Center (S&OC) are detailed in a series of technical reports describing the coronagraphic operations concepts.

- [1] Science Use-Cases for the Preparation of Coronagraphic Operations Concepts and policies (JWST-STScI-004140)
- [3] Comparative study of the efficiency of various coronagraphic observations strategies (JWST-STScI-004165; this report)
- [5] Coronagraphic Astrometric and Photometric Calibrations (JWST-STScI-004166)
- [7] Coronagraphic pipeline architecture, data products (JWST-STScI-004169)
- [8] Coronagraphic pipeline algorithms (JWST-STScI-004170)
- [9] Small-Grid Dithers for Coronagraphic Observations (JWST-STScI-004142 and JWST-STScI-004172)
- [10] Coronagraphic policies (JWST-STScI-004171)

1.2 Reference Documents

The following list of documents provides additional context or background information for the material in this document. For Technical Reports and other STScI documents that are not specific contract deliverables, the internal STScI Configuration Item (CI) (“JWST-STScI-“) is referenced, followed by the Next Generation Integrated Network (NGIN) library number for a documents available on NGIN.
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Gordon et al., (2001) JWST Observatory and Instrument Overheads, JWST-STScI-002564

Lajoie et al. (2013), Simulations of MIRI Four-Quadrant Phase Mask Coronagraph (III): Target Acquisition and CCC Mechanism Usage, JWST-STScI-3546

Gersh-Range, Jessica and Perrin, Marshall D., Improving active space telescope wavefront control using predictive thermal modeling, (2012), Journal of Astronomical Telescopes, Instruments, and Systems, Volume 1, Number 1,


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2 Context

JWST coronagraph observations require the combination of several exposures for each target, generally including observations at two spacecraft orientations, and of a reference PSF star in order to calibrate the effect of wavefront errors and of uncertainties in the Target Acquisition process using PSF subtraction post-processing in the pipeline.

The Coronagraphs Working Group (CWG) has followed an approach based on science use-cases (see report [1]) to develop the observing templates (see report [2]) and more generally the coronagraphic operations concepts.

Coronagraphic observations are built upon the “basic coronagraph sequence”, which involves three observations:

- The science target in one spacecraft orient (usually +/- 5 deg off nominal)
- The science target in the other spacecraft orient (usually -/+ 5 deg off nominal, respectively to produce a 10-deg roll)
- The reference PSF star

The science use-cases described in report [1] include several variants of this basic sequence for which the science target would be observed in several JWST filters or coronagraphic masks. The typical application is the characterization of the atmosphere of already-known exo-planets. As detailed in reports [1,2] in more details, JWST coronagraphic sequences (including these more complex ones with multiple filters and masks) must be scheduled together without interruption by other observations (aka “sequence non-int”). The goal of this report is to investigate the organization of the observations within a coronagraphic sequence that includes several filters or coronagraph. The approach is to quantify the overheads associated with two possible observing strategies:

- An “optimal wavefront stability” strategy for which the observations are consecutive in each filter to minimize the chance of any wavefront changes. This strategy increases the number of slews and rolls for the telescope.
- An “optimal efficiency” strategy for which observations for a given target are organized in each filter and coronagraphs to minimize the number of rolls and slews. This strategy increases the time between an observation of a target in a given filter and the corresponding reference PSF star observation in the same filter, which may allow increased variations in PSF properties, but which will not necessarily do so.

As detailed below, we find that the “optimal wavefront stability” approach can require up to several hours of additional overheads per science target, depending on the number of filters and coronagraphs being used. Estimates for the temporal stability of JWST

We caution that the true temporal stability of JWST Point Spread Function (PSF) will not be known until flight, and will depend on many factors including telescope thermal stability, reaction wheel and cryocooler induced dynamic vibrations, mechanism settling times, etc. It is outside the scope of this report to make any quantitative assessment of achieved coronagraphic contrast versus operating scenarios. We are here assessing solely the implications for operational efficiency. Updated predictions for JWST image quality and stability have recently been presented by Lightsey et al. (2014). We summarize these here for reference. Lightsey et al. identify two broad classes of instability: (1) slow thermal distortion of the optical system,
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responding to observatory changes in attitude with respect to the sun, and (2) rapid dynamical response to mechanical disturbances. The thermal stability requirements are to achieve < 58 nm rms variation on time scales of up to 2 weeks in the absence of wavefront control, in the presence of the worst-case thermal rate of change after the largest possible slew. Typical coronographic observations are expected to be much shorter in duration than the 2-week requirements case, which was motivated by extragalactic deep fields. On timescales of 24 hours, thermal distortion is expected to be < 10 nm rms for the worst-case slew occurring immediately prior to the coronographic observation (see Lightsey et al. (2014), figure 16). Correspondingly smaller variation would be expected for the more realistic case of a smaller slew preceding the coronographic science visits. See Gersh-Range & Perrin (2014) for estimates of potential JWST thermal distortion evolution using more realistic observing schedules.

On even shorter timescales, wavefront variations are expected to be dominated by dynamic disturbances (e.g. slight vibration of the secondary mirror induced by the reaction wheels or MIRI cryocooler). The requirement for these is that they cause less than 30 nm rms variation on any time scale. Note that this requirement is calculated for the edge case of all reaction wheels spinning at the maximum allowed speed (J. S. Knight, private communication). Once again, we can expect correspondingly smaller disturbances for less extreme cases. These dynamic variations occur on timescales much shorter than an exposure (e.g. many Hertz); it is the variation in the amplitude of oscillations over time, not the oscillations themselves that will show up as differences in coronographic PSFs. It is plausible that for typical coronographic sequences of a few hours or less in total duration, these dynamic effects will dominate the overall wavefront stability budget. Their temporal evolution is uncertain and may be quite small, for the case of the spacecraft just repeatedly slewing a small distance back and forth between science target and reference star, which would not lead to large changes in reaction wheel spin rates.

We thus emphasize that the strategy we have labeled “optimal wavefront stability” is only strongly optimal if the telescope’s wavefront were to evolve relatively rapidly in time. If performance in flight achieves the relatively stable and benign predictions presented by Lightsey et al., this would likely be a broad optimum, without substantial difference in contrast performance between different strategies for ordering observations, except perhaps for very deep observations lasting multiple days in total integration time. Again, our purpose in this document is not to compare in detail the relative contrast of the two scenarios, but only to compare their relative overheads.
3 Assumptions

Our calculations are carried out based on the overhead estimates described in the Technical Report by Gordon et al. (2011). We have developed an automated script to allow these calculations to efficiently be updated if needed. Below, we discuss the assumed numbers used for the calculations.

3.1 Telescope Slew and Roll

We used Figure 1 from Gordon et al., reproduced below, and fitted a power law in order to describe the slew time as a function of separation between the science target and the reference star:

\[ T_{\text{Slewtime Calibrator}}(\theta_{\text{arcsec}}) = 6 \times [\theta_{\text{arcsec}}]^{1/2} \text{ s}. \]

Figure 3.1 shows that this power law is in good agreement with Gordon et al. within the 1-degree range in which most of coronagraph observations will occur. Since this quantity will be an important component of our overhead budget with the total overhead being a function of the science target-reference separation, we reproduce this power law on the same axes as Figure 3.1 from Figure 1 in Gordon et al..

In Gordon et al. (2011) the “slew time” associated with a telescope roll is considered to be the “average slew” of 1800 s. After further discussion with the MESA group, the CWG updated this value to 14 minutes plus 1 minute of slew settle time (900 s total).

\[ T_{\text{Roll}} = 900 \text{ s}. \]

3.2 Dithers and Integrations

In this document we do not consider the overheads associated with dither patterns since our main focus is to compare the two strategies described in Section 2. Assuming the same dither pattern is
used regardless of the strategy adopted for ordering the visits, we can simplify our analysis by not including dithers because the dither overhead will be exactly the same in both scenarios. Similarly, we assume the actual exposure times will be identical for both observing strategies. We can thus, safely for this purposes of this paper, ignore the overheads associated with detector resets and reads since they will be identical for the two observing scenarios under consideration.

3.3 NIRCam

We use the values in Table 2 of Gordon et al. (2011). The quantities of interest for this study are summarized on the table below:

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
<th>Time (s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_GuideStar</td>
<td>Acquisition of the guide star for each new visit</td>
<td>240</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_TANircam</td>
<td>NIRCam coronagraph Target Acquisition</td>
<td>300</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_FilterWheelMove_NIRCam</td>
<td>Move of the NIRCam filter wheel</td>
<td>30</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_PupilWheelMove_NIRCam</td>
<td>Move of NIRCam pupil wheel</td>
<td>30</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_VisitCleanUpNircam</td>
<td>NIRCam visit clean up</td>
<td>12</td>
<td>Gordon et al.</td>
</tr>
</tbody>
</table>
Figure 3-2: Flow chart summarizing a NIRCam coronagraphic observation sequence and the associated overheads. The overhead values used in this document are summarized in the table above (as per Gordon et al., 2011).

### 3.4 MIRI

We use the values in Table 2 of Gordon et al. (2011). The quantities of interest for this study are:

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
<th>Time (s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_GuideStar</td>
<td>Acquisition of the guide star for each new visit</td>
<td>240</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_TALyot_MIRI</td>
<td>MIRI Lyot coronagraph Target Acquisition</td>
<td>600</td>
<td>Gordon et al.</td>
</tr>
</tbody>
</table>

Note that the Target Acquisition overhead was updated from 600 s to 300 s following discussions with the MIRI team.
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<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
<th>Time (s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_TAFQPM_MIRI</td>
<td>MIRI FQPM coronagraph Target Acquisition (reduced from 1200s to 600 due limited use of Contamination Control Contraption)</td>
<td>600</td>
<td>Gordon et al.</td>
</tr>
<tr>
<td>T_FilterWheelMove_MIRI</td>
<td>Move of NIRCam pupil wheel</td>
<td>120</td>
<td>Gordon et al.</td>
</tr>
</tbody>
</table>

Figure 3-3: Flow chart summarizing a MIRI coronagraphic observation sequence and the associated overheads. The overhead values used in this document are summarized in the table above (as per Gordon et al., 2011).

Note that in Gordon et al. the overhead associated with MIRI FQPM Target Acquisition was estimated to be 1200 s; in light of updated estimates for Small Angle Maneuvers (SAM) accuracy and current plans for target acquisition (Lajoie et al. 2013), this has been updated by the MIRI team and CWG to be 600 s.
4 Observing Sequences

Based on these numbers, we now estimate the overheads associated with the operations of NIRCam and MIRI coronagraphs and then combine those to estimate the overheads in the two scenarios discussed in Section 2: wavefront-optimized and efficiency-optimized.

4.1 NIRCam

The overheads associated with a NIRCam sequence during a visit depend on the number of coronagraphs (occulters) used and the number of filters used per coronagraph. (For NIRCam, each filter wheel can move independently of the coronagraph Lyot stops in the pupil wheels allowing potentially multiple filters to be used with a given occulter. The long-wave and short-wave occulters are in different locations and cannot be used in parallel.) Here we make the simplifying assumption that each coronagraph will be used with the same number of filters (e.g. one broadband filter per coronagraph, or two medium band filters, etc.). While this is not strictly required in practice, the conclusions of this report do not depend on this assumption, it just simplifies the bookkeeping. The overhead associated with a NIRCam observation in a given coronagraph is:

\[ T_{\text{Overhead\_perCorono\_NIRCam}}(N\text{Filters\_perCorono\_NIRCam}) = T_{\text{VisitCleanUp}\text{Nircam}} + N\text{Filters\_perCorono\_NIRCam} \times T_{\text{FilterWheelMove\_NIRCam}} \]

The overhead associated with a NIRCam visit composed of several occulter and filters per occulter is:

\[ T_{\text{Coronos\_NIRCam}}(N\text{Corono\_NIRCam}, N\text{Filters\_perCorono\_NIRCam}) = T_{\text{GuideStar}} + N\text{Corono\_NIRCam} \times T_{\text{TANircam}} + N\text{Corono\_NIRCam} \times T_{\text{Overhead\_perCorono\_NIRCam}}(N\text{Filters\_perCorono\_NIRCam}) \]

4.2 MIRI

The overheads associated with a MIRI sequence during a visit depend on which subset is used of the four coronagraphs (Lyot plus three FQPMs). Each MIRI coronagraph is designed to be used with one particular filter, and each always requires its own coronagraphic target acquisition.

\[ T_{\text{Overhead\_Lyot\_MIRI}} = T_{\text{TALyot\_MIRI}} + T_{\text{FilterWheelMove\_MIRI}} \]

\[ T_{\text{Overhead\_FQPM\_MIRI}} = T_{\text{TAFQPM\_MIRI}} + T_{\text{FilterWheelMove\_MIRI}} \]

Then the total overhead associated with a MIRI sequence is:

\[ T_{\text{Coronos\_MIRI}}(N\text{Lyot\_MIRI}, N\text{FQPM\_MIRI}) = T_{\text{GuideStar}} + N\text{Lyot\_MIRI} \times T_{\text{Overheads\_Lyot\_MIRI}} + N\text{FQPM\_MIRI} \times T_{\text{Overhead\_FQPM\_MIRI}} \]

Here, N\text{FQPM\_MIRI} is the number of the FQPMs that are used, and N\text{Lyot\_MIRI} is 0 or 1 depending on whether the Lyot coronagraph is used.
4.3 Overheads for a “stability optimized” observation strategy:

In this framework, we consider that for a given filter the telescope rolls to a new orient or slews to the reference star after each observation. We work in the framework of the standard coronagraph sequence for which exposures at two telescope orientations and a reference star are acquired, i.e., for each filter we observe in a sequence the science target, science target after a 10 degree roll, and the reference star; then we go on to the next filter or coronagraph. This strategy is aimed at minimizing the potential for changes in wavefront between exposures for optimal PSF subtraction. If it proves to be the case that JWST’s wavefront evolves significantly on the timescales relevant for coronagraphic observations, this strategy is envisioned to yield the best sensitivity to faint companions. The total overheads associated with this strategy are:

\[
T_{\text{Stability Optimized}} (\text{NLyot}_\text{MIRI}, \text{NFQPM}_\text{MIRI}, \text{NCorono}_\text{NIRCam}, \text{NFilters perCorono}_\text{NIRCam}) = 3*(\text{NCorono}_\text{NIRCam} \ast \text{NFilters perCorono}_\text{NIRCam})* T_{\text{Coronos}}_\text{NIRCam}(1,1) + 3* \text{NLyot}_\text{MIRI} \ast T_{\text{Coronos}}_\text{MIRI}(1,0)+ 3* \text{NFQPM}_\text{MIRI} \ast T_{\text{Coronos}}_\text{MIRI}(0,1)+ (2* (\text{NCorono}_\text{NIRCam} \ast \text{NFilters perCorono}_\text{NIRCam}+ \text{NLyot}_\text{MIRI}+ \text{NFQPM}_\text{MIRI}) -1)* T_{\text{Slewtime Reference}} (\text{theta arcsec}) + (\text{NCorono}_\text{NIRCam} \ast \text{NFilters perCorono}_\text{NIRCam}+ \text{NLyot}_\text{MIRI}+ \text{NFQPM}_\text{MIRI})*T_{\text{Roll}}
\]

Where:
- We assume that the overheads count starts once the slew to the science target has been executed.
- We assume that the rolls are back to back (no reference in between)
- The factor of two in front of the science/ reference slew corresponds to a first slew to the reference and then a second slew back to the science target for the next filter. (The “-1” offset corresponds to the lack of a slew back to the science target for the last filter).

4.4 Overheads for an “efficiency optimized” observation strategy:

In this framework we consider that all coronagraphs and all filters are observed on the same science target in a row, before an observatory roll or a slew to a calibrator star. As noted above, depending on the timescales for measurable wavefront evolution for the observatory, this might result in larger PSF variations between telescope orients and/or science-calibrator PSFs, and thus might not yield optimal PSF subtraction and, ultimately, sensitivity. However, if the observatory is relatively stable, or if coronagraph data reduction methods taking advantage of large PSF libraries can mitigate any increase in PSF temporal variability, then observers can take advantage of the gain in efficiency associated with this strategy at no cost to the science. The total overheads associated with this strategy are:

\[
T_{\text{Efficiency Optimized}} (\text{NLyot}_\text{MIRI}, \text{NFQPM}_\text{MIRI}, \text{NCorono}_\text{NIRCam}, \text{NFilters perCorono}_\text{NIRCam}) = 3* T_{\text{Coronos}}_\text{NIRCam}(\text{NCorono}_\text{NIRCam}, \text{NFilters perCorono}_\text{NIRCam})+ 3* T_{\text{Coronos}}_\text{MIRI} (\text{NLyot}_\text{MIRI}, \text{NFQPM}_\text{MIRI})+ T_{\text{Slewtime Calibrator}} (\text{theta arcsec})+ T_{\text{Roll}}
\]
Where we assume that a guide star acquisition is necessary when switching instruments, or switching coronagraphs on the same instrument. This is a conservative assumption because depending on guide star location, in some cases it may be possible to switch the target to a different coronagraph while staying with the same guide star.
5 Results

In Figures 6-1 to 6-5 we present the results of our analysis of 5 different scenarios. Using the terminology defined in [1] we consider both detailed “characterization” mode observations that use many filters on one target, and “survey mode” observations that do not include PSF reference stars because they assume multiple science targets will be used to cross-calibrate each other.

While the total overheads depend on the distance between science target and reference, we find that the difference between the two scenarios is generally dominated by the “constant” terms: the different number of rolls of the spacecraft and the different number of target acquisitions. For each scenario we calculate how much additional time is required to implement the “stability optimized” scenario, and separately account for those contributing overheads:

- Survey mode with NIRCAM (instrument configuration: 1 coronagraph, 2 filters). In this configuration, the extra overhead between the two strategies, not including the extra slew(s) back and forth from the reference include:
  - extra-roll: 900
  - extra guide star(s) and target acquisition(s): 1656

- Survey modes with MIRI (instrument configuration: 2 coronagraphs). In this configuration, the extra overhead between the two strategies, not including the extra slew(s) back and forth from the reference, include:
  - extra roll: 900
  - extra guide star(s) and target acquisition(s): 720

Note that the difference is less dramatic for MIRI since a Target Acquisition needs to be carried out for each coronagraph/filter combination for MIRI. Indeed in the case of MIRI the TA overhead cannot be alleviated using the back-to-back filters “optimal efficiency” scheduling approach. In the case of NIRCam on the other hand one can use the same TA for consecutive filters, which reduces the contribution of the Target Acquisition in the overhead budget. Overall overheads are larger in the case of MIRI by a factor of ~2.

- Characterization with NIRCAM (instrument configuration: 3 coronagraphs, 2 filters per coronagraph). In this configuration, the extra overhead between the two strategies, not including the extra slew(s) back and forth from the reference, include:
  - extra roll(s): 4500
  - extra guide star(s) and target acquisition(s): 7344s

- Characterization with MIRI (instrument configuration: 3 FQPM coronagraphs, 1 Lyot coronagraph). In this configuration, the extra overhead between the two strategies, not including the extra slew(s) back and forth from the reference, include:
  - extra roll(s): 2700
  - extra guide star(s) and target acquisition(s): 2160

Note that the difference is less dramatic for MIRI since a Target Acquisition needs to be carried out for each coronagraph/filter combination for MIRI, whereas for NIRCam using the same TA for consecutive filters can reduce overheads. However, the overall overheads are larger in the case of MIRI even though the number of coronagraphs is smaller for this example MIRI program than for the NIRCam program previously considered.
• Characterization with both MIRI and NIRCam (instrument configuration: MIRI: 3 FQPM
coronagraphs, 1 Lyot coronagraph, NIRCam: 3 coronagraphs, 2 filters per coronagraphs.
In this configuration, the extra overhead between the two strategies, not including the
extra slew(s) back and forth from the reference, include:
  o one extra roll(s): 2700+ 4500
  o extra guide star(s) and target acquisition(s): 2160s+ 7344s
6 Conclusions

The difference between the two observation strategies is very significant, ranging from 1 to 7 hours of extra overheads for the "stability optimized" approach. This difference is greatest for characterization mode observations, and is smallest (but still 0.5-1 hours extra) for survey mode observations. The source of this loss in efficiency is the combined result of extra telescope maneuvers, extra guide star acquisitions and target acquisitions that are not necessary when simply switching filters or even coronagraphs on the target. The less efficient strategy seems prohibitive, particularly given our current estimates as discussed in section 3.1 that the temporal evolution of the wavefront error may be relatively small for the timescales relevant here.

As a consequence the CWG recommends that for coronagraphic sequences involving more than one filters or coronagraphic occulters, observations should be organized in the most efficient manner by the super-template. As defined in reports [1] and [2], the overall coronagraphic sequence for each target (plus its associated reference star, if present) has to be scheduled together (sequence non-int). This recommendation only impacts the ordering of the observations within that sequence for a given target.

As detailed in report [2], the user will still have the ability to switch the organization of a sequence to a less efficient one, if motivated by a particular science case, by editing manually the APT observation folders. This non-standard use of the super-template will be detected by APT and will result in the user being prompted to enter additional justification to be evaluated by the TAC, as described in [2] and [10].

However, since there remain important unknowns about the temporal stability of the OTE, this recommendation of the most efficient coronagraphic sequence organization might be revisited potentially after commissioning. The flexibility designed in [2] and mentioned in the previous paragraph will allow users to adapt as needed to measured on orbit performances and lessons in best practices.
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Figure 6-1: Overheads associated with an observing sequence corresponding to a NIRCam coronagraph survey (instrument configuration: 1 coronagraph, 2 filters).
Top curve wavefront-optimized observing sequence, bottom curve efficiency-optimized observing sequence.

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Figure 6-2: Overheads associated with an observing sequence corresponding to a MIRI coronagraph survey (instrument configuration: 2 coronagraphs).
Top curve wavefront-optimized observing sequence, bottom curve efficiency-optimized observing sequence.
Figure 6-3: Overheads associated with an observing sequence corresponding to a NIRCam characterization sequence (instrument configuration: 3 coronagraphs, 2 filters per coronagraphs). Top curve wavefront-optimized observing sequence, bottom curve efficiency-optimized observing sequence.
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Figure 6-4: Overheads associated with an observing sequence corresponding to a MIRI characterization sequence (instrument configuration: 3 FQPM coronagraphs, 1 Lyot coronagraph).
Top curve wavefront-optimized observing sequence, bottom curve efficiency-optimized observing sequence.

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Figure 6-5: Overheads associated with an observing sequence corresponding to a NIRCam+MIRI characterization program (instrument configuration: MIRI: 3 FQPM coronagraphs, 1 Lyot coronagraph, NIRCam: 3 coronagraphs, 2 filters per coronagraphs). Top wavefront-optimized observing sequence, bottom efficiency-optimized observing sequence.
## Appendix A. Acronym List

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4QPM</td>
<td>Four Quadrant Phase Mask.</td>
</tr>
<tr>
<td>APT</td>
<td>Astronomer’s Proposal Tool</td>
</tr>
<tr>
<td>ETC</td>
<td>Exposure Time Calculator</td>
</tr>
<tr>
<td>FPM</td>
<td>Focal plane Mask</td>
</tr>
<tr>
<td>FSM</td>
<td>Fast Steering Mirror</td>
</tr>
<tr>
<td>PSF</td>
<td>Point Spread Function</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
</tbody>
</table>

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