# Analyzing the Operational Behavior of NFIRAOS LGS MCAO Acquisition on the Thirty Meter Telescope using SysML

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**ABSTRACT**

In the new era of Extreme large Telescopes (ELT) performance requirements are not the only critical parameters in the design space. Other requirements such as acquisition times and operational behavior of systems can influence the design significantly.

In an effort to address this challenge, this paper presents the TMT preliminary results of an ongoing effort towards creating a model, which captures the functional and physical architecture, behavior, requirements, and parametric relationships for TMT NFIRAOS LGS MCAO Acquisition Sequence and related use case scenarios at system level. Specifically, demonstrated and discussed are the results of using OMG's Systems Modeling Language (SysML) to verify timing requirements in the early life-cycle phase through system-level simulation.

Operational modes and behavior are modeled using activity diagrams. Scenarios are captured primarily using sequence and activity diagrams. Verifiable requirements are formally captured using constraints on properties.

This type of modeling can prove to be particularly useful when wanting to investigate the effect of parallelizing or re-ordering sequence acquisition tasks.

**Keywords:** MBSE, SysML, Requirements, TMT

## 1. INTRODUCTION

In the new era of Extremely Large Telescopes (ELTs), performance requirements are not the only critical parameters in the design space. Others requirements such as acquisition times and operational behavior of systems [1] can influence the design significantly (Table 1). Modelling such scenarios can help to understand critical items that constrain the system or identify areas were opportunities can open.

In this paper, we present the latest findings on our model- and use-case-based approach to analyzing the operational behavior of Acquisition Sequence for NFIRAOS LGS MCAO for the purpose of verifying requirements on timing.

## 2. TOOLS

Operational modes and behavior are modeled using activity and state machine diagrams in the Systems Modeling Language (SysML) in NoMagic MagicDraw. Scenarios are captured primarily using sequence and activity diagrams with probabilistic flows. Verifiable requirements are formally captured using constraints on properties.

This type of modeling can prove to be particularly useful when wanting to investigate the effect of parallelizing or reordering sequence acquisition tasks. This is because diagrammatic language makes it easy to re-order or reconnect things quickly that result in fairly complex changes in the underlying behavior

## 3. METHOD

First, we identify requirement(s) for modeling/analysis (Table 1). Second, for each mode, identify all plausible scenarios where the requirement(s) will apply (Table 2). Third, we group scenarios by commonalities (Table 2, Table 3 last 4 columns). Finally, we model the scenarios and groups with activity and sequence diagrams (Figure 1, 2, 3 and 4).

**Table 1: Requirements**

| Requirements |
|---|
| **[REQ-1-ORD-1800] Within 3 minutes, the telescope and enclosure shall be able to point from any one position on the sky to any other in a way ensuring the uninterrupted execution of the next observation, and settle control loops and structural dynamics sufficiently to be ready for object acquisition.** *Discussion: Average slew time between targets is ~1 minute.* |
| **[REQ-1-ORD-1805] The TMT Observatory shall perform the complete target acquisition sequence in less than 5 minutes when an instrument change is not needed.** *Discussion: The target acquisition sequence includes telescope configuration (including slew time), enclosure configuration, instrument configuration, AO system configuration, and guide star acquisition.* |

**Table 2: Plausible Scenarios for LGS MCAO mode with IRIS (Complete list not shown)**

| | | | | | | | | | | | A | B | C | D | E | F | G | H | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | All | | | | | High Order Truth (Radial Order) | Low Order (TTFA or TT) | | | | Low Truth Asterism (TT or TTFA) | | | | | | | | |
| | | | | | | HO | Tier 1 | Tier 1 | Tier 2 | Tier 2 | Tier 3F | Tier 3 | Tier 3/3F | Tier 3/3F | Tier 3/3F | Tier 3/3F | Tier 3 | Tier 3/3F | |
| Asterism | PWFS (TTF) | OIWFS(TTF) | OIWFS (TT) | OIWFS(F) | ODGW (TT) | PWFS(Truth) | PWFS (TTF) | OIWFS(TTF) | OIWFS (TT) | ODGW (TT) | OIWFS(TTF) | ODGW (TT) | ODGW (TT) OIWFS (F) | OIWFS(TTF) 2 OIWFS(TT) | OIWFS(TTF), OIWFS(TT) ODGW(TT) | OIWFS(TTF), 2 ODGW(TT) | 3-4 ODGW(TT) | 3-4 ODGW(TT) OIWFS(F) | Groups |
| 1 | | | | | | 1 | 1 | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 1a | 1 | 1 | | | | 1 | 1 | | | | ✓ | | | | | | | | Group2 |
| 1b | 1 | | | | 1 | 1 | 1 | | | | | ✓ | | | | | | | Group2 |
| 1c | 1 | | | 1 | 1 | 1 | 1 | | | | | | ✓ | | | | | | Group2 |
| 1d | 1 | 1 | | | 2 | 1 | 1 | | | | | | | ✓ | | | | | Group2 |
| 1e | 1 | 1 | 1 | | 1 | 1 | 1 | | | | | | | | ✓ | | | | Group2 |
| 1f | 1 | 1 | | | 2 | 1 | 1 | | | | | | | | | ✓ | | | Group2 |
| 1g | 1 | | | | 3-4 | 1 | 1 | | | | | | | | | | ✓ | | Group2 |
| 1h | 1 | | | 1 | 3-4 | 1 | 1 | | | | | | | | | | | ✓ | Group2 |
| 2 | | | | | | 1 | 1 | | 1 | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 2b | 1 | | 1 | | 1 | 1 | 1 | | 1 | | | ✓ | | | | | | | Group1 |
| 2c | 1 | | 1 | 1 | 1 | 1 | 1 | | 1 | | | | ✓ | | | | | | Group1 |
| 2d | 1 | 1 | 1,2 | | | 1 | 1 | | 1 | | | | | ✓ | | | | | Group1 |
| 2e | 1 | 1 | 1,1 | | 1 | 1 | 1 | | 1 | | | | | | ✓ | | | | Group1 |
| 2f | 1 | 1 | 1 | | 2 | 1 | 1 | | 1 | | | | | | | ✓ | | | Group1 |
| 2g | 1 | | 1 | | 3-4 | 1 | 1 | | 1 | | | | | | | | ✓ | | Group1 |
| 2h | 1 | | 1 | 1 | 3-4 | 1 | 1 | | 1 | | | | | | | | | ✓ | Group1 |

Table 3: Compliance Summary

| Time(s) avg±stdev | REQ compliance | Groups | HO Truth | Tier1 | Tier2 | Tier3/3f |
|---|---|---|---|---|---|---|
| 181±47 | ✔ | Group1 | PWFS | PWFS | X | X |
| 119±22 | ✔ | Group2 | PWFS | PWFS | | X |
| 153±30 | ✔ | Group3 | PWFS | OIWFS | | X |
| 195±48 | ✗ | Group4 | PWFS | OIWFS | X | X |
| 141±35 | ✔ | Group5 | | OIWFS | | X |
| 164±32 | ✔ | Group6 | | OIWFS | X | X |

## 4. ANALYSIS

After the model is created, we start the analysis. The simulation is run a number of times automatically using a plugin, and all results are stored in SysML instances, which represent the end state of the system after each run. We run different scenarios in a Monte-Carlo statistical sense with probabilistic flows. After, we compare the data obtained from simulations with requirement(s) and re-evaluate model assumptions (Table 3).

Later, we run model and compare results with inputs until they converge or desired outcome is reached. Finally, new requirements based on the scenario simulations will be applied to subsystems' components (e.g. probe arm speed, close loop settle time, parallelizing activities for sequences)

## 5. SUMMARY:

This poster demonstrates and discusses the results of using the Object Management Group (OMG) Systems Modeling Language (SysML) to verify timing requirements in the early life-cycle phase through system-level simulation for the LGS MCAO and IRIS acquisition mode. This system modeling approach is effective because the integrated model and diagrammatic language allows for a number of analyses and quick trades to be performed: e.g. understanding the effect of parallelization of tasks on timing allows us to check interfaces and specify new requirements.

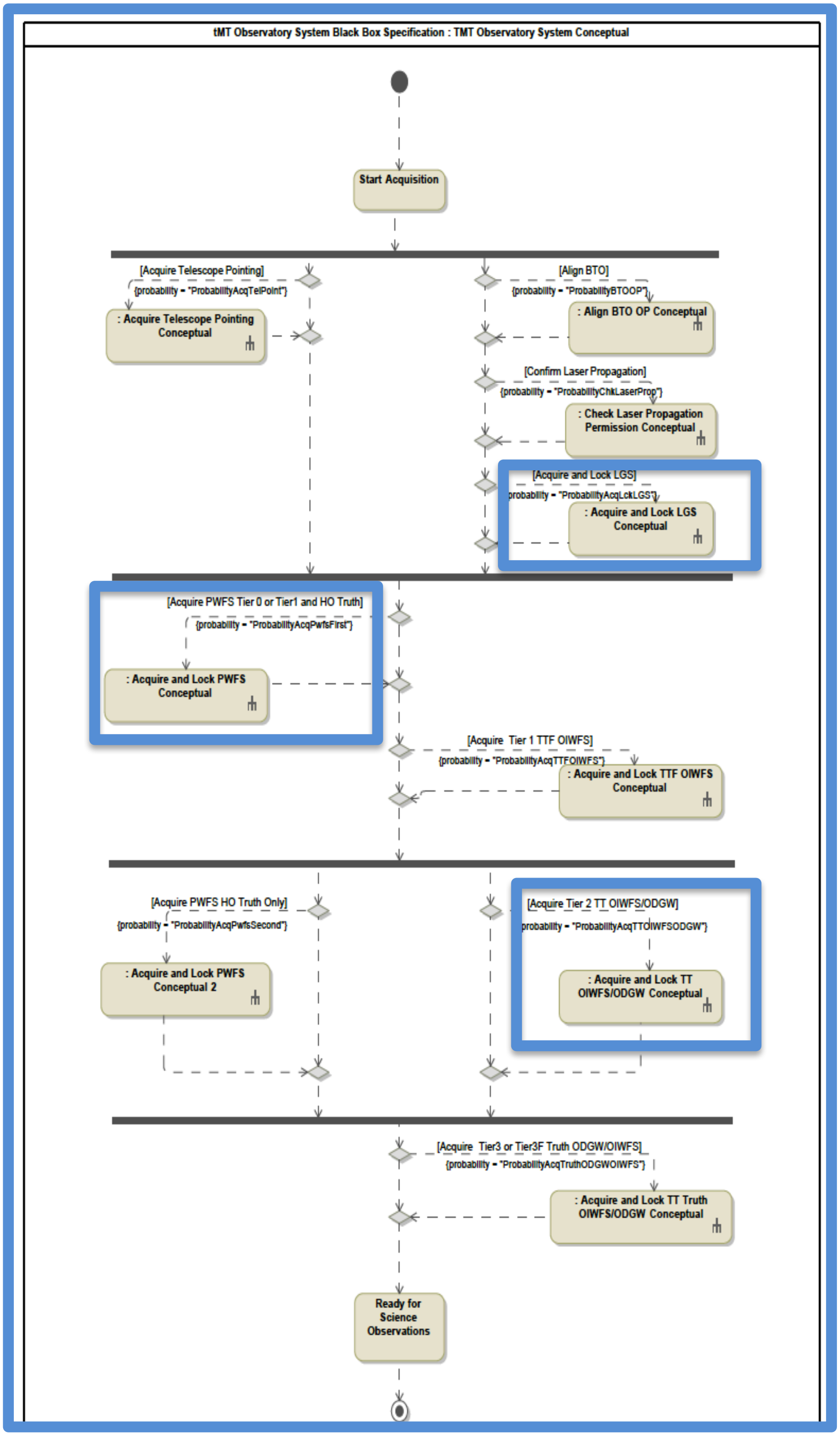


**Figure 1: LGS MCAO mode with IRIS Acquisition**

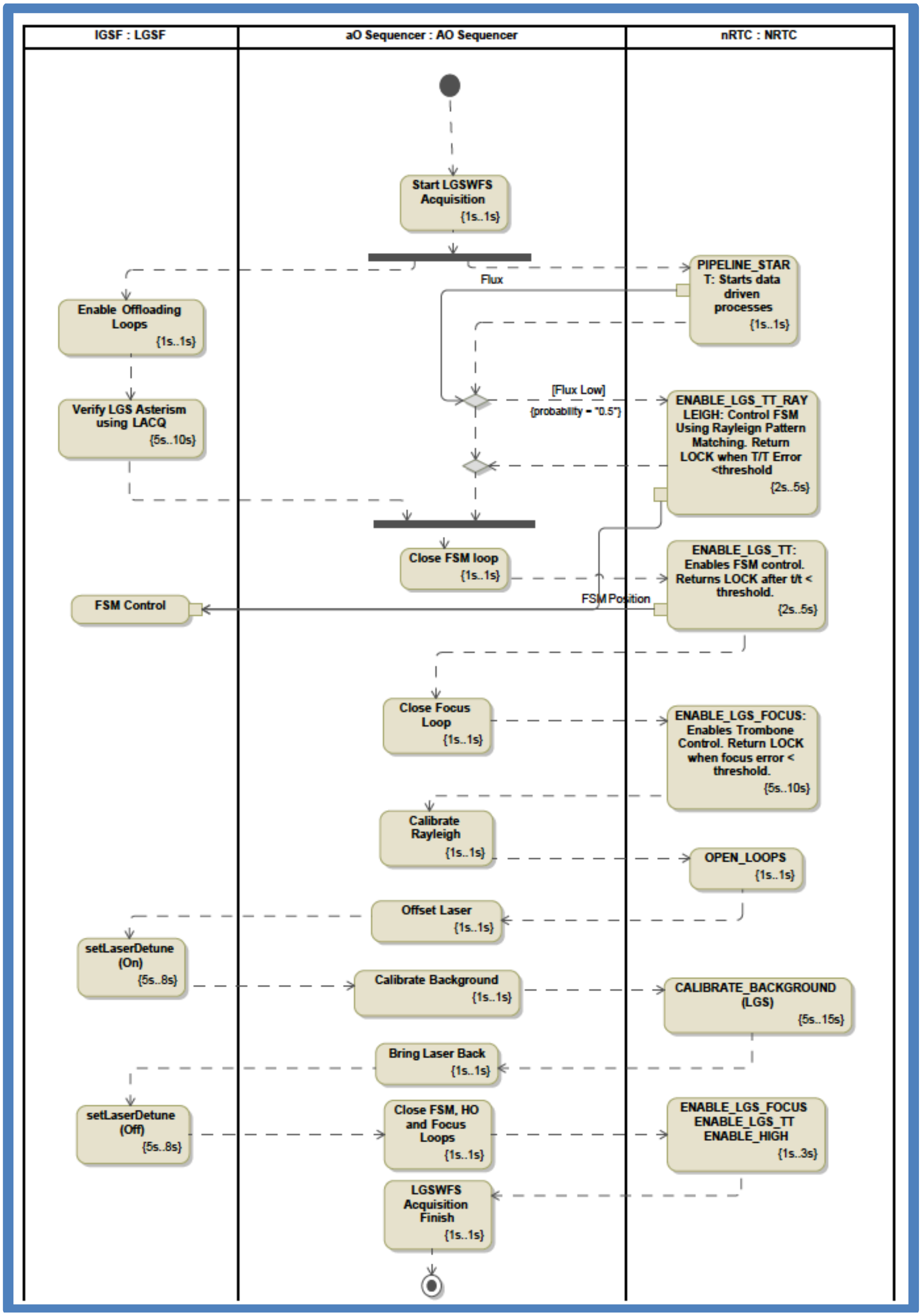


**Figure 2: Acquisition and Lock LGS**

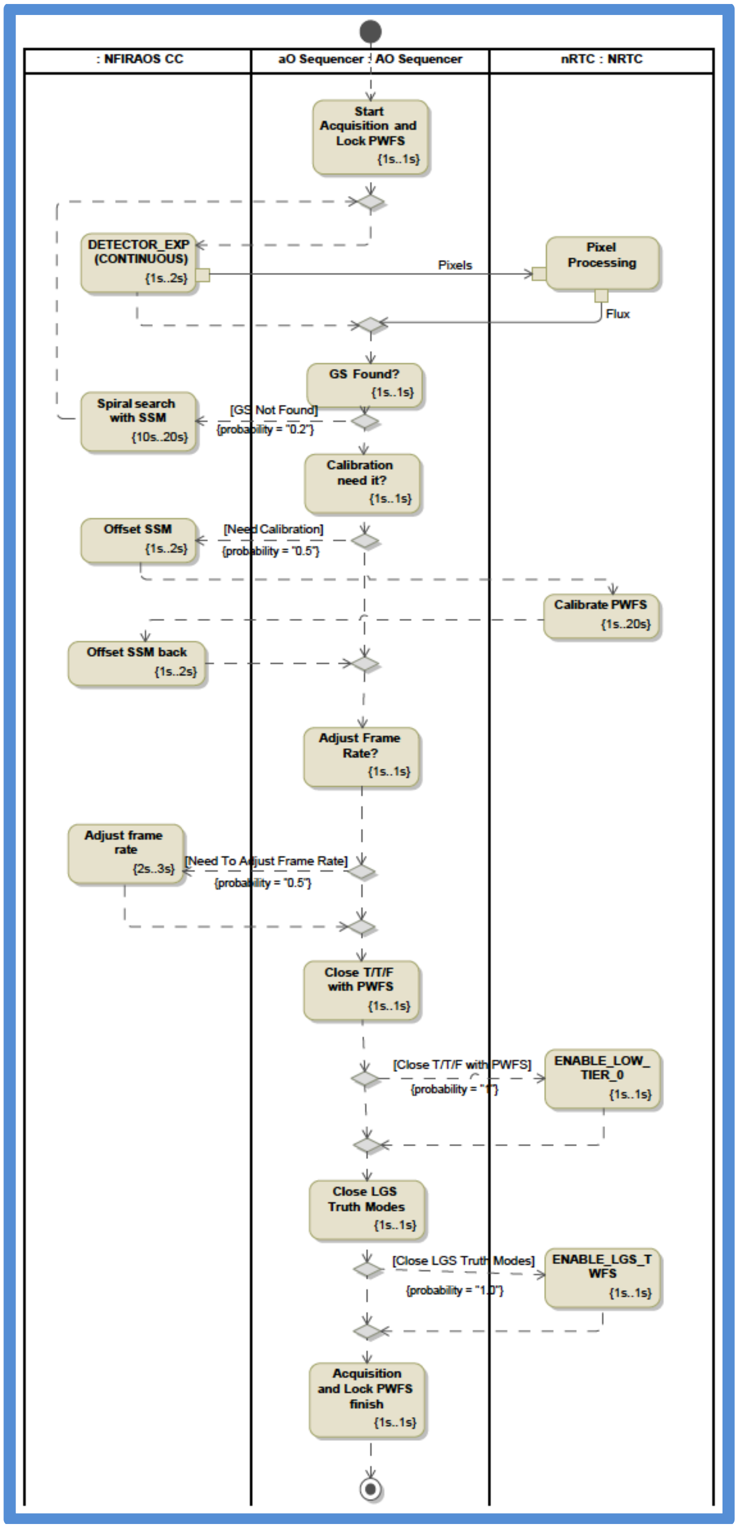


**Figure 3: Acquisition and Lock PWFS**

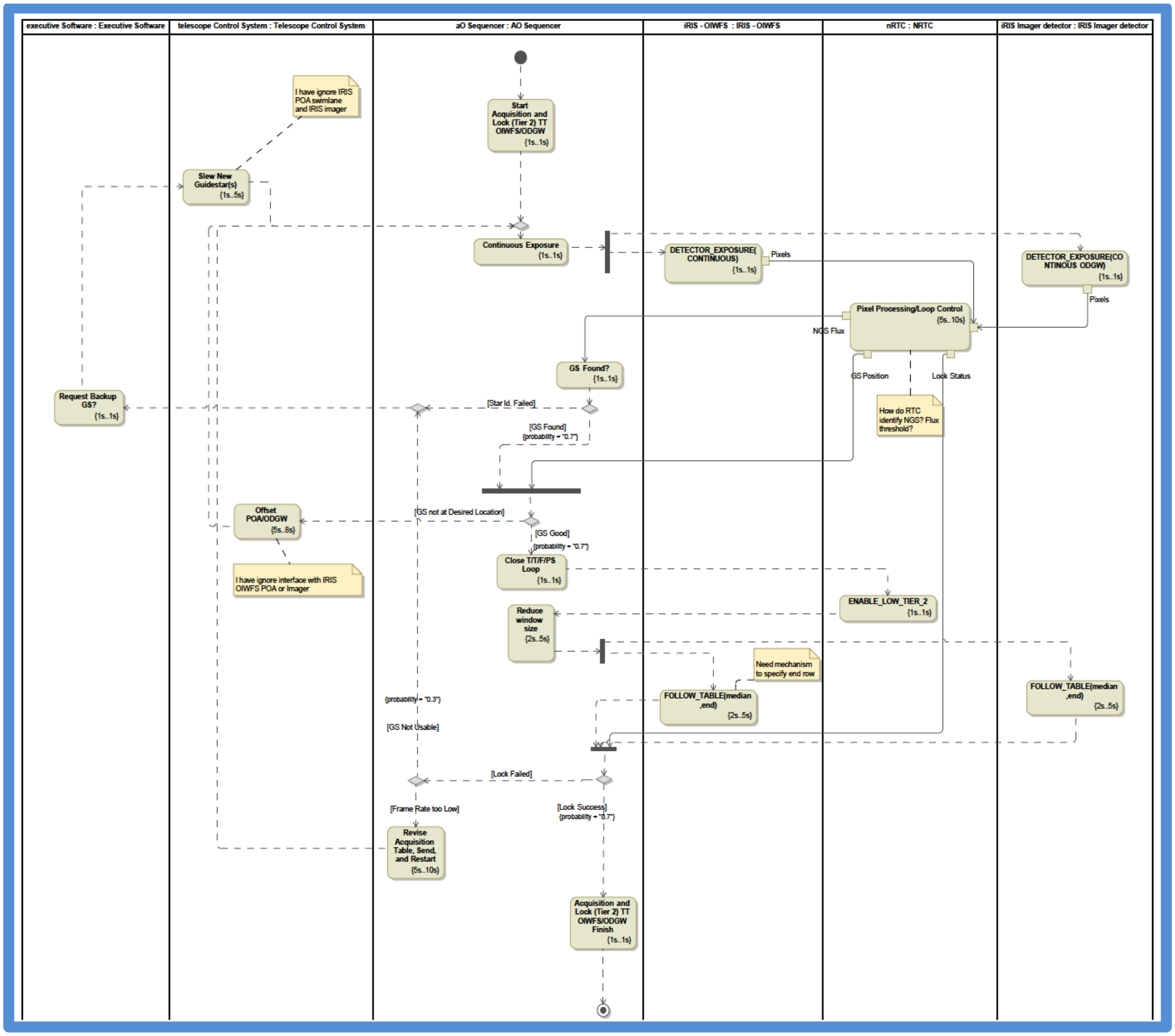


**Figure 4: Acquisition and Lock of TT OIWFS and ODGW**

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

[1] Sebastian J. I. Herzig, Robert Karban, Gelys Trancho, Frank G. Dekens, Nerijus Jankevicius, and Mitchell Troy "Analyzing the Operational Behavior of the Alignment and Phasing System of the Thirty Meter Telescope using SysML" in [Adaptive Optics for Extremely Large Telescopes (AO4ELT) ], (2017).