ROMAN SPACE TELESCOPE

Jet Propulsion Laboratory
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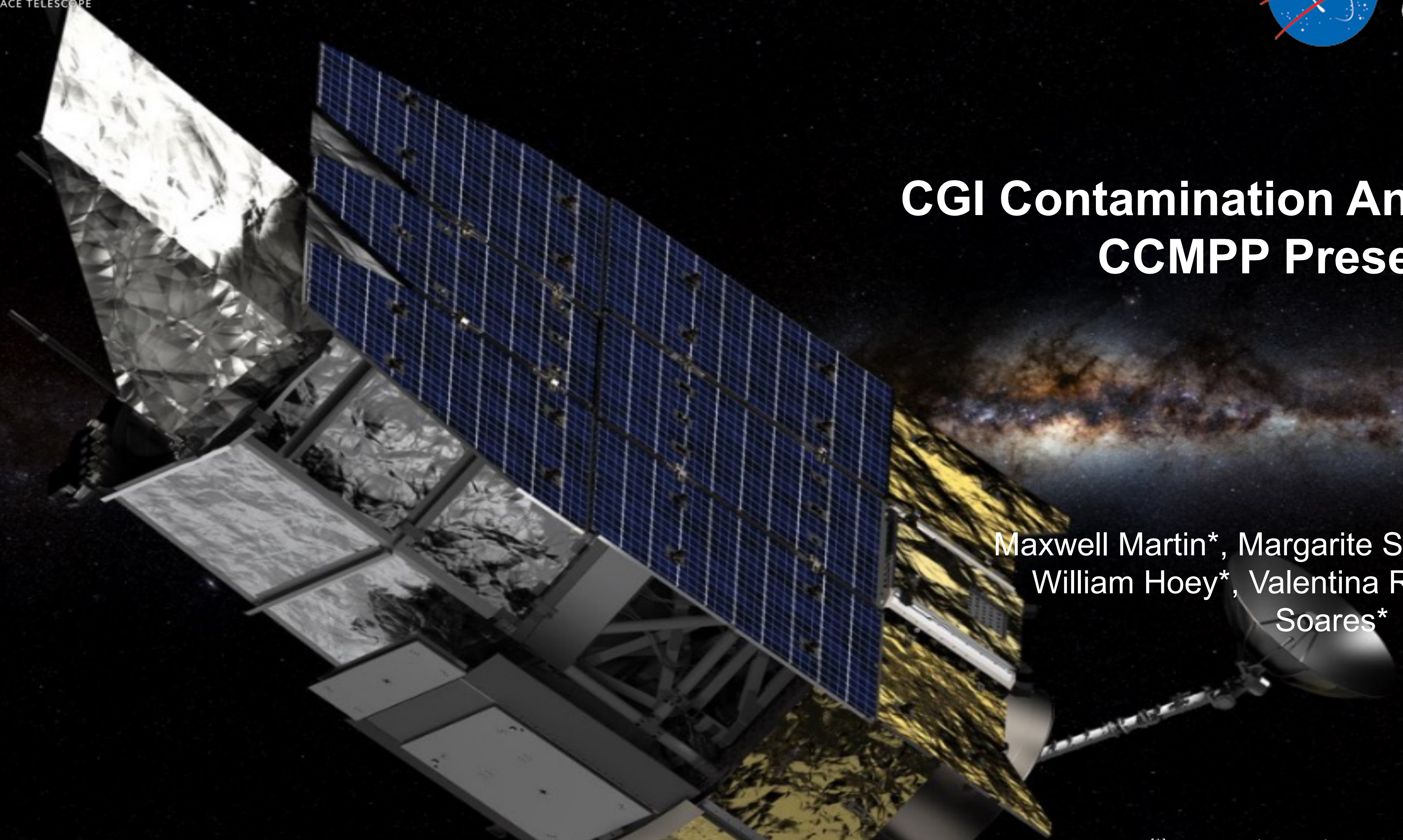
CGI Contamination Analysis Overview
CCMPP Presentation



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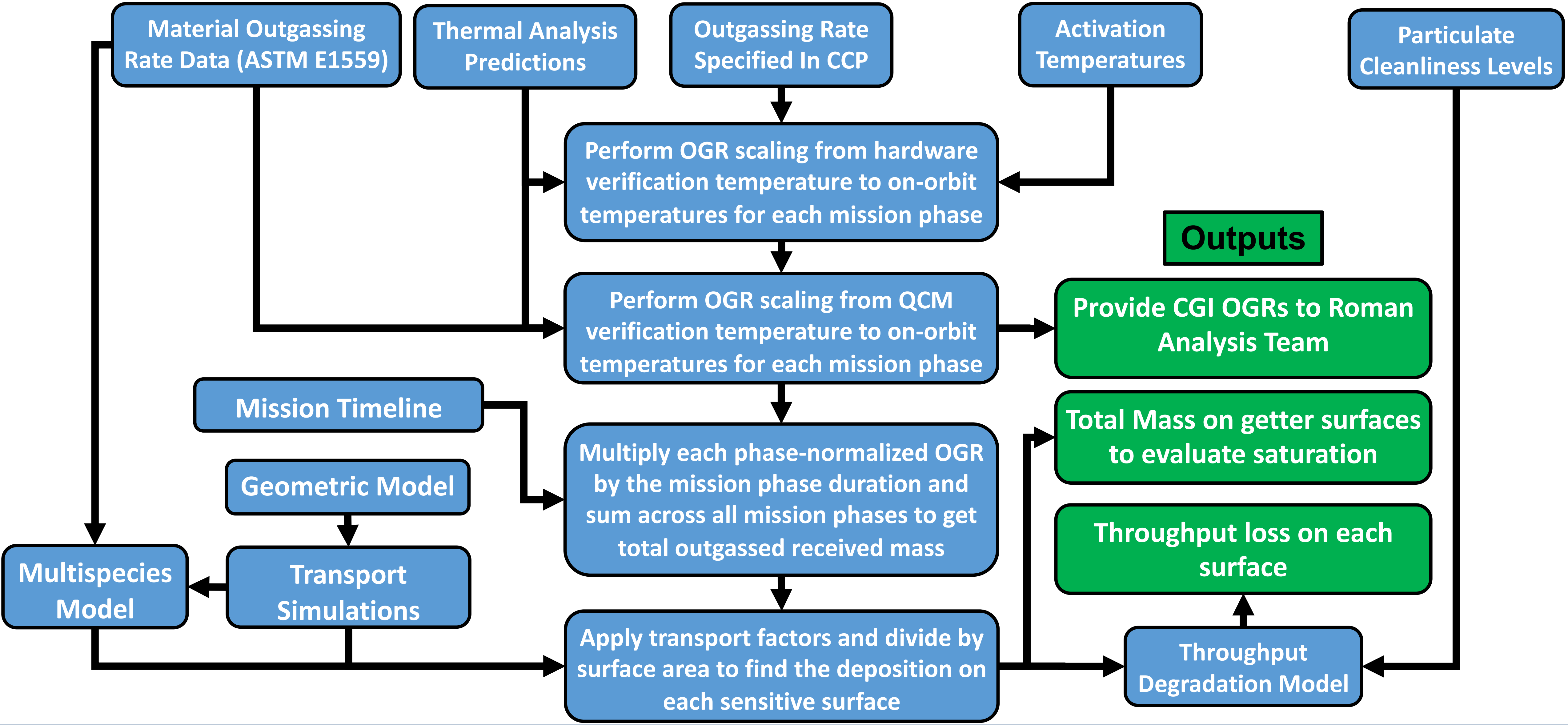
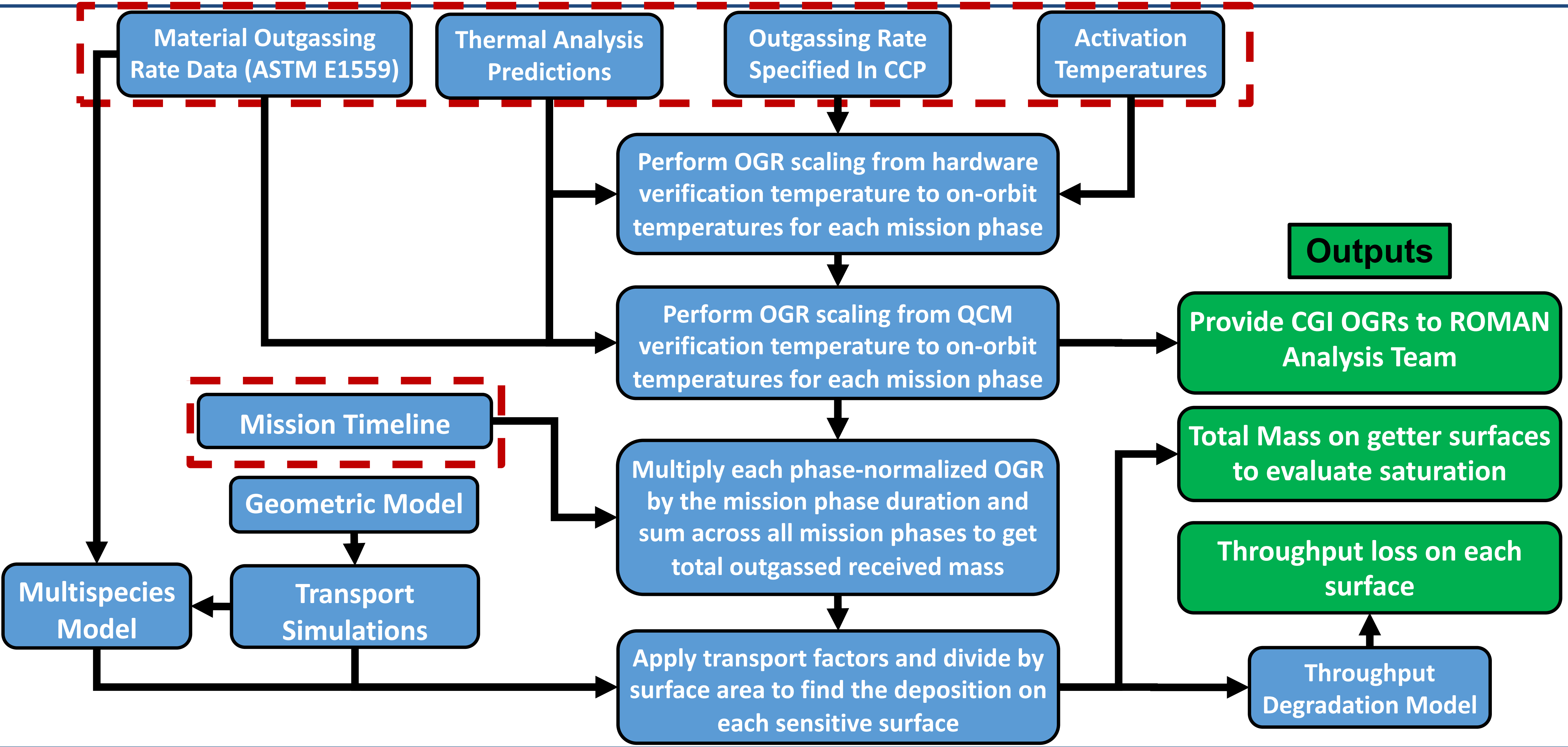
CGI Contamination Analysis Overview

- Model Inputs:
  - Thermal predictions
  - Mission timeline
  - Hardware outgassing rate requirements
  - Material outgassing rate data
- Model Methodology:
  - Outgassing rate extrapolation
  - Geometric model and mesh creation
  - Transport simulations
  - Multispecies modelling
  - Optical throughput modelling

Molecular Contamination Model Overview



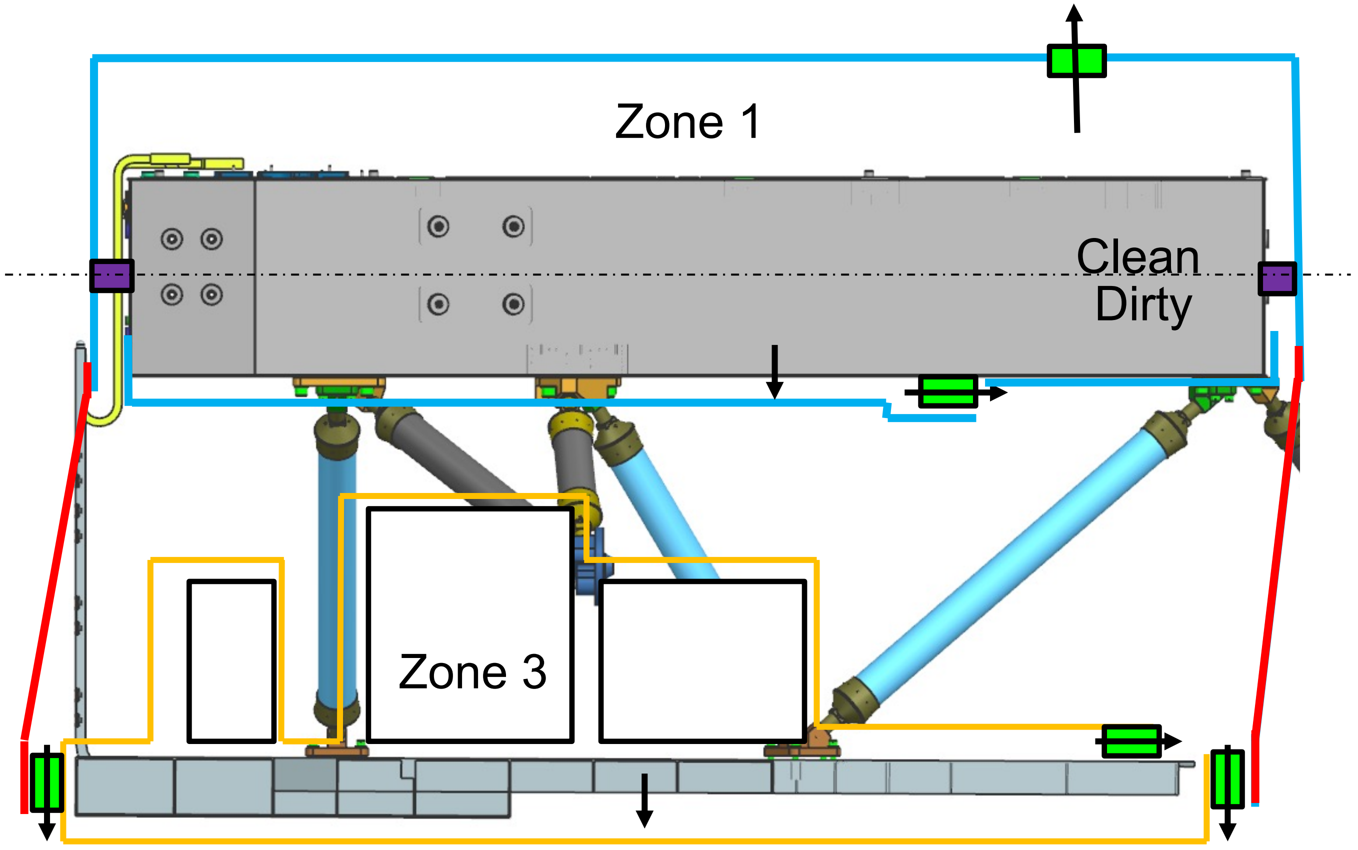
Inputs



Material Outgassing Rate Data (ASTM E1559)
Thermal Analysis Predictions
Outgassing Rate Specified In CCP
Activation Temperatures
Perform OGR scaling from hardware verification temperature to on-orbit temperatures for each mission phase
Perform OGR scaling from QCM verification temperature to on-orbit temperatures for each mission phase
Mission Timeline
Geometric Model
Multiply each phase-normalized OGR by the mission phase duration and sum across all mission phases to get total outgassed received mass
Multispecies Model
Transport Simulations
Apply transport factors and divide by surface area to find the deposition on each sensitive surface
Outputs
Provide CGI OGRs to ROMAN Analysis Team
Total Mass on getter surfaces to evaluate saturation
Throughput loss on each surface
Throughput Degradation Model

CGI Outgassing Zones

- CGI is broken into 3 different outgassing zones:
  - Zone 1 – Optical bench
  - Zone 2 – Exterior Components
  - Zone 3 – Electronics Enclosure
- Within each zone, each component has a specific outgassing rate requirement (mass/time)
- For the CGI analysis, Zone 1 is broken up into two portions:
  - MLI, Composite, Harnessing and Adhesives which have ASTM E1559 data and are handled via the Multispecies Model
  - Everything else in the optical bench is handled via the excel model



Intended to be a pseudo barrier/tortuous path for contaminants

Nominal vent path

Thermal Predictions

Mission Phase	Zone 1 and 2 Thermal Case Assumed	Zone 3 Thermal Case Assumed	Sensitive Surface Thermal Case Assumed
Launch	Survival	Survival	Survival
Cruise	Decontamination	Star Acquisition Hot	Decontamination
Operations	Star Acquisition Hot	Star Acquisition Hot	Observation Cold
Standby	Standby Hot	Standby Hot	Standby Cold

Mission Phase	Zone 1 Temps (C)	Zone 2 Temps (C)	Zone 3 Temps (C)	Other SC Temps (C)	Hot Optics Temp (C)	Cold Optics Temp (C)	Warm Radiator Temp (C)	Cryo Radiator Temp (C)	TOMA Temp (C)	Getter Temp (C)
Launch	19	19	-16	20	-23	-135	-30	-138	-25	-188
Cruise	19	19	-3.8	20	16	26	-29	-75	-25	-188
Operations	21	21	50	20	17	-110	24	-129	-25	-188
Standby	-12	-12	-3.8	20	-23	27	-20	-126	-25	-188

Mission Timeline

- The overall mission description provided to the CC team was approximately 2 days of “early launch” equivalent to survival, followed by approximately 70 days of cruise. The next 18 months would be split between 3 months of operation and 15 months of standby.
- The CC team was asked to assess an approximately 21 day continuous operational duration.

Hardware Outgassing Rate Requirements

- Outgassing rate requirements are given for each component and subsystem, to be verified at various levels of integration using QCM monitoring.
- In general, outgassing rates are specified in ng/hr as measured with the hardware at 25C and the QCM at -105C with some measurements taken at alternate temperatures to accommodate hardware or chamber availability.
- For materials that are well suited to area-normalized outgassing rates (MLI, composite structure, harnessing, adhesives) existing outgassing rate data per ASTM E1559 is used for initial estimates.

Outgassing Rate from Spacecraft Sources

- Spacecraft outgassing rates entering the CGI Aperture were provided by the Nancy Roman contamination analysis team.
- The Hot Optics, Cold Optics and Getter should not accumulate water, so the water vapor outgassing is not included.

Here are aperture flux onto CGI instrument. CGI aperture is 7.15 in^2. Water vapor data was obtained either from MOLEKIT data or other sources. VCM data is for receiver at -20C.

(A) VCM.

- Composite. Majority from TOMA internal surfaces, with total area of 2540 in^2, 20C (293K, heated)
- Rate1= 3.08E-11 exp (-t/344) g/s, t (hrs)
  = 6.678E-13 exp (-t/344) $g/cm^2/sec$, t (hrs)
- MLI. Mainly from bottom side of the TOMA, 20C., the rest from spacecraft at much lower temperature.
- Rate 2= 6.64E-11 exp(-t/200) g/s, t(hrs)

  = 1.44E-12 exp(-t/200) $g/cm^2/sec$, t(hrs)

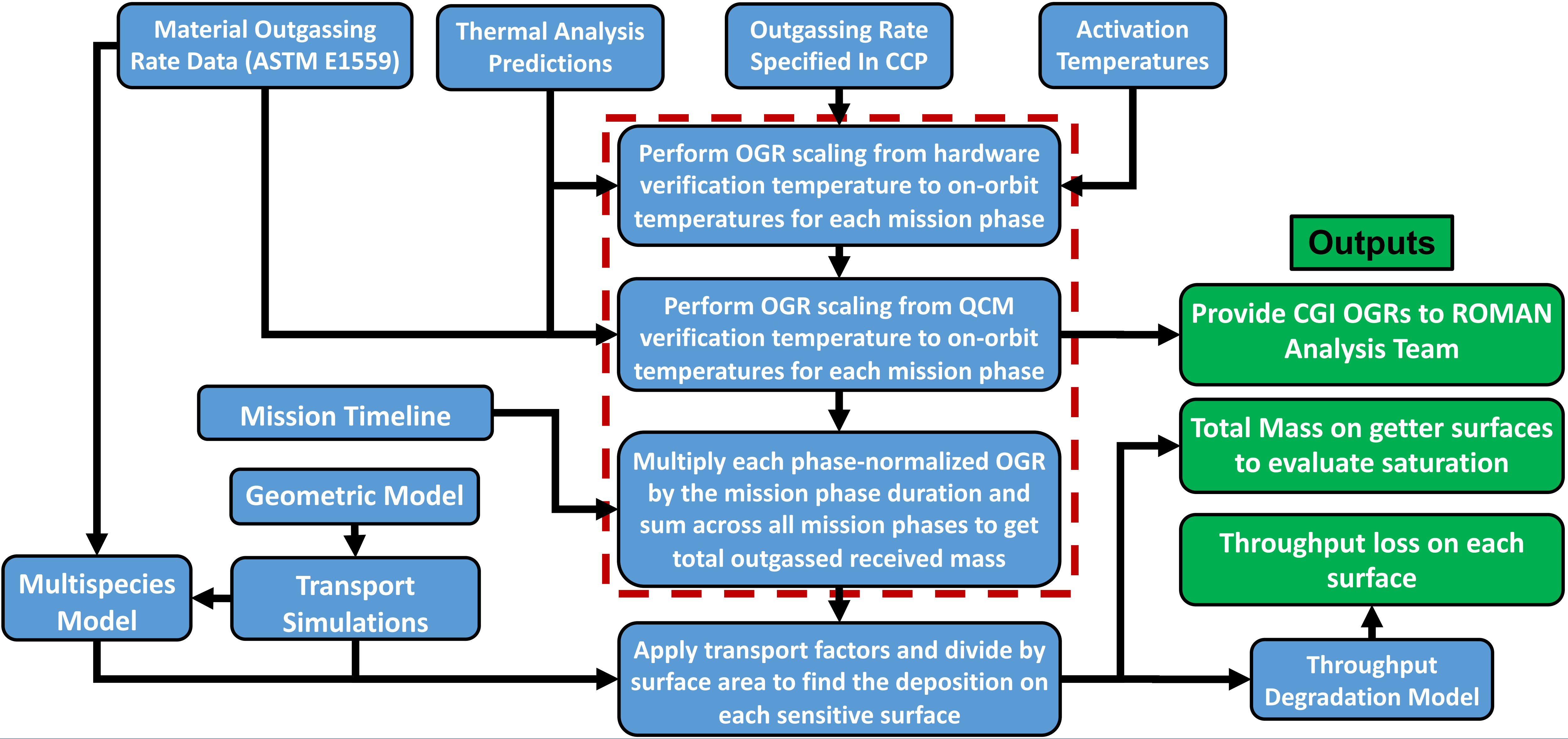
  Total aperture flux = rate1 + rate2

(B) Water Vapor.

- Composite. Majority from TOMA internal surfaces, 20C .
  - diffusion coefficient D = 1.31E-10 cm^2/sec.
  - initial concentration C_o = 4.2E-4 g/cm^3
  - thickness = 80 mils (mainly 80 mils according to Gary at L3-Harris)
- Rate3 = 1.931E-8 * $t^{0.5}$ g/s where t is in seconds
  = 4.186 E-10 * $t^{0.5}$ $g/cm^2/sec$, where t is in seconds.
- MLI. Majority from TOMA bottom side surface, 20C, the rest from S/C at much lower temp.
- Rate4 = 5.08E-7 * $t^{1.56}$ g/s, where t is in hours.
  = 1.1E-8 * $t^{1.56}$ $g/cm^2/s$, where t is hours

  Total water aperture flux = rate3 + rate4

Outgassing Rate Extrapolation



Outgassing Rate Extrapolation Overview

Sum each component OGR (mass/time) in CCP for each Zone specified for a specific hardware temperature and QCM temperature → Use an Arrhenius scaling to extrapolate each Zone's OGR from hardware certification temperature to on-orbit temperature for each mission phase → Use QTGA data to scale the deposition predicted for the certification QCM temperature to each sensitive surface temperature for each mission phase

$$OGR_{Zone} = \sum OGR_{components}$$

$$OGR_{extrap} = OGR_{Zone}\, e^{\left(\frac{T_A}{T_{cert}} - \frac{T_A}{T_{mission}}\right)}$$

T_A = Activation Temp. (K)

T_{cert} = Hardware Certification Temp. (K)

$T_{mission}$ = Hardware on-orbit Temp. (K)

Assuming T_A = 10000K

Step 1: Normalize QTGA data to base frequency

$$f(T)_{norm} = f(T) - f(T)_{min}$$

Step 2: Determine Sticking Fraction

$$F_{Stick}(T) = \frac{f(T)_{norm}}{f(T)_{norm,Max.}}$$

Step 3: Compute ratio of certification temperate and mission temperature sticking fractions

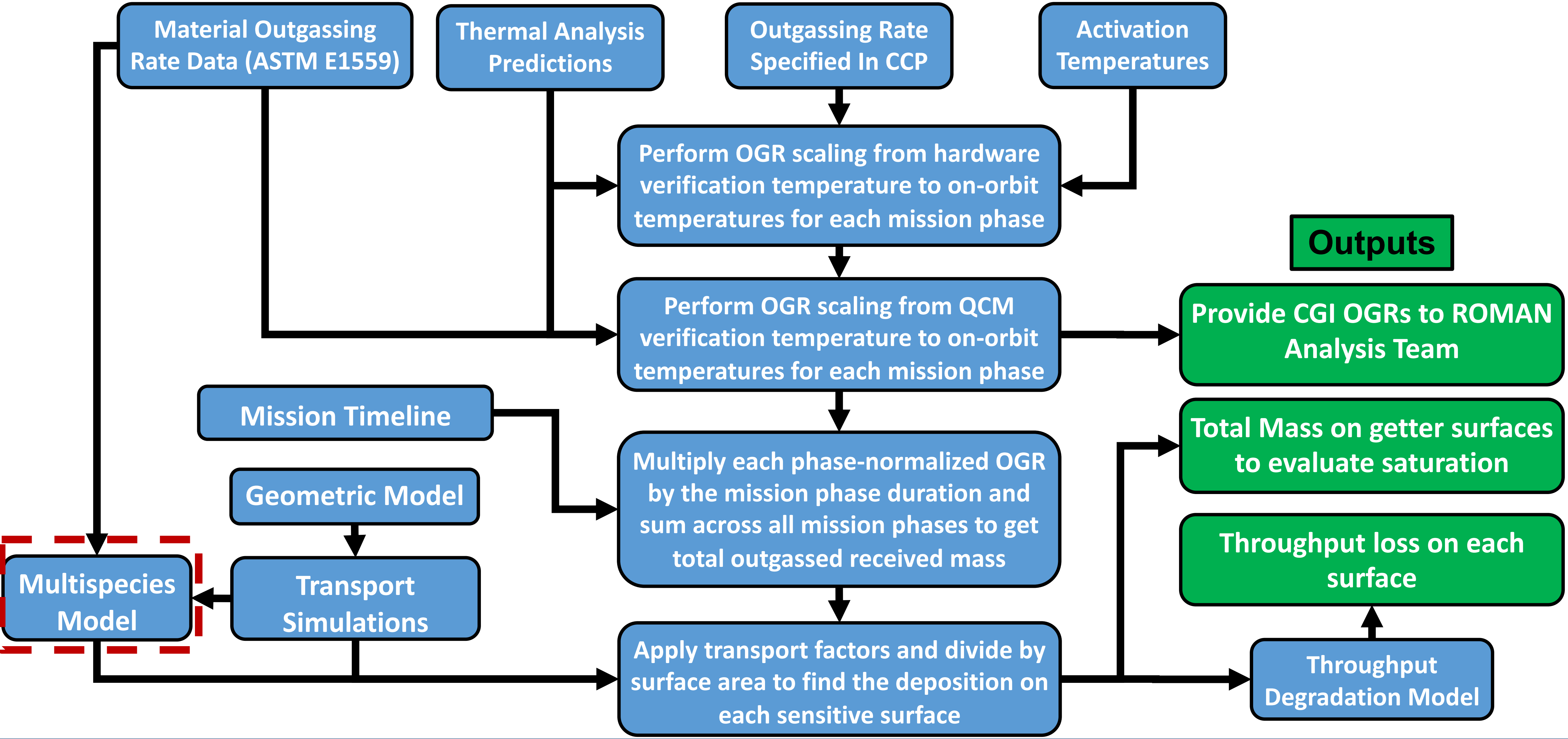
$$R(T_{mission}) = \frac{F_{Stick}(T_{mission})}{F_{Stick}(T_{cert})}$$

Step 4: Multiply by the normalization factor

$$OGR_{Norm} = OGR_{Extrap} * R(T_{mission})$$

Step 5: Repeat these steps for all combinations of Certification/QCM/On-orbit temperatures

Multispecies Model



Outgassing Test Data

- ASTM E1559 test
  - Quartz crystal microbalances (QCM) are utilized to measure outgassing mass
    - QCMs are extremely sensitive mass instruments with temperature control
    - Can be used to measure condensable outgassing at a specified receiver temperature.
- Two test exercises to characterize outgassing kinetics
  1. Isothermal:
     - Sample is held at constant temperature or predefined temperature steps. Controls diffusion of outgassing out of sample material
     - Multiple QCMs at different temperatures measure outgassing collection over time. Controls residence time on different QCMs
  2. QCM Thermo Gravimetric Analysis (QTGA)
     - QCM temperature is slowly raised (1C/min). Slowly changes residence time so contaminant species desorb.

Fitting Scheme

- Available materials test consists of multiple datasets
- Multispecies fit ideally includes all datasets (Isothermal + QTGA) to derive set of material parameters

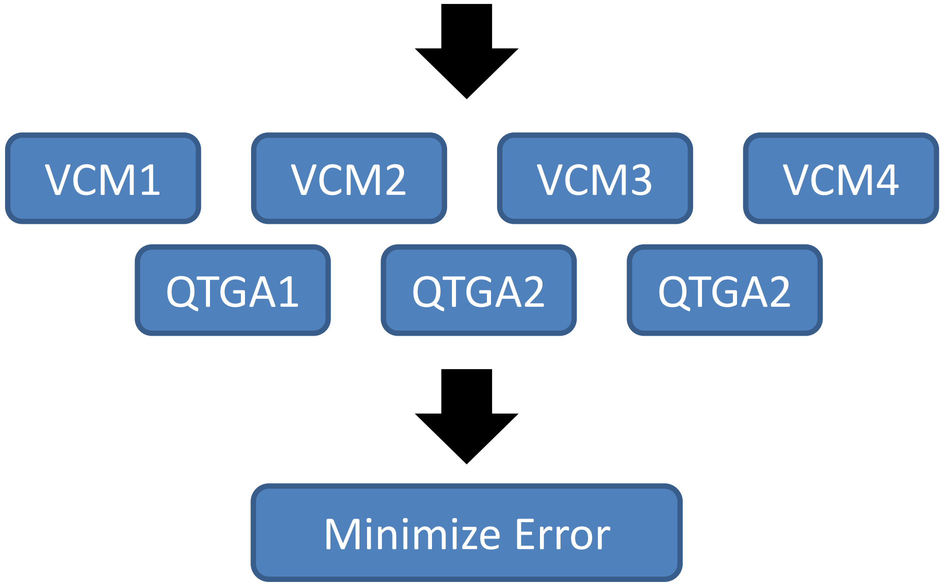
Model Input Variables

Material Parameters

$\{D_0,\ E_{a,diff}\ ,\ C_0,\ \tau_{0,des}, E_{a,des}\}$

Datasets to fit

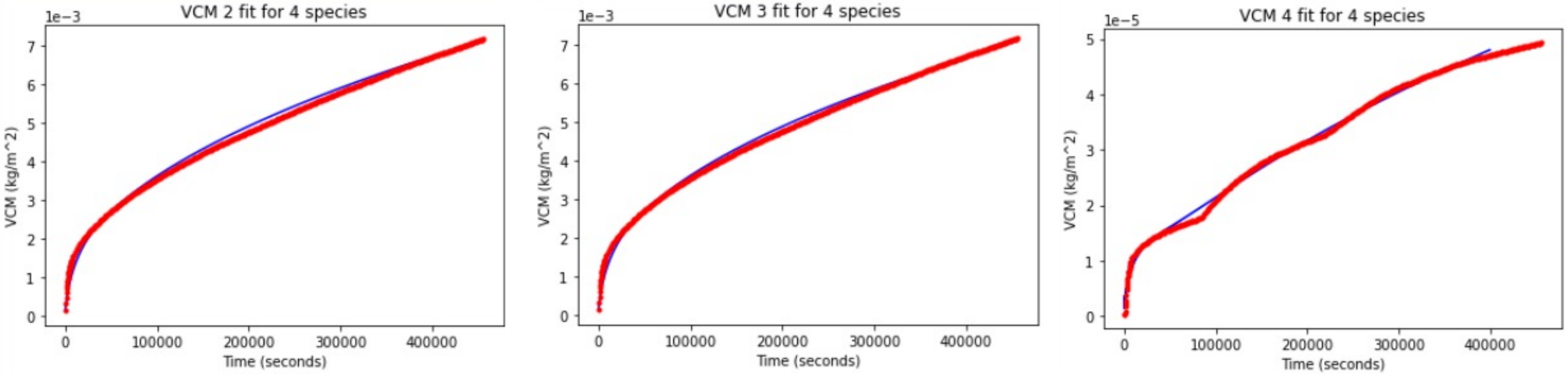
Objective Function



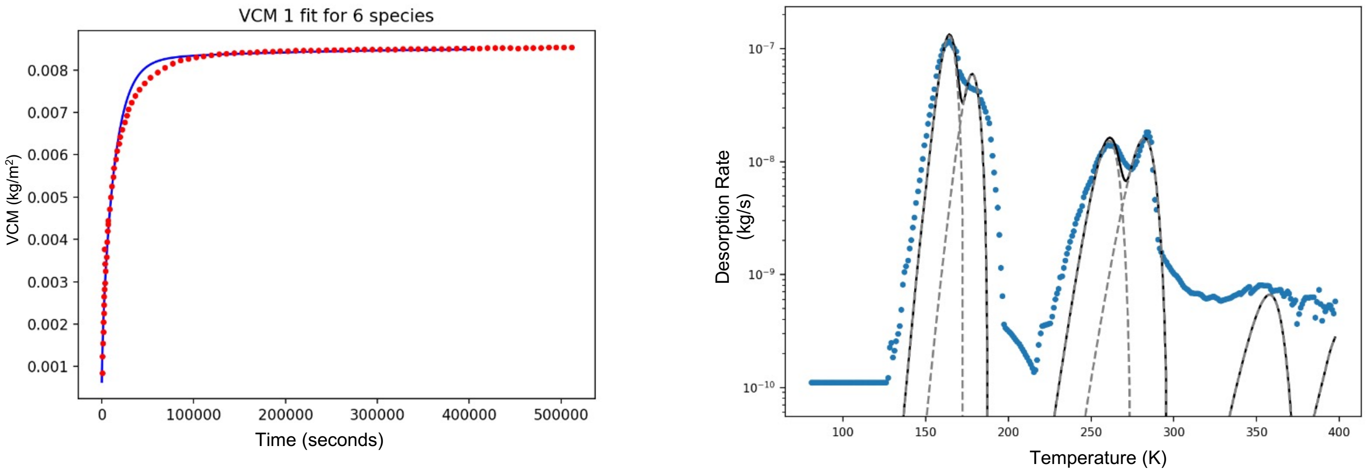
CGI Materials Fits

- Multispecies fit fully characterizes outgassing kinetics
- For CGI multispecies fits were performed for: Cable Harness, M55J, Black Kapton, Hysol Eccobond 57C

Cable Harness

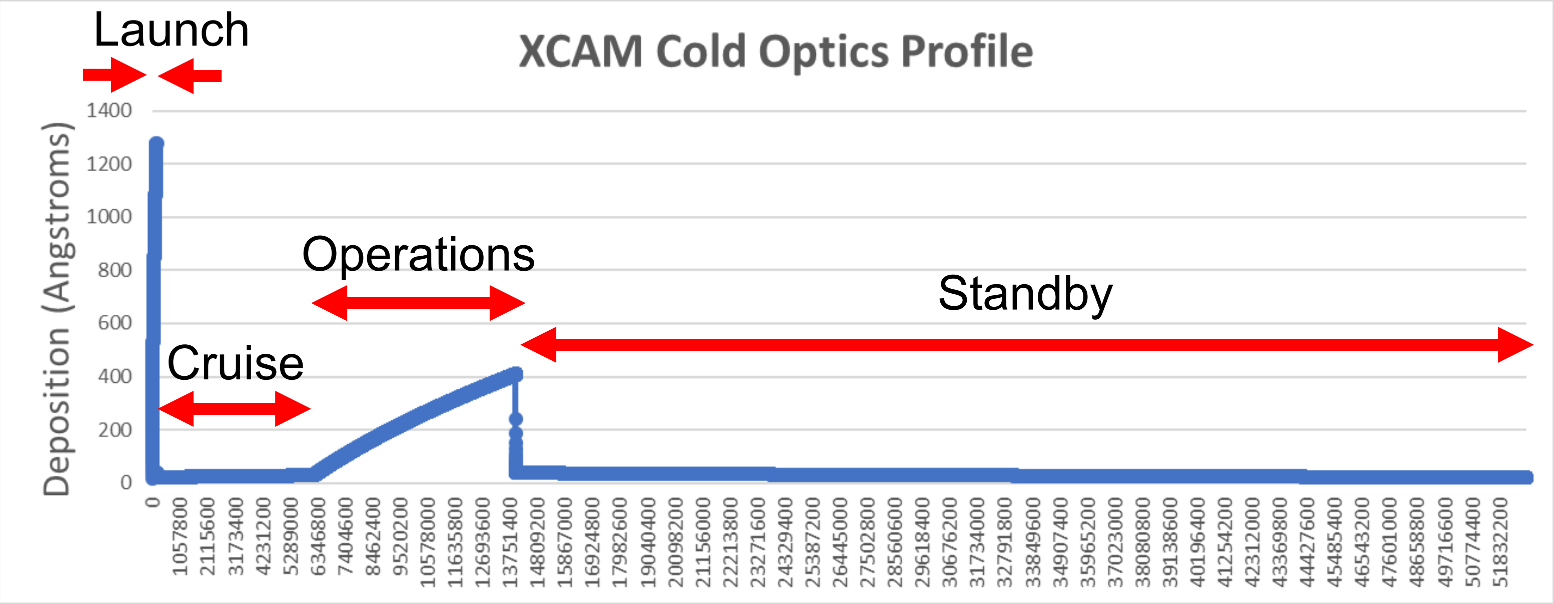


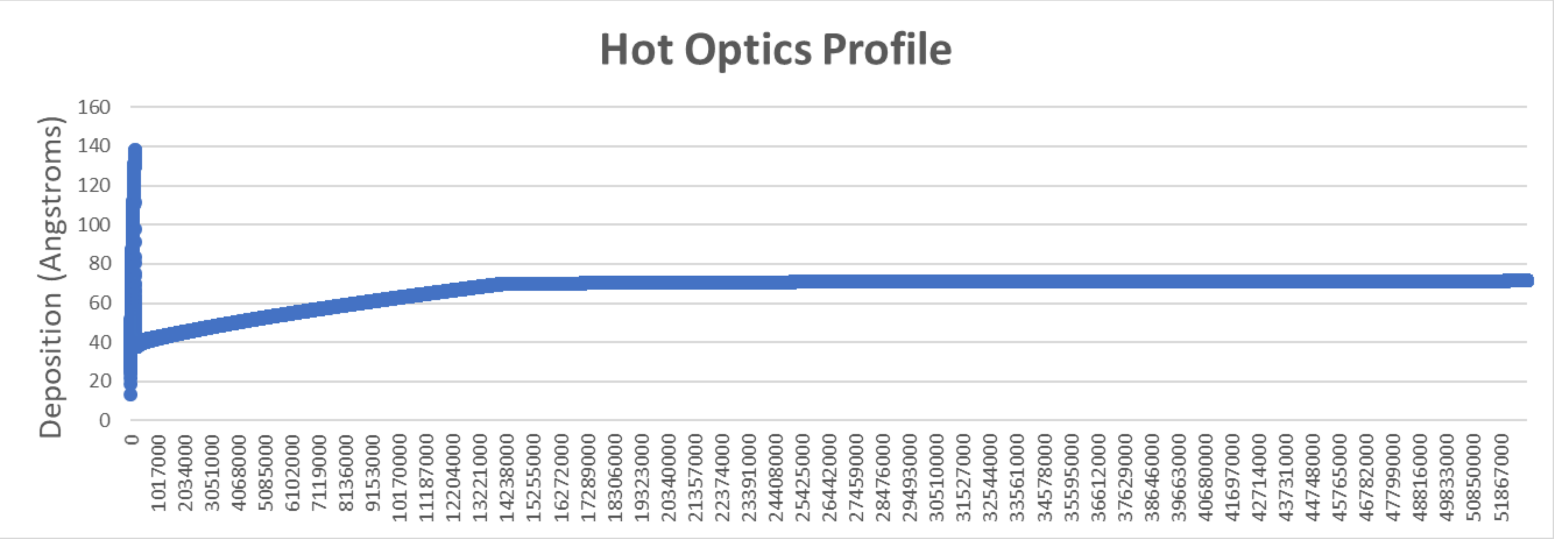
Hysol Eccobond 57C



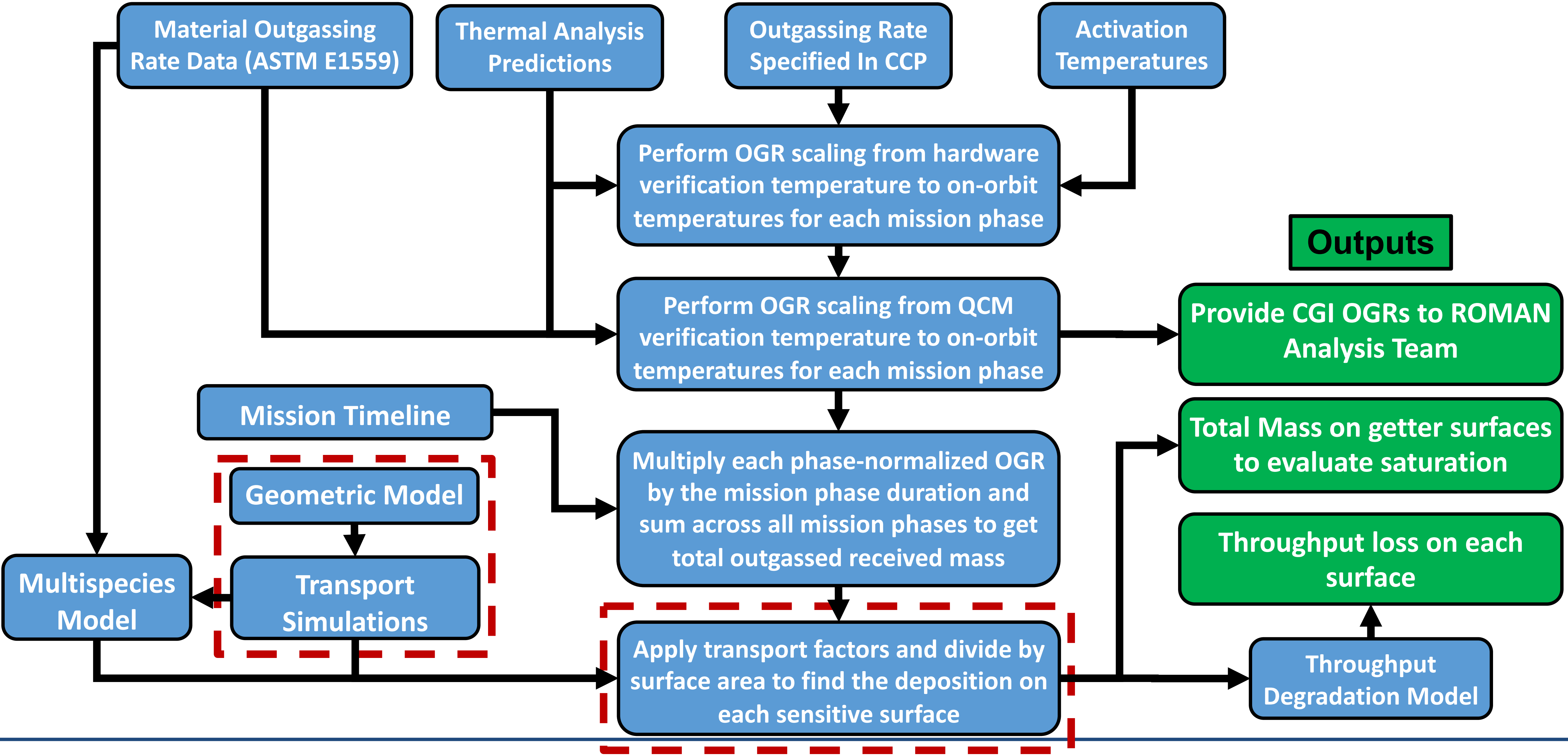
Multispecies Results

- Multispecies modelling was run for each optical surface, and a representative cold optics and hot optics case are shown to the left.
- The cold optics case assumed 90 days of continuous operation, which is scaled to the 21 day accumulation assessed in this analysis.





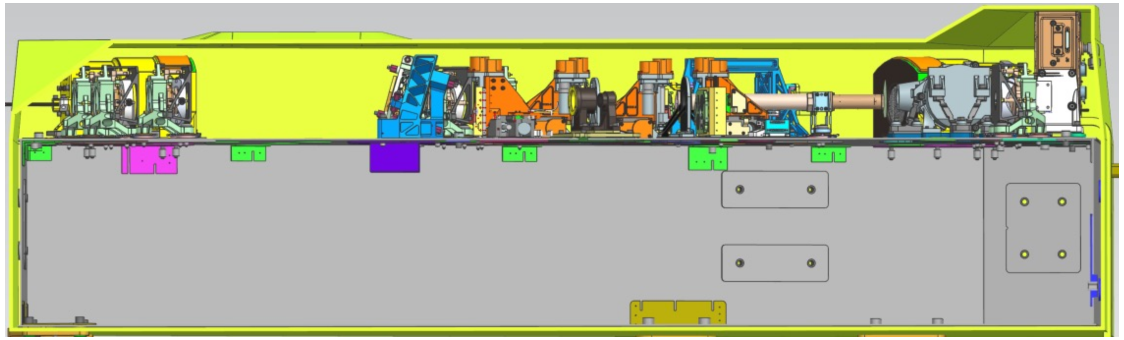
Geometric Modelling and Transport Simulations

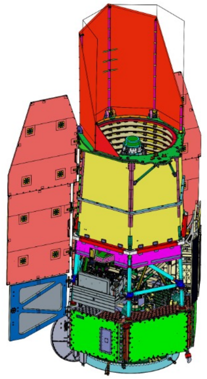


CAD Model Processing

As-Received Model

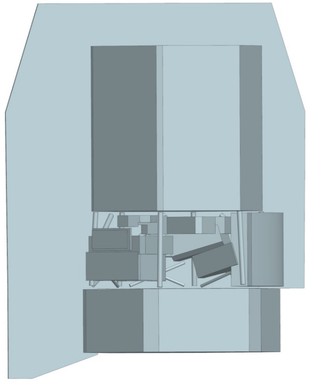
- Would result in too many elements for transport modelling codes to process





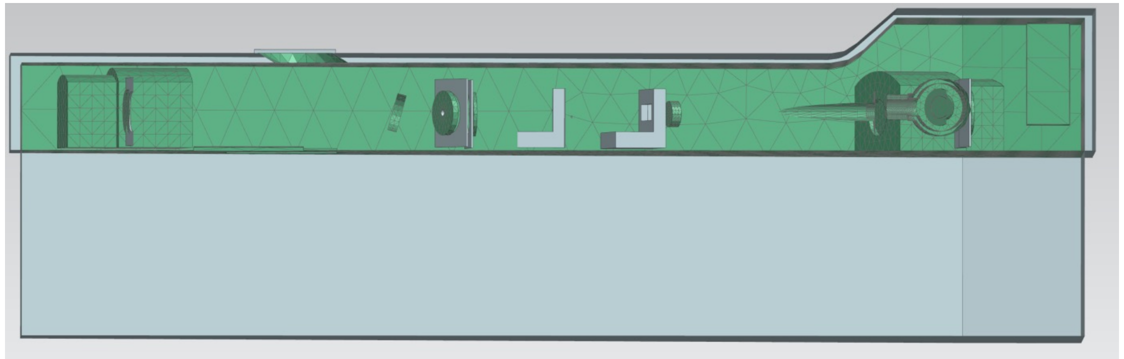
Simplified Model

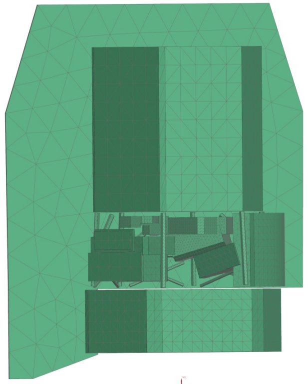
- Recreate S/C with enough detail to capture outgassing direct/reflected effects but with manageable element count.



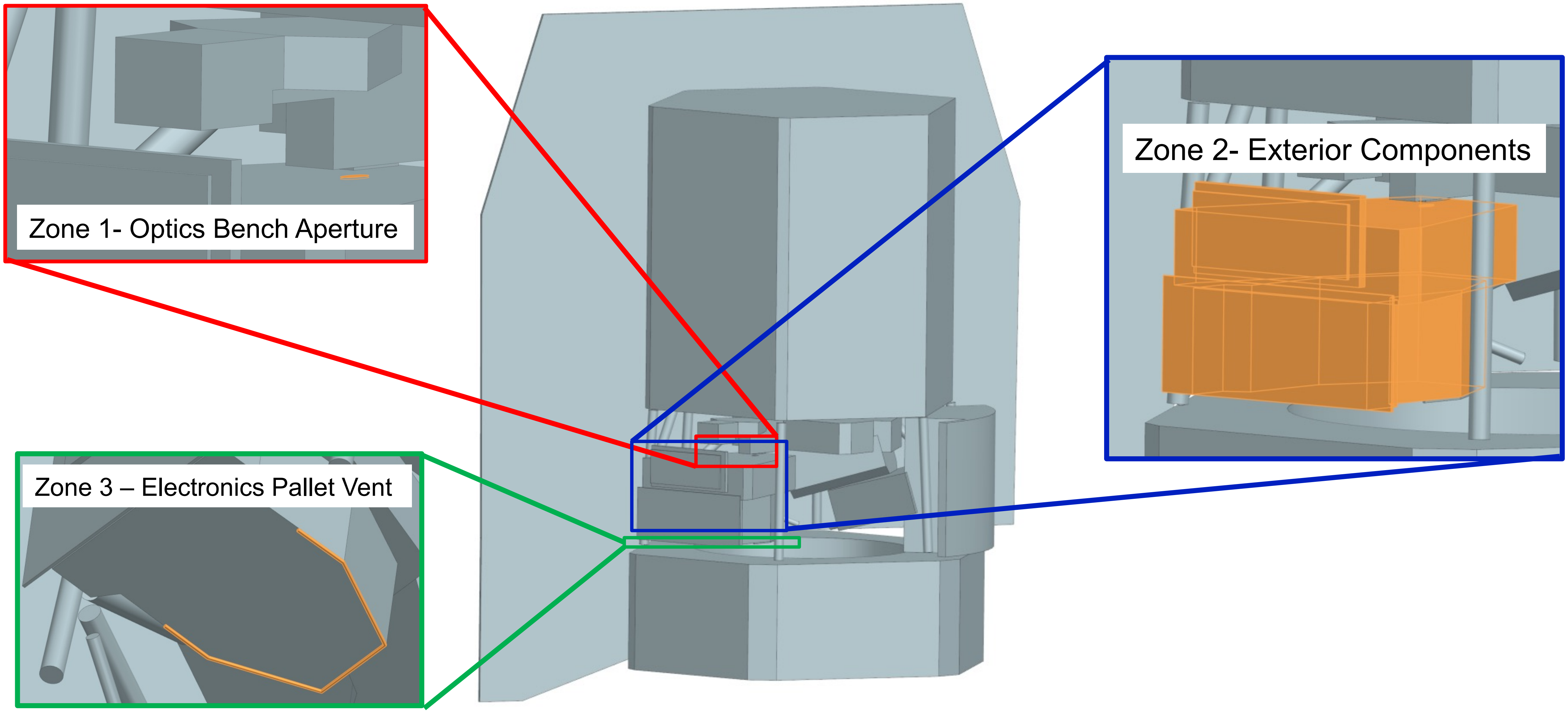
Meshed Model

- Optimize meshing of model to meet element count target, with finer meshes around important surfaces



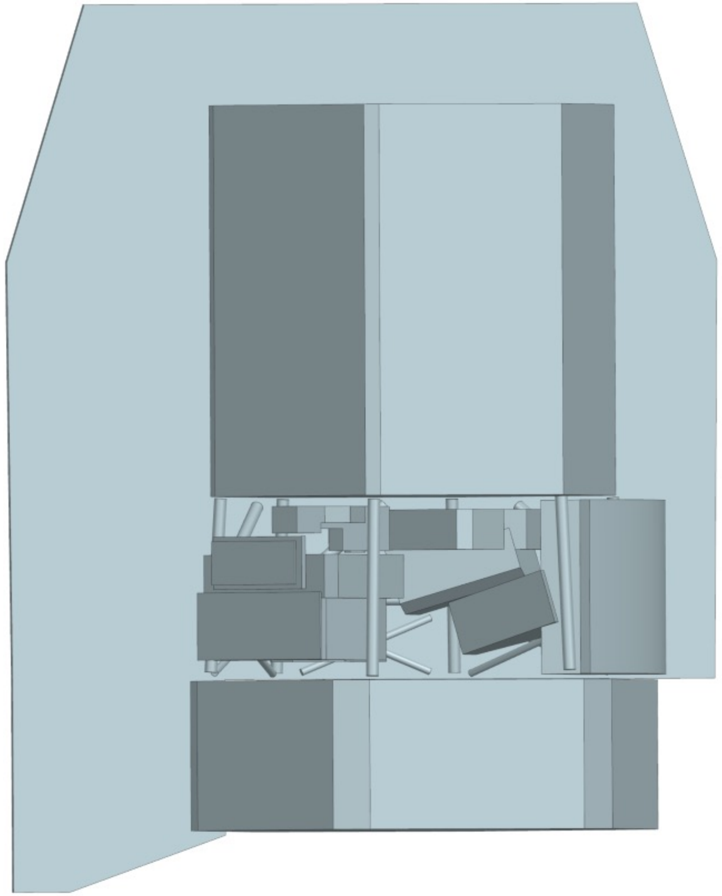


ROMAN Reduced Model



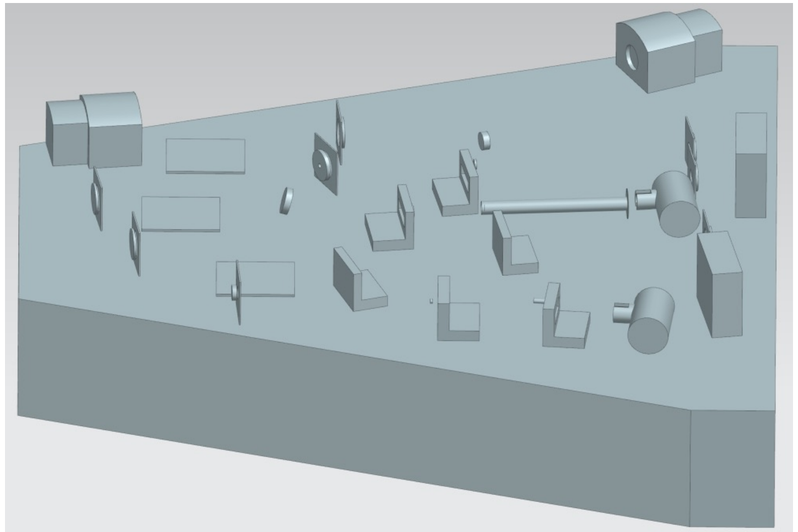
Using Multiple Models

External Model



Analyzed using JPL's
View Factor Code

Internal Model

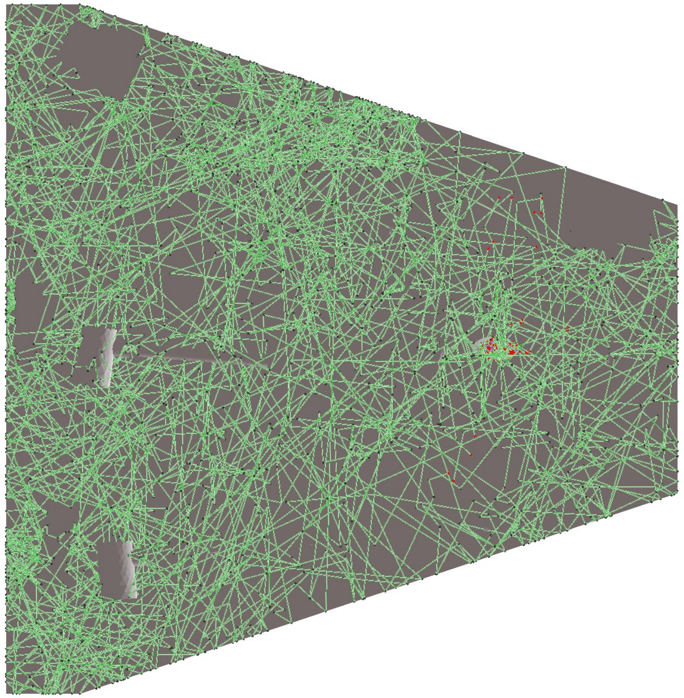


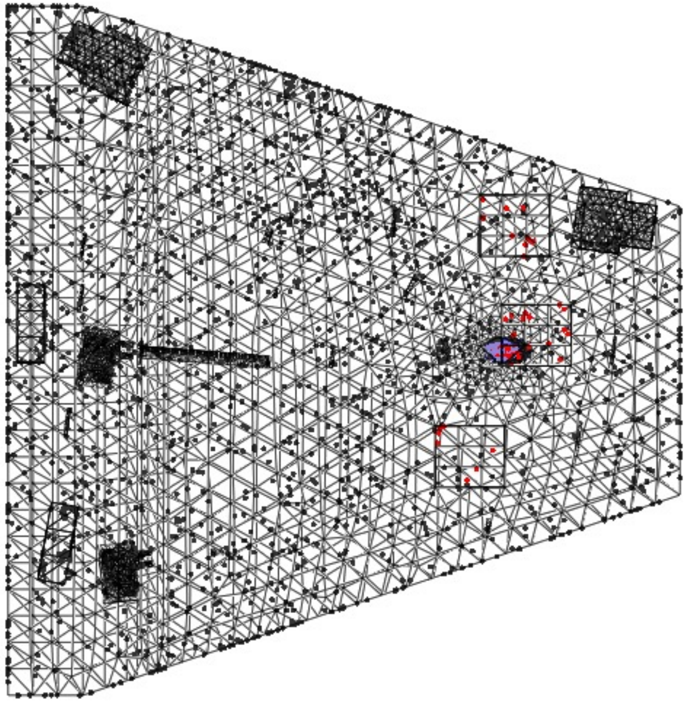
Analyzed using
MOLFLOW+

GSFC
Modelling

Internal Transport: JPL CC Ray-Tracing Methodology

This is a visualization of a *ray-tracing Monte Carlo* result for internal transport within the CGI optical bench, calculated using CERN's MOLFLOW+ package. In this case, emitting facets release rays from a cosine angular distribution with uniform probability per-unit-area, and impinging 'hits' onto each sensitive-surface facet can be understood as a measure of molecular flux for a given rate of source outgassing [in mass / area / time].

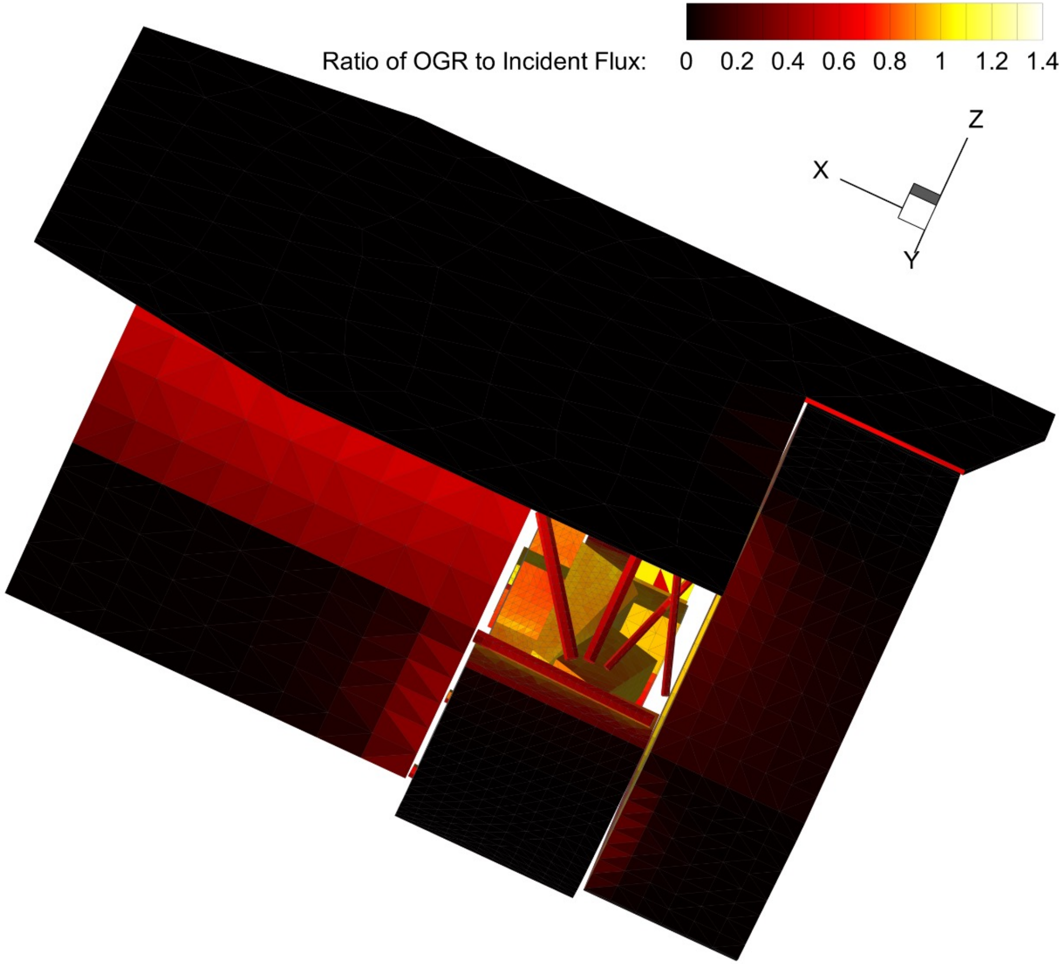


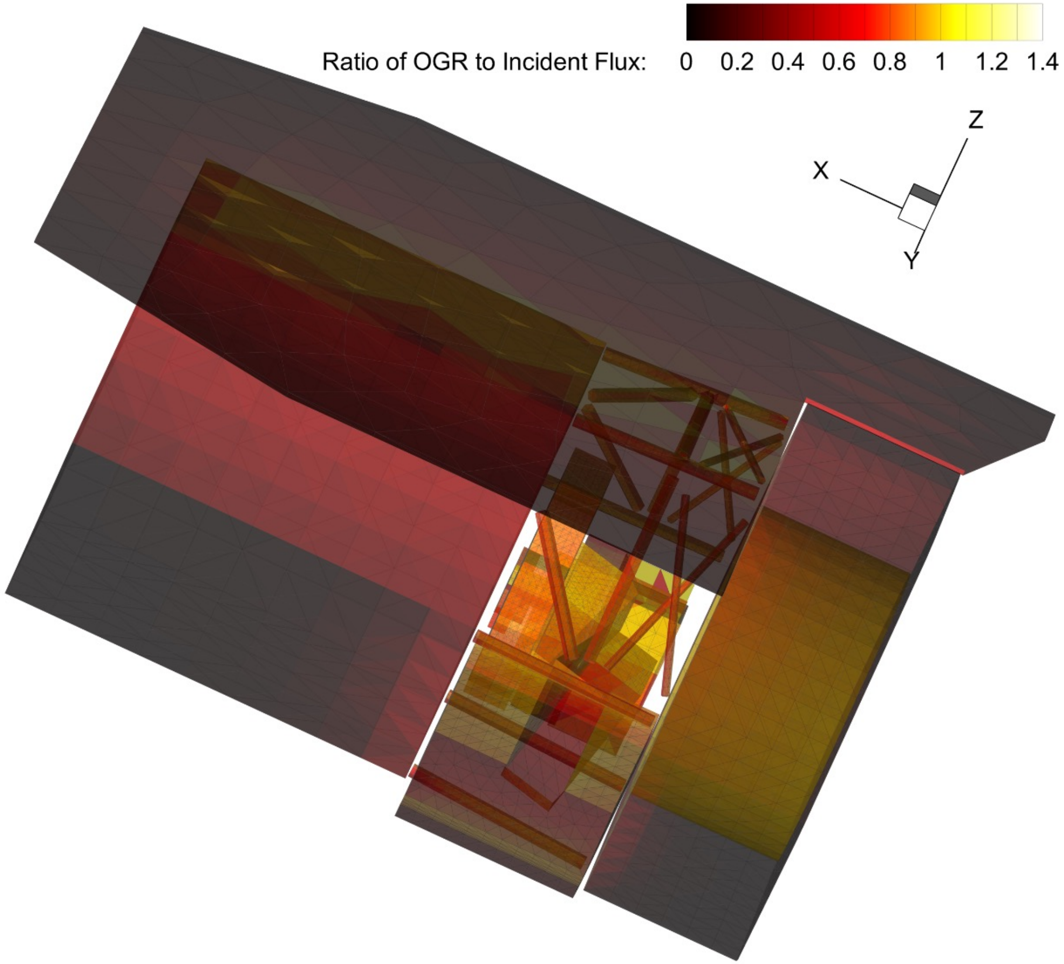


Ray-tracing Monte Carlo schemes propagate individual representative molecular trajectories throughout an instrument environment along lines-of-sight punctuated by wall interactions by which rays experience diffuse molecule surface reflections; each ray ultimately either escapes or adsorbs onto a designated sensitive surface.

Ex: ROMAN Viewfactor Transport

In this example, all surfaces outgas at a uniform rate, and stick all incident contaminant flux.





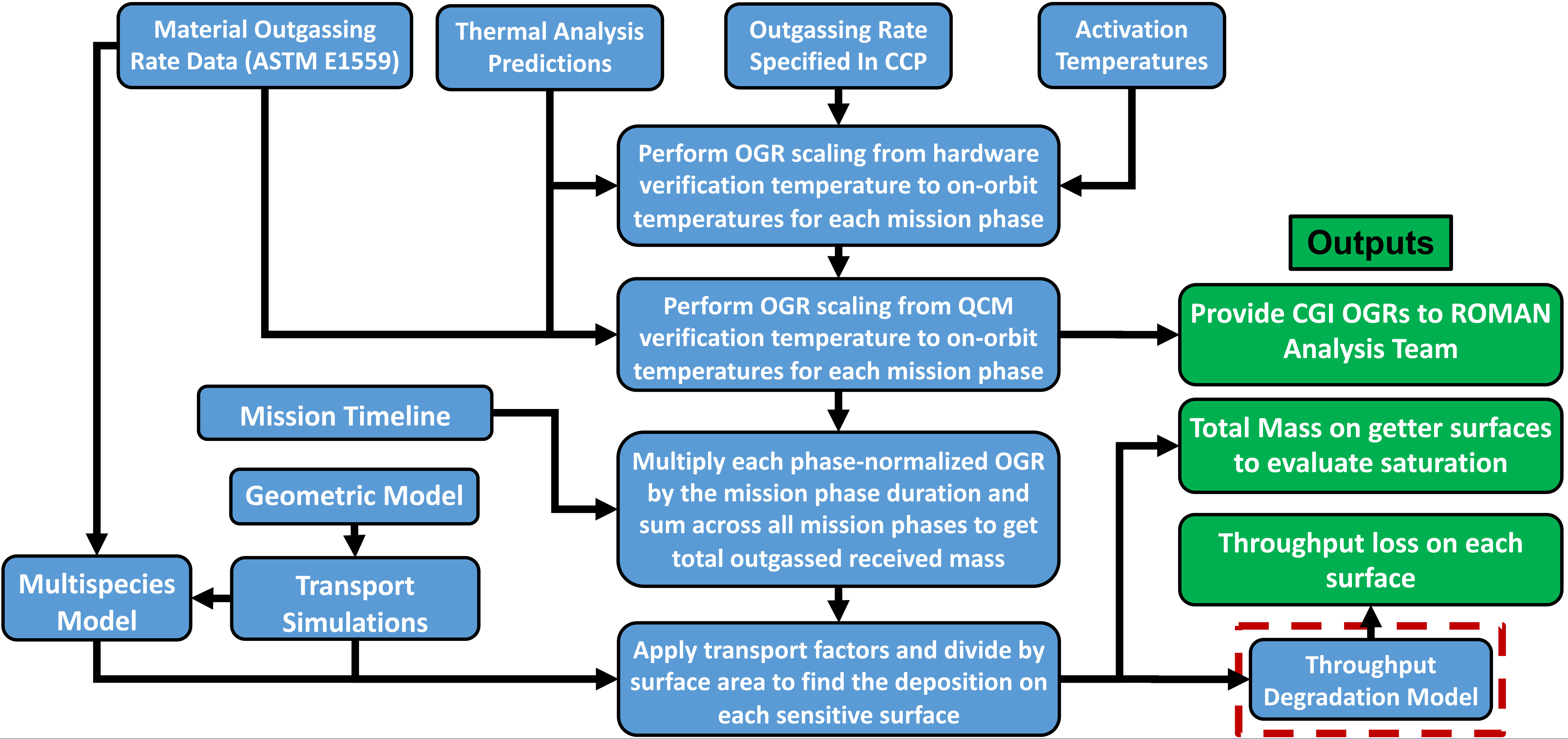
This is the simplest visual representation of the complete N×N viewfactor transport matrix, which contains information about transport from each mesh element to all other mesh elements, and which we use to compute contaminant transport from each outgassing source group to each receiver group.

Transport Factor Implementation and Combination

- Internal and external models are connected by multiplying view factors together.
- For example, to calculate the amount of outgassing from Zone 3 that reaches a detector:
  - (Zone 3 OGR) * (Zone 3 → CGI Aperture) * (CGI Aperture → Detector)
  - (Zone 3 OGR) * (3.586E-05) * (0.001)

Electronics Pallet (Zone 3) --> CGI Aperture	3.586E-05
Electronics Pallet (Zone 3) --> TOMA	9.509E-05
Electronics Pallet (Zone 3) --> WFI	7.240E-05
Electronics Pallet (Zone 3) --> Warm Radiators	2.951E-06
Electronics Pallet (Zone 3) --> Cold Radiators	2.663E-05
Other SC Sources ---> CGI Aperture	1.000E+00
Other SC Sources --> Warm Radiators	1.000E+00
Other SC Sources --> Cold Radiators	1.000E+00
Aperture Inlet --> Getter	0.6500
Aperture Inlet --> Detector	0.0010
Aperture Inlet --> Aperture (reflected back out)	0.3450
General Bench Materials --> Getter	0.946
General Bench Materials --> Aperture	0.041
General Bench Materials --> Detector	0.0032
Aperture Outlet --> TOMA	0.19
Aperture Outlet --> WFI	4.51E-06
Aperture Outlet --> Warm Radiator	1.83E-06
Aperture Outlet --> Cold Radiator	6.02E-06
Exterior (Zone 2) --> Aperture	7.39E-04
Exterior (Zone 2) --> TOMA	4.74E-03
Exterior (Zone 2) --> WFI	1.21E-04
Exterior (Zone 2) --> Warm Radiators	8.29E-04
Exterior (Zone 2) --> Cold Radiators	7.83E-05

Throughput Degradation Model



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Throughput Model Methodology

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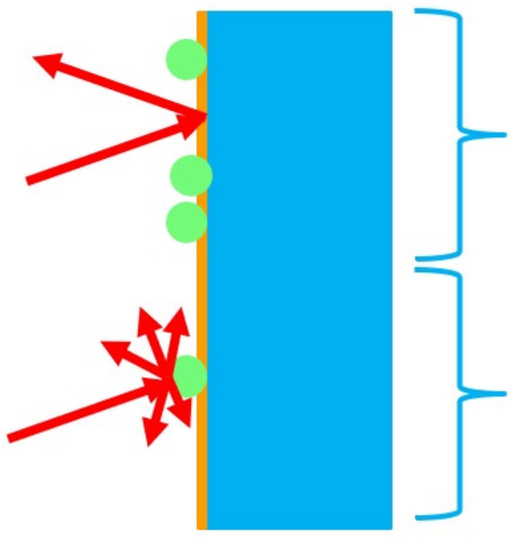
- Due to the large size difference between particles and molecular film thicknesses, this analysis considers light to first interact with particles and then with molecular films. This is shown schematically below.
- In order to combine the effects of particulate and molecular contamination of the instrument, we follow the light path for both transmit and receive modes and first apply degradation due to particulates and then by molecular contamination on each surface.
- Throughput loss due to molecular contamination is calculated according to Beer's law



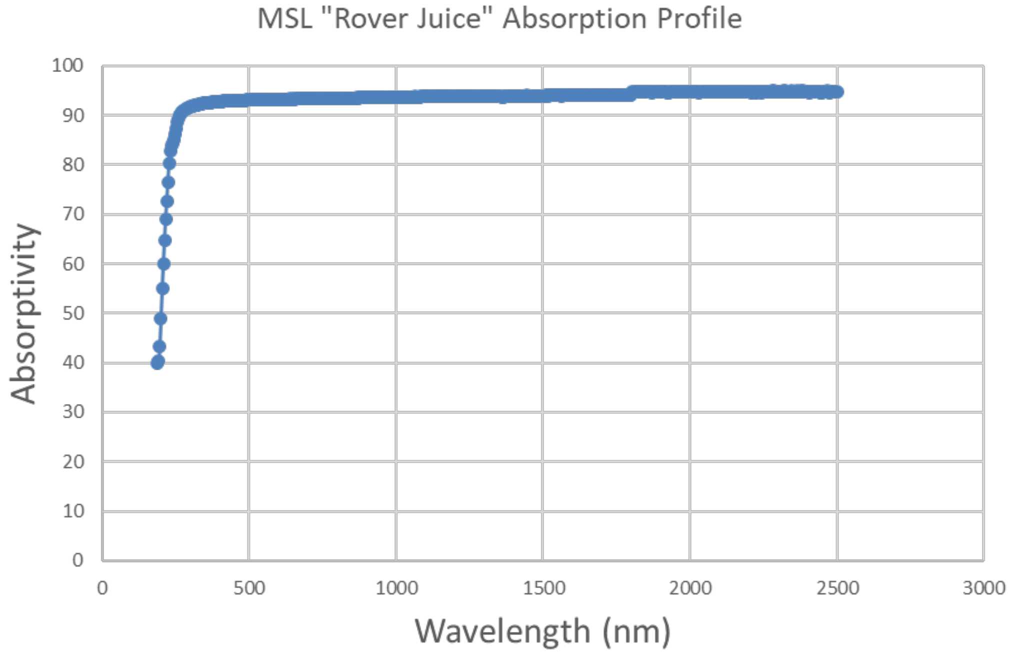
Case 1: light doesn't hit a particle, passes through 1 film thickness inbound and 1 film thickness outbound

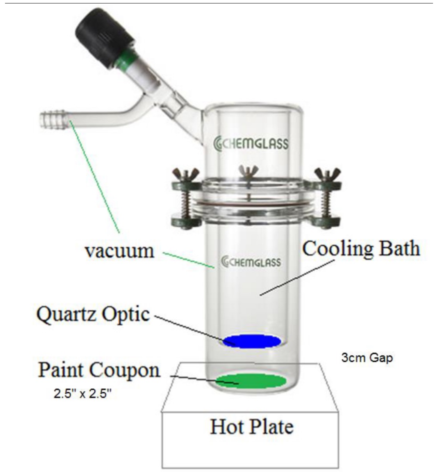
Case 2: light hits a particle, scatters or reflects prior to interacting with the molecular film

Light Path Sequence #	Sequence Description	Type of Sequence	Film Path Transits	Particulate Cleanliness (PAC)	Molecular Cleanliness (Angstroms)	Particle Contaminated Throuput (%)	Molecular Contaminated Throughput (%)
0	Light from TOMA	Empty	0	-	-	100.000	100
1	FSM	Reflect	2	0.02%	169.14	99.980	99.108
2	OAP1	Reflect	2	0.02%	169.14	99.088	98.224
3	Focus Mechanism	Reflect	2	0.02%	169.14	98.205	97.348
4	OAP2	Reflect	2	0.02%	169.14	97.329	96.480
5	DM1	Reflect	2	0.02%	169.14	96.461	95.619
6	DM2	Reflect	2	0.02%	169.14	95.600	94.767
7	OAP3	Reflect	2	0.02%	169.14	94.748	93.921
8	FM	Reflect	2	0.02%	169.14	93.903	93.084
9	OAP4	Reflect	2	0.02%	169.14	93.065	92.253

Throughput Analysis Absorption profile

- The CGI throughput analysis uses the absorption profile of the MSL "Rover Juice" collected from the cold finger of an MSL rover TVAC test.
- The collected effluent from the cold finger was deposited on a quartz optic and the throughput difference between the pristine and contaminated sample.
- That is then converted to an absorption per angstrom of deposition using the known contaminant thickness.
- That absorption/angstrom is then multiplied by the contamination deposition for each surface to get the throughput loss on each surface.





Conclusions

- JPL CC has successfully implemented this analysis methodology to flow requirements to CGI hardware teams.
- Hardware ATLO has begun, with bakeouts underway that will be used to anchor the predicted outgassing rates.
- Additional analysis updates will be performed as more data becomes available and to accommodate updates from thermal and mission planning.

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