

# Overview of MBSE at GMT

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#### Overview



- MBSE effort goals
- Overview of system modeling at GMT
- Modeling challenges
- Conclusions

## MBSE goals



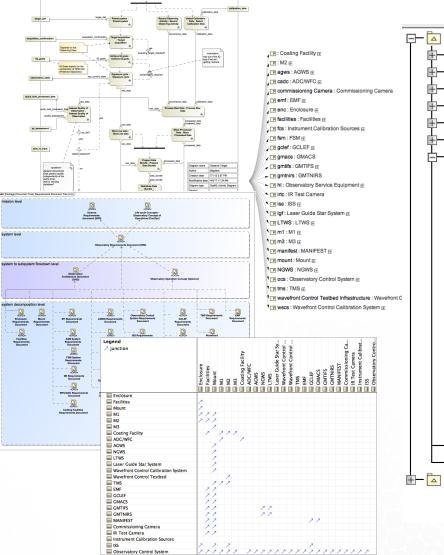
- Provide consistency in the flow down of requirements
- Ensure traceability between analysis and requirements
- Provide support for system decomposition
- Develop observatory top-level life-cycle concepts model

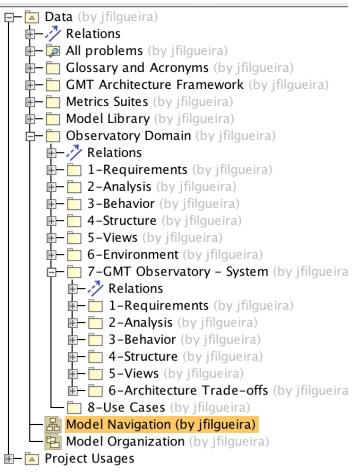
## Overview of system modeling



- Product Tree
- Document Tree
- NxN

- Doc generation
- Behaviors

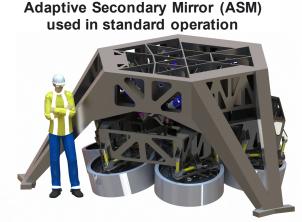




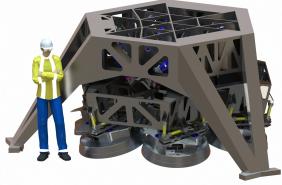
#### Modeling challenges

GMT

- Large ground based observatories have complex characteristics:
  - Complex mission expressed often as a science book or set of white papers
  - Complex environment (e.g. seismic, wind,...)
  - Long life time ~50 years
  - Project already in motion
  - Required multiple arrangements of optics and instruments that are deployed incrementaly to deliver the mission

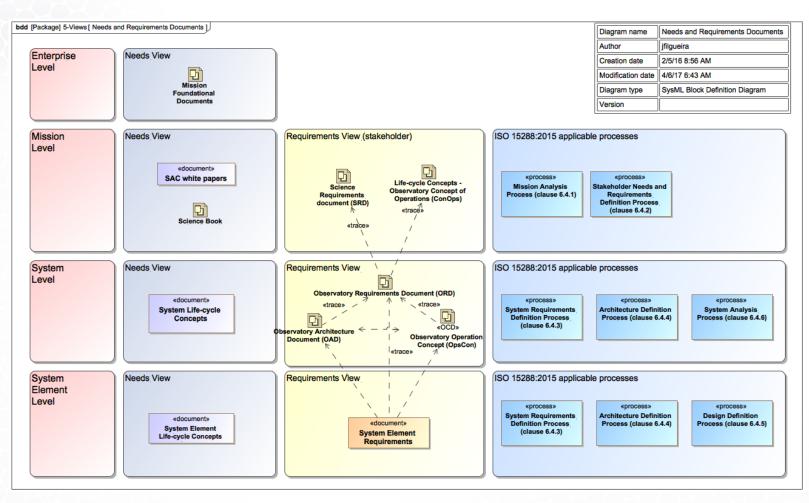


Fast-Steering Secondary Mirror (FSM) (used in commissioning)





## Modeling challenges playground

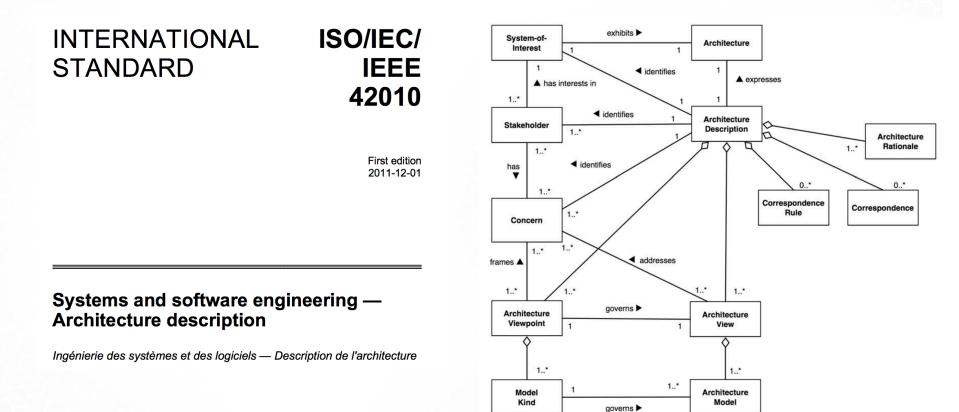


How MBSE can help to address those challenges?

### **MBSE** approach

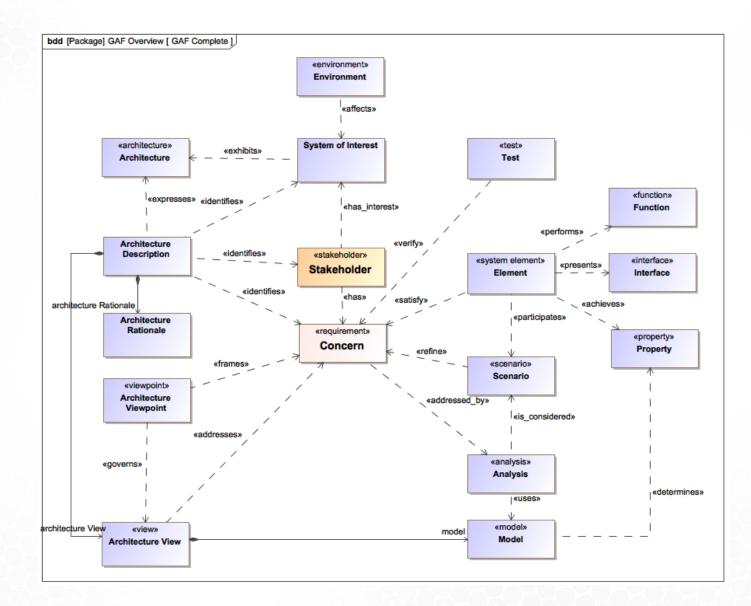


Build a vocabulary



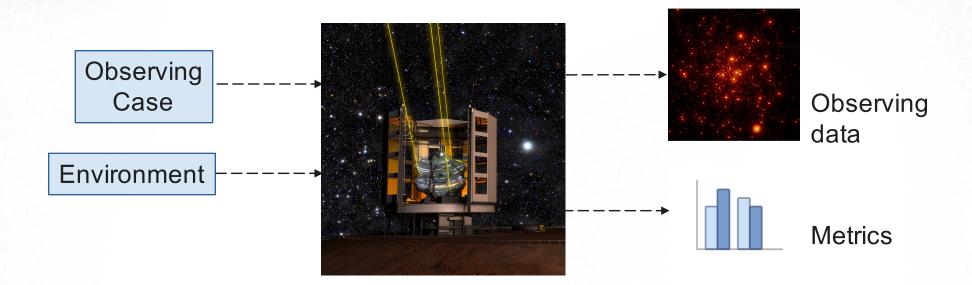


#### **Define an Architecture Framework**



#### Observatory as a function



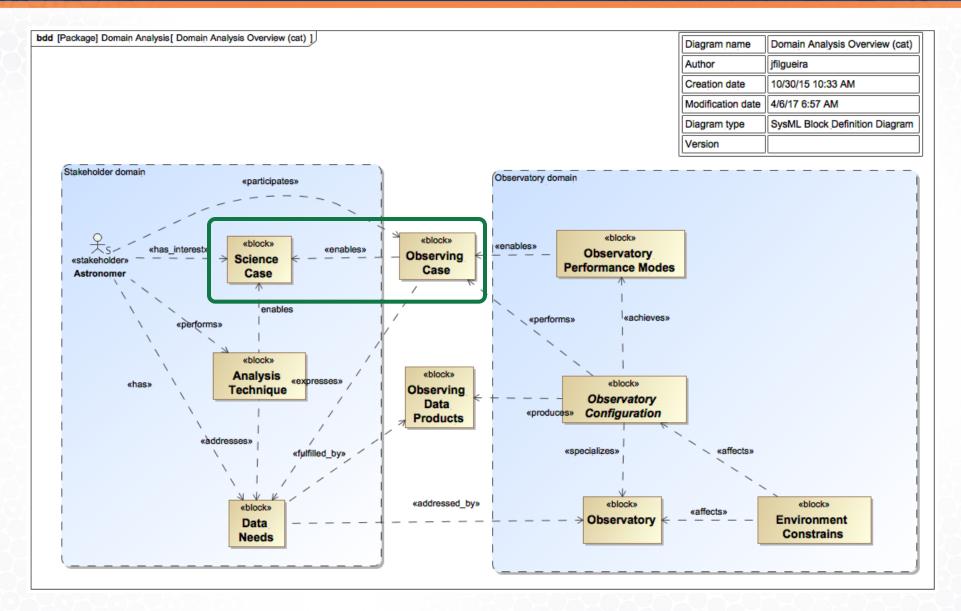


- Performance function : f<sub>P</sub>(obs\_case, env) = obs\_data
- Efficiency function :
- Safety function :

- $f_{E}(obs\_case, env) = obs\_efficiency\_metrics$
- f<sub>S</sub>(obs\_case, env) = obs\_safety\_metrics

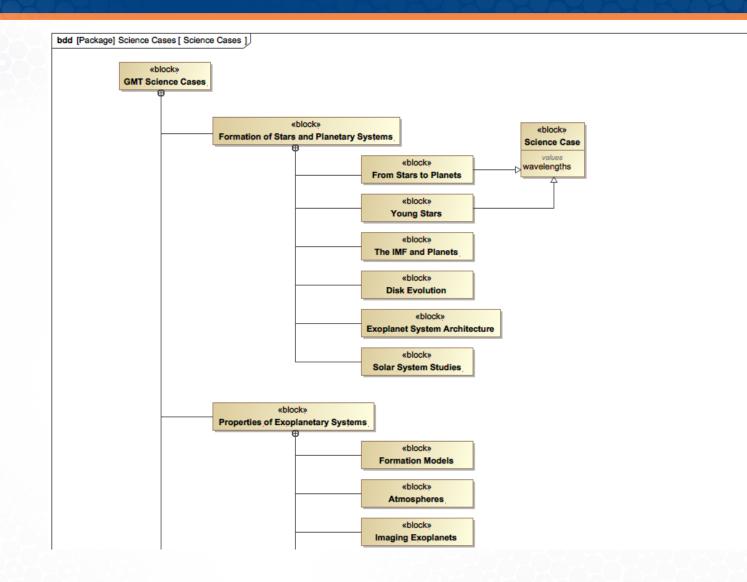
#### **Top level concepts**





#### **Science Cases**





## **Observing Cases**

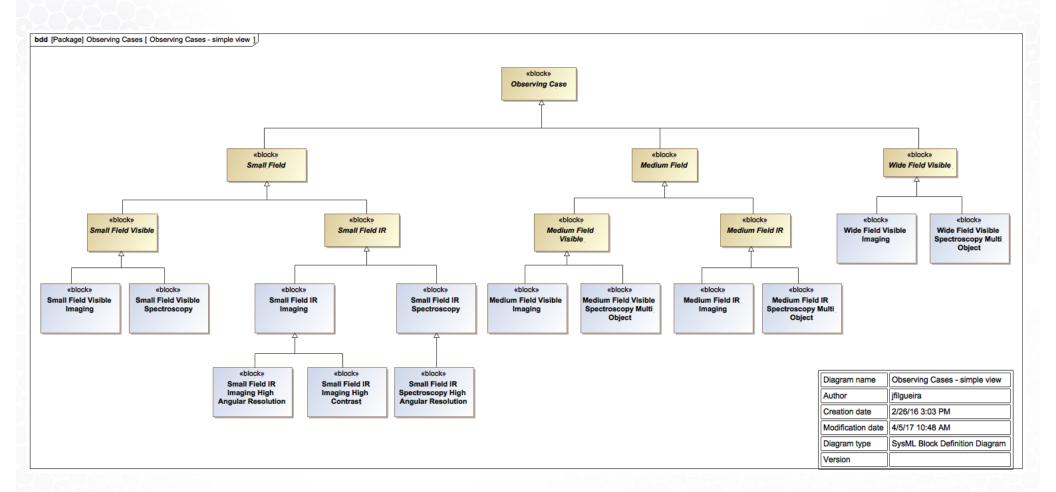


Set of properties relevant to the astronomer that need to occur simultaneously

	«block»
	Observing Case
«moe» wavel «moe» wavel «moe» FOV_ «moe» FOV_ «moe» sensit «moe» sensit «moe» photo «moe» image «moe» time_ «moe» astror «moe» image	values um_measurable_radial_velociy: ISO80000-3 Space and Time::Quantities::velocity::velocity[centimetre per second] = 10.0{unit = centimetre per second} ength_range_upper_limit: ISO80000-3 Space and Time::Quantities::wavelength:wavelength[micrometre] = 25{unit = micrometre} ength_range_lower_limit: ISO80000-3 Space and Time::Quantities::wavelength:wavelength[micrometre] = 0.32{unit = micrometre} min : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::angle = 3.0 {unit=arcmin} max : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 99.0 ivity_on_axis : Real [2,6] = ivity_variation_max : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 metry_error_relative : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 metric_variation_max : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 1.0 _ quality: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 metric_variation_max : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 metric_variation_max : Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 = quality_uniformity: Observatory Domain::1-Requirements::Mission and Stakeholder Needs::Value Types::percentange = 5.0 =

# **Observing Cases**





# **Observing Cases**



#	Name	Attribute
		V FOV_min : angle [arcmin] = 10.0 (unit=arcmin)
		V FOV_max : angle [arcmin] = 10.0 (unit=arcmin)
1	Medium Field	<pre>time_to_start_exposure_max : time[second] = 3600.0</pre>
		v sky_coverage_min : percentange = 99.0
		v astrometric_variation_max : percentange = 0.003
		<pre>wavelength_range_upper_limit : wavelength[micrometre] = 25</pre>
		<pre>wavelength_range_lower_limit : wavelength[micrometre] = 0.8</pre>
		v sensitivity_on_axis : Real [2,6] =
2	Medium Field IR	v sensitivity_variation_max : percentange = 5.0
		<pre>photomety_error_absolute : percentange = 3.0</pre>
		<pre>photometry_error_relative : percentange = 2.0</pre>
		Image_quality : FWHM = 0.2
3	🔜 Medium Field IR Imaging	
4	Medium Field IR Spectroscopy Multi Object	
		<pre>wavelength_range_upper_limit : wavelength[micrometre] = 1.3</pre>
		<pre>wavelength_range_lower_limit : wavelength[micrometre] = 0.32</pre>
	Medium Field Visible	v sensitivity_on_axis : Real [2,6] =
5		v sensitivity_variation_max : percentange = 5.0
		<pre>photomety_error_absolute : percentange = 2.0</pre>
		<pre>photometry_error_relative : percentange = 1.0</pre>
		image_quality : FWHM = 0.3
6	🔜 Medium Field Visible Imaging	
7	🔚 Medium Field Visible Spectroscopy Multi Object	
		minimum_measurable_radial_velociy : velocity[centimetre per second
		<pre>m wavelength_range_upper_limit : wavelength[micrometre] = 25</pre>
		<pre>wavelength_range_lower_limit : wavelength[micrometre] = 0.32</pre>
		<pre>FOV_min : angle = 3.0 {unit=arcmin}</pre>
_		m FOV_max : angle = 10.0 (unit=arcmin)
8	Observing Case	<pre>m sky_coverage_min : percentange = 99.0</pre>
		m sensitivity_on_axis : Real [2,6] =
		<pre>sensitivity_variation_max : percentange = 5.0</pre>
		m photomety error absolute : percentance = 1.0

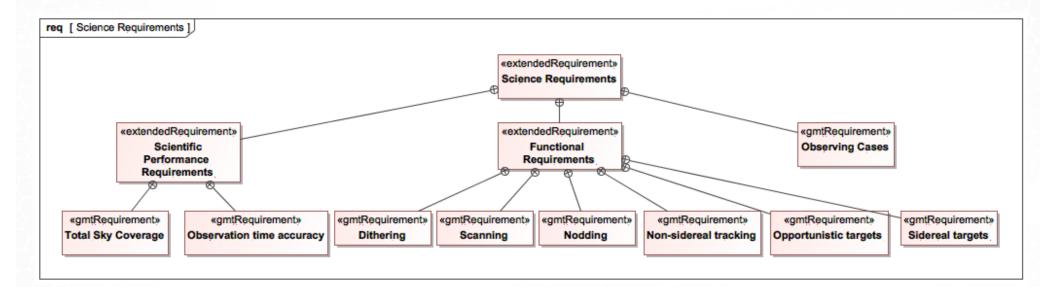


# **Observing Cases vs Science Cases**

Legend			Ob	sen	ving	) Ca	ase	S							
Allows answering questions such as: What science will be impacted if?		🛄 Small Field Visible Imaging	Small Field Visible Spectroscopy	Small Field Visible Spectroscopy PRV	🔲 Small Field IR Imaging	🛄 Small Field IR Imaging High Angular Resoluti	🔜 Small Field IR Imaging High Contrast	🔜 Small Field IR Spectroscopy	🔜 Small Field IR Spectroscopy High Angular Re	🔜 Medium Field Visible Imaging	🛄 Medium Field Visible Spectroscopy Multi Obj	🔜 Medium Field IR Imaging	🔜 Medium Field IR Spectroscopy Multi Object	🔜 Wide Field Visible Imaging	Wide Field Visible Spectroscopy Multi Object     Small Field ID Installed Units December
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🗆 🔜 GMT Science Cases															
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E Formation of Stars and Planetary Systems	6		2	2			2	2 2	2 2		2		2		2
Formation of Stars and Planetary Systems From Stars to Planets	6 8			2			2	∠ ∠ ∠	2 2 2		2	2	2		2
Formation of Stars and Planetary Systems     From Stars to Planets     Young Stars	6		4	2			2				2		2		
Formation of Stars and Planetary Systems     From Stars to Planets     Young Stars     The IMF and Planets	6 8		2	∠			2				2		2		
Formation of Stars and Planetary Systems     From Stars to Planets     Young Stars     The IMF and Planets     Disk Evolution	6 8 3		2			2	2 2 2		2	2	2		2		
Formation of Stars and Planetary Systems     From Stars to Planets     Young Stars     The IMF and Planets     Disk Evolution     Exoplanet System Architecture	6 8 3 5			2		2	2 2 2		2	2	2		2		
Formation of Stars and Planetary Systems     From Stars to Planets     Young Stars     The IMF and Planets     Disk Evolution     Exoplanet System Architecture     Solar System Studies	6 8 3 5 6 5			2		2	_	-	2	2	2		2		
<ul> <li>Formation of Stars and Planetary Systems</li> <li>From Stars to Planets</li> <li>Young Stars</li> <li>The IMF and Planets</li> <li>Disk Evolution</li> <li>Exoplanet System Architecture</li> <li>Solar System Studies</li> <li>Properties of Exoplanetary Systems</li> </ul>	6 8 3 5 6			2		-	_	-	2 2 2	2	2		2		
<ul> <li>Formation of Stars and Planetary Systems</li> <li>From Stars to Planets</li> <li>Young Stars</li> <li>The IMF and Planets</li> <li>Disk Evolution</li> <li>Exoplanet System Architecture</li> <li>Solar System Studies</li> <li>Properties of Exoplanetary Systems</li> <li>Formation Models</li> </ul>	6 8 3 5 6 5 5 5 1			2		2	2	2		2	2		2		
<ul> <li>Formation of Stars and Planetary Systems</li> <li>From Stars to Planets</li> <li>Young Stars</li> <li>The IMF and Planets</li> <li>Disk Evolution</li> <li>Exoplanet System Architecture</li> <li>Solar System Studies</li> <li>Properties of Exoplanetary Systems</li> <li>Formation Models</li> <li>Atmospheres</li> </ul>	6 8 3 5 6 5 5 5			2		2	2	2		2	2		2		

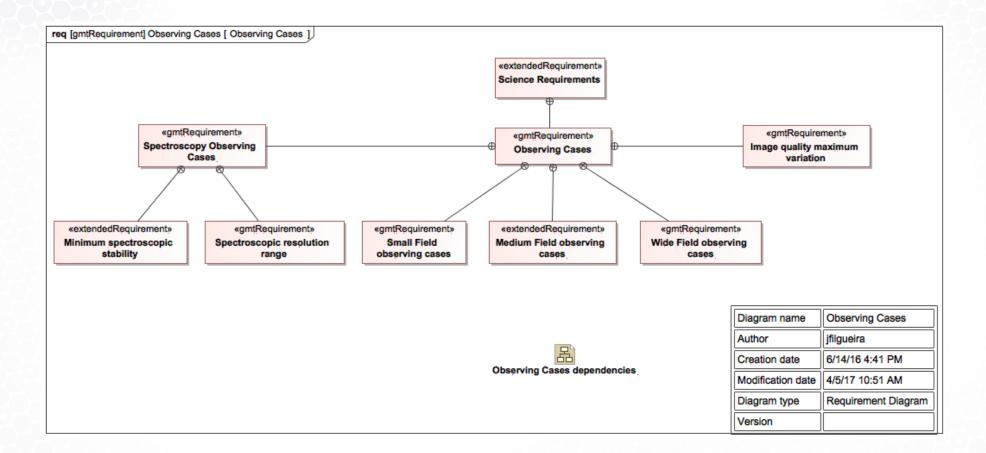
#### **Science Requirements**





#### **Science Requirements**





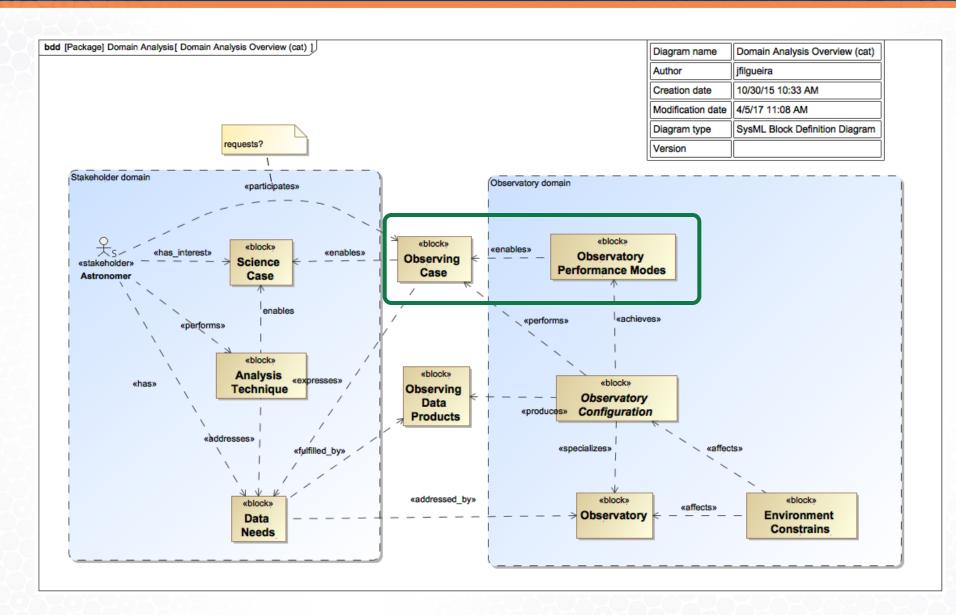


# **Observing Cases Test**

Legend ↗ Verify		E SCI-1.3 Observing Cases [Science Requirements::Scie     E SCI-1.3.3 Small Field observ      E SCI-1.3.4
/ verify		
		<ul> <li>Visible Imaging Observing Test Program</li> <li>Visible Spectroscopy PRV Test Program</li> <li>Visible Spectroscopy Test Program</li> <li>Visible Spectroscopy Test Program</li> <li>Nisible Spectroscopy RV Test Program</li> <li>IR Imaging High angular resolution test p</li> <li>IR Imaging High Angular Resolutiona</li> <li>Firetroscopy High Angular Resolutiona</li> <li>IR Spectroscopy High Angular Resolutiona</li> <li>IR Imaging Observing test Program</li> <li>IR Imaging Test Program</li> <li>IR Imaging Test Program</li> <li>IR Imaging Test Program</li> </ul>
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🖂 🔤 SCI-1.3 Obs		
	5	
	Image quality maximum variation	
	Spectroscopy Observing Cases	
	3.2.1 Spectroscopic resolution range	7       4       2       1       2       1       1         7       4       2       1       1       1       1
	3.2.2 Minimum spectroscopic stability	
	Small Field observing cases	
	8.3.1 Small Field maximum field of view	8       8       3       4       4       5       4       4       4         8       8       3       4       4       5       4       4       4
	3.3.2 Maximum Time to start and exposure	
	3.3.3 Small Field Visible observing cases	
	1.3.3.3.1 Small Field Visible minimum field of view 1.3.3.3.2 Small Field Visible wavelength range lower limit	3 3 3 4 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	5 5	3 3 3 4 4 4
	1.3.3.3.3 Small Field Visible wavelength range upper limit	
	1.3.3.3.4 Small Field Visible image quality	
	1.3.3.3.5 Small Field Visible on-Axis sensitivity 1.3.3.3.6 Small Field Visible maximum sensitivity variation	3 3 3 4 4 4
	1.3.3.3.7 Small Field Visible absolute photometric accuracy	
	1.3.3.3.8 Small Field Visible relative photometric accuracy	
	1.3.3.3.9 Small Field Visible minimum sky coverage	
	1.3.3.3.10 Small Field Visible Imaging observing cases	
	1.3.3.3.11 Small Field Visible maximum astrometric variation	
	1.3.3.3.12 Small Field Visible Spectroscopy observing cases	
	CI-1.3.3.3.12.1 Small Field Visible precision radial velocity stability	
	3.3.4 Small Field Infrared observing cases	
	5	
EI SCI-	1.3.3.4.1 Small Field IR image quality	5 5 5 5 4 4 4 4

# GMT

#### **Observatory Performance Modes**



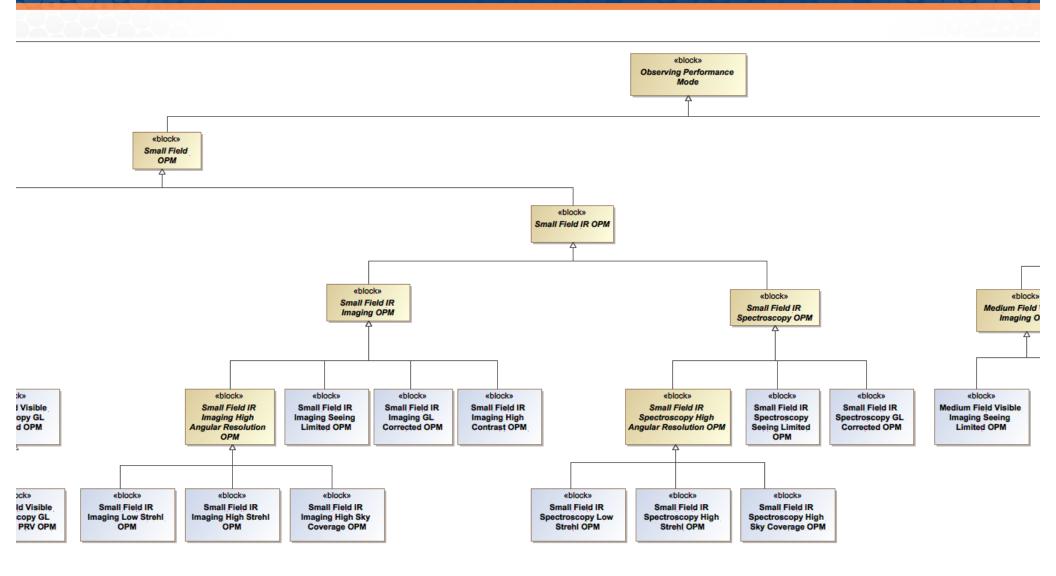
#### **Observing Performance Modes**



Set of system properties that need to occur simultaneously

	«block»
	Observing Performance Mode
	values
	<pre>«tpm» wavelength_range_upper_limit: wavelength[micrometre](unit = micrometre]</pre>
	<pre>«tpm» wavelength_range_lower_limit: wavelength[micrometre](unit = micrometre) «tpm» FOV min</pre>
	«tpm» FOV_min «tpm» FOV max
	«tpm» rov_max «tpm» sky_coverage_min : percentange
	«tpm» image guality plot
	<pre>«tpm» time_to_start_exposure_max : period duration[second]{unit = second}</pre>
	«tpm» system_throughput
	«tpm» system_scattered_light
	«tpm» system_emissivity
	«tpm» detection_read_noise
	«tpm» pupil_stability
	«tpm» stray_light_night
	«tpm» stray_light_day
	«tpm» vignetting_max
	«tpm» flux_calibration
1	«tpm» wavelength_calibration
	«tpm» focal_length_variation: percentange
	«tpm» zenith_angle_max
	«tpm» temperature_gradient_max
	«tpm» wind_speed_max

#### **Observing Performance Modes**



GMT

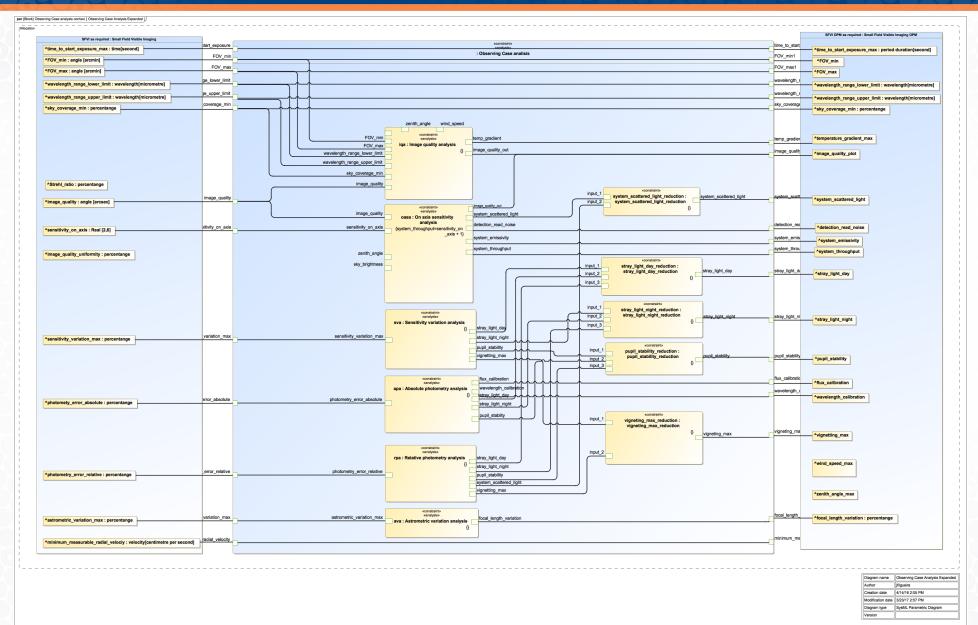


# **Observing Case Analysis**

k] Observing Case analysis context [ Observing Case Analysis II ]					Diagram name	Observing Case An
					Author	jfilgueira
					Creation date	3/16/16 9:29 AM
					Modification date	4/5/17 5:15 PM
					Diagram type	SysML Parametric I
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			stray_light_night			
			pupil stability	^stray_light_night		
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			-	^flux_calibration		
			wavelength_calibration			
				^wavelength_calib	ration	
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			-	^vignetting_max		
			focal_length_variation	Afocal longth vari		1
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Aminimum_measurable_radial_velociy : velocity[centimetre per second]	minimum_measurable_radial_velocity		minimum_measurable_radial_velocity1		~	
				^zenith_angle_max	·	
				^wind_speed_max		

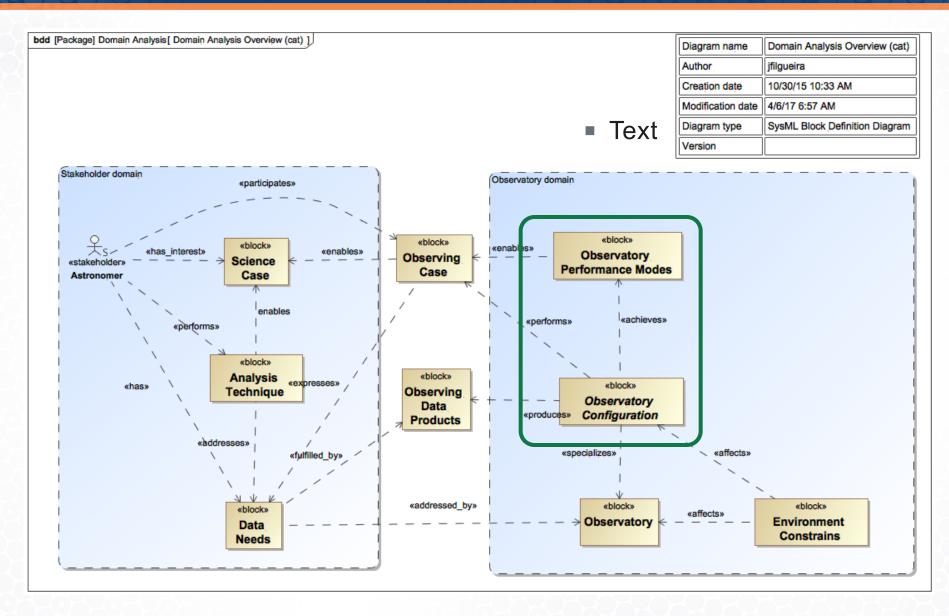
#### Analysis





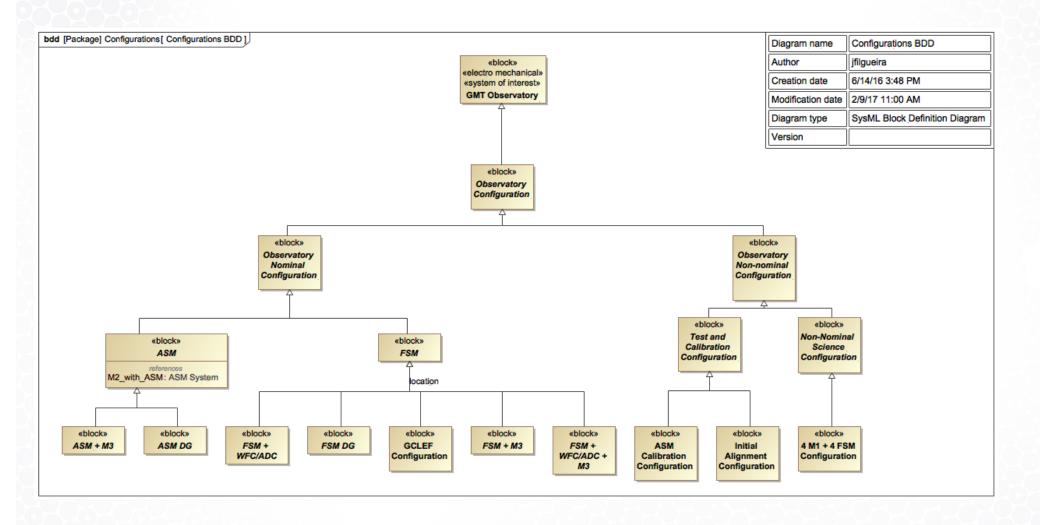


#### **Observatory Configurations**



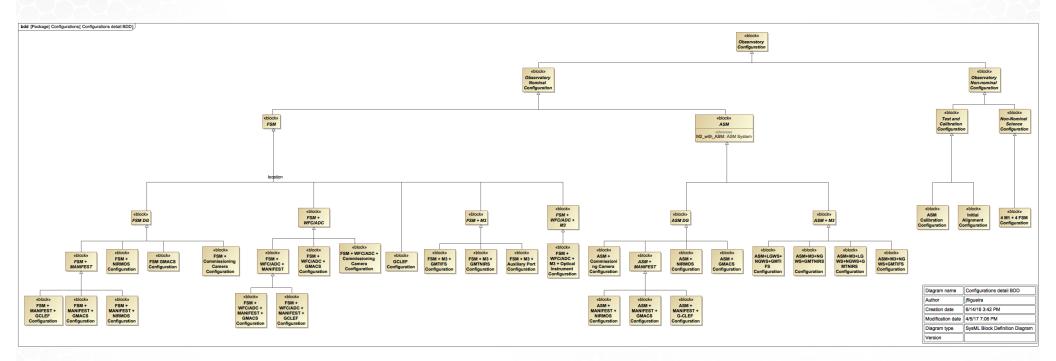


#### **Observatory Configurations**



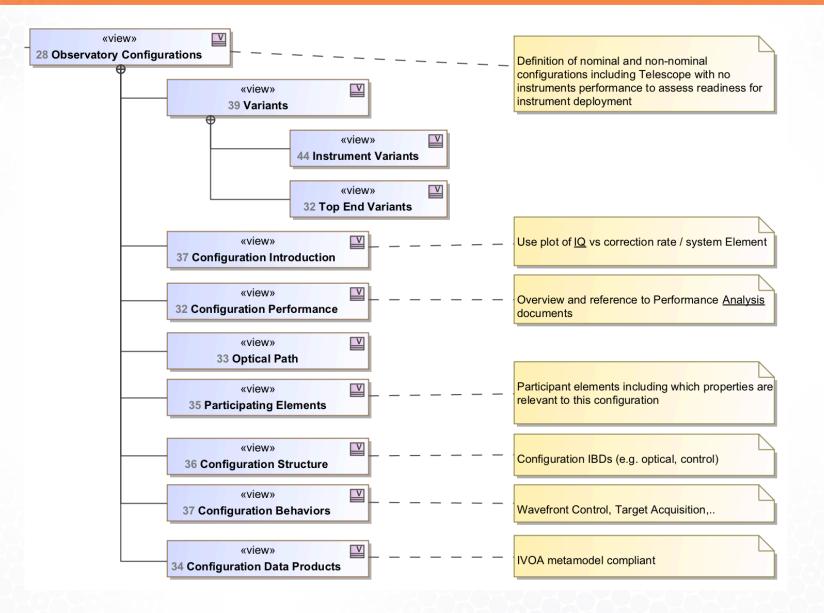
# **Observatory Configurations**







# **Observatory Configuration Definition**

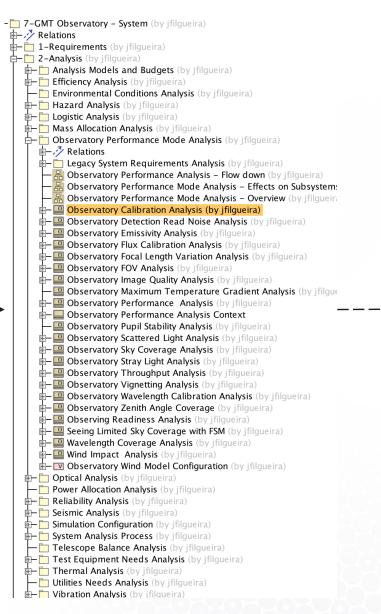


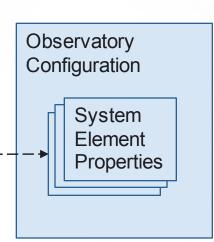


#### **Observing Performance Mode Analysis**



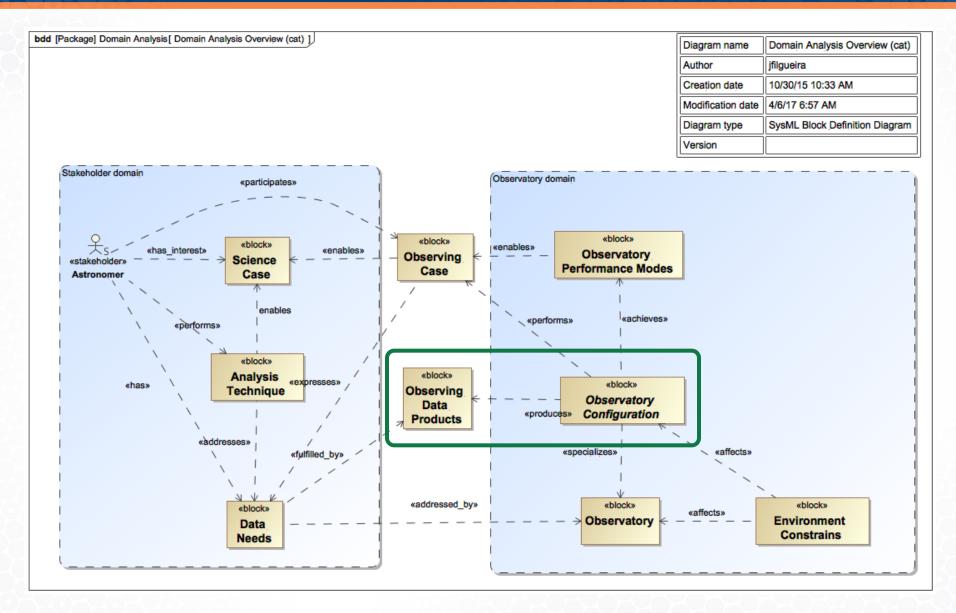
«tpm» <u>wavelength\_range\_upper\_limi</u>t: wavelength[micrometre]{unit = micrometre} «tpm» wavelength\_range\_lower\_limit: wavelength[micrometre]{unit = micrometre} «tpm» <u>FOV</u> min tpm» FOV max (tpm» sky\_coverage\_min : percentange «tpm» image quality plot «tpm» time to start exposure max : period duration[second]{unit = second} «tpm» system throughput «tpm» system\_scattered\_light «tpm» system emissivity «tpm» detection read noise «tpm» pupil stability «tpm» stray light night «tpm» stray\_light\_day «tpm» vignetting\_max «tpm» flux\_calibration «tom» wavelength calibration «tpm» focal length variation: percentange «tpm» zenith\_angle\_max «tpm» temperature\_gradient\_max «tpm» wind\_speed\_max





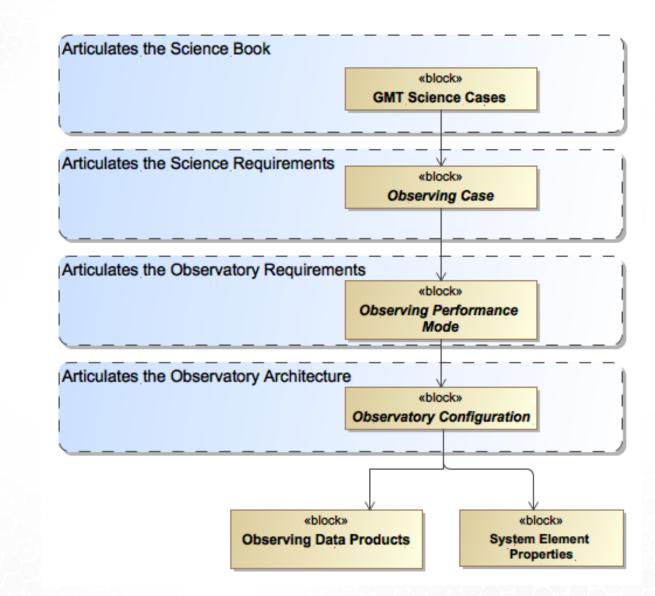
# MBSE goals





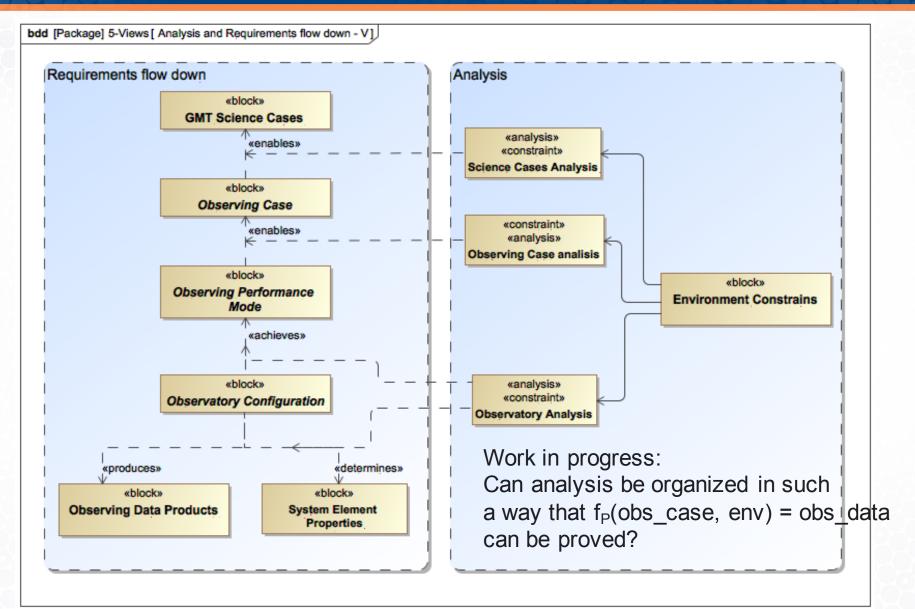


#### Requirements flow down





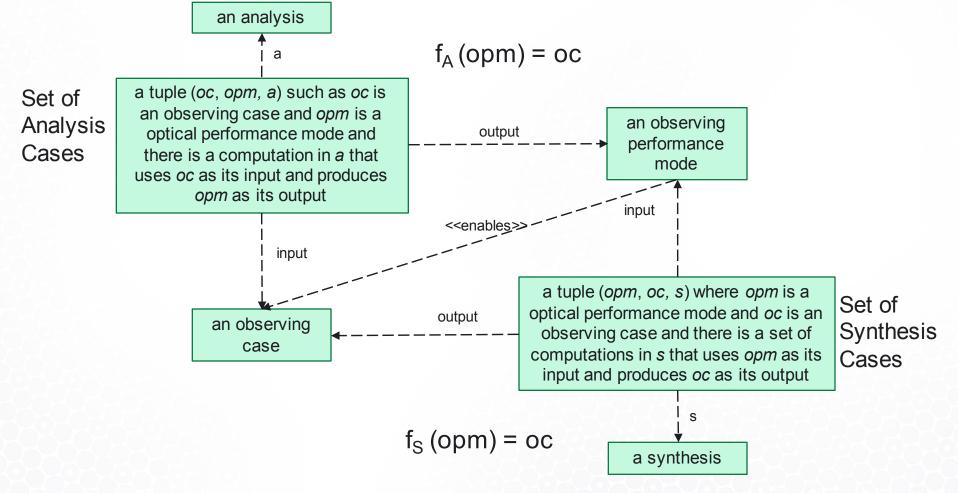
### Requirements flow down and analysis



#### Formal considerations

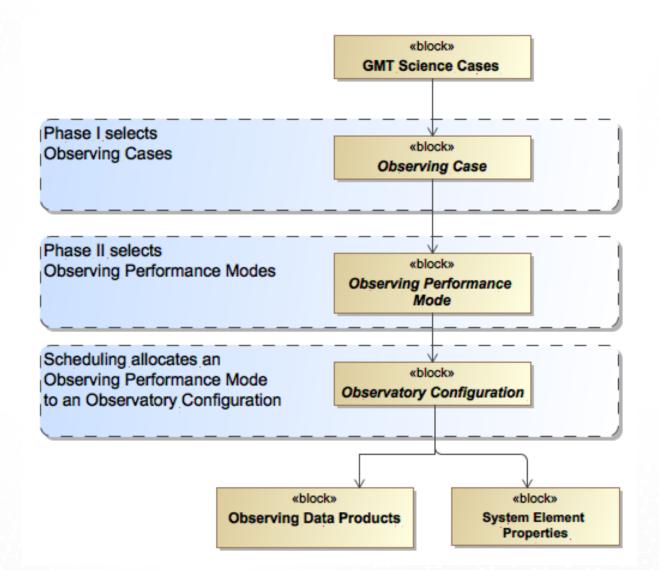


- What are the semantics of the <<enables>> relationship?
- We use some normalization rules to make it more "categorical"



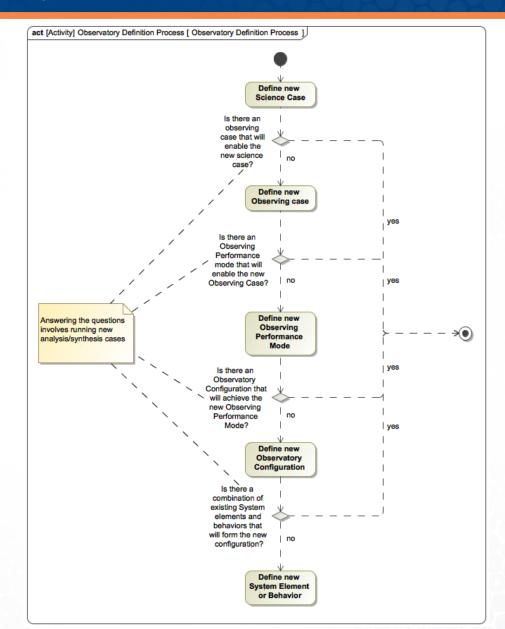
#### **Observing process**





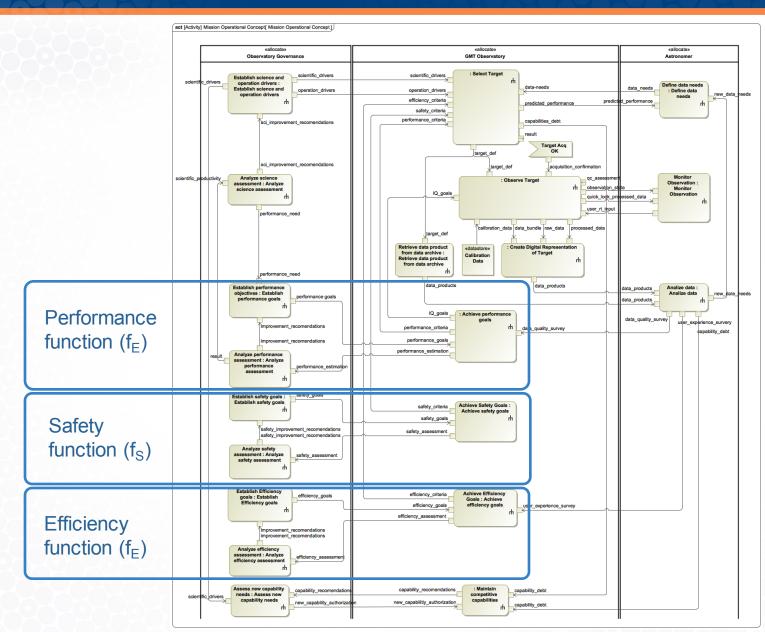
### **Observatory definition process**





## **Operation concept**





#### **MBSE** conclusions

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- MBSE helps finding emerging concepts that are useful for:
  - Decomposing the system
  - Flown down of requirements
  - Articulating life-cycle concepts
  - Organizing the analysis effort
- Provides a formal framework to consider correctness and truth
- Helps to find holes in the specifications