Modeling contamination migration on the Chandra X-ray Observatory — III

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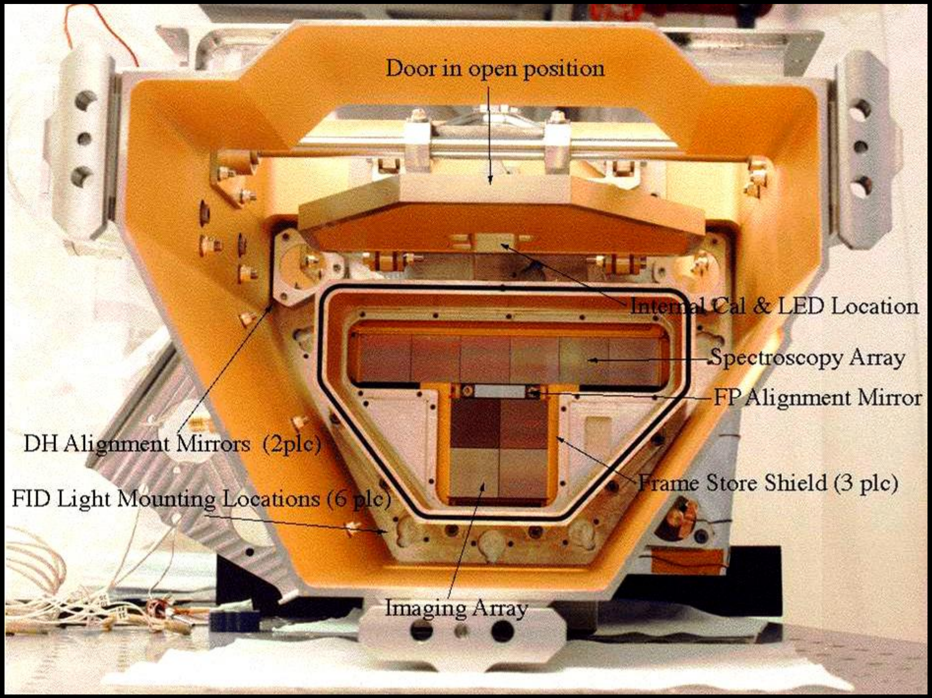
Outline

- Introduction
- Molecular contamination on ACIS filters
- Thermal model for ACIS cavity
- Molecular transport simulations
- Summary

Chandra's Advanced CCD Imaging Spectrometer (ACIS)

- ACIS cavity
  - Collimator
  - Snoot & door
  - Camera top & filters (OBF)

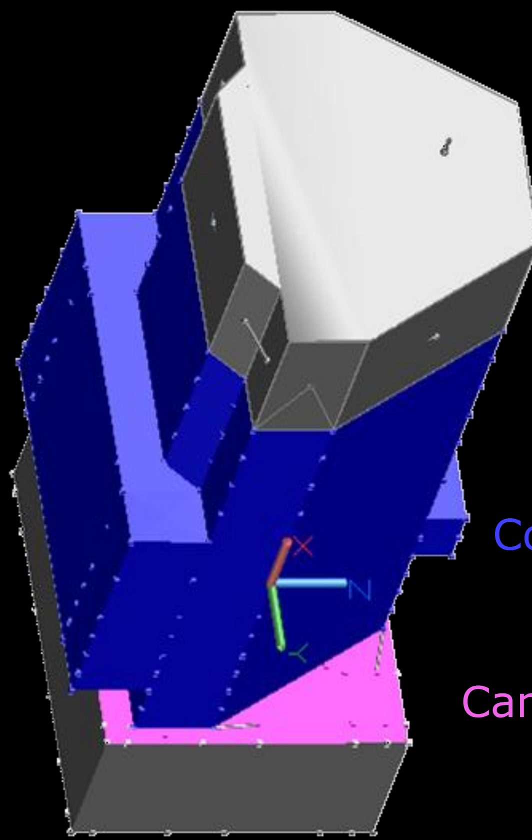


- ACIS operating temperatures
  - Focal plane T_{FP}=-120°C
  - Camera housing T_{DH}=-60°C
    - ≈8°C colder with heaters off
  - Optical blocking filters T_{OBF}
    - ≈T_{DH}≈-60°C near OBF edge
    - 5–20°C warmer near center depending on emissivity ε_{OBF}
- Contamination on cold OBFs
  - Mass column ≈ 200 μg cm^{-2}.
    - ≤ 1 g in entire *Chandra* optical cavity (calculated)
    - ≈ 30 × pre-flight estimates
  - Thicker near OBF edge

Contamination-migration simulations for Chandra

- 2004 (I)
  - Low-resolution geometrical model for ACIS cavity
  - Supported bake-out decision in 2004
- 2013 (II)
  - High-resolution geometrical model for ACIS cavity
  - Higher emissivity for contaminated surfaces
- 2015 (III)
  - Same model as 2013
  - Will support bake-out decision in 2016

- ACIS geometrical model (exterior view)



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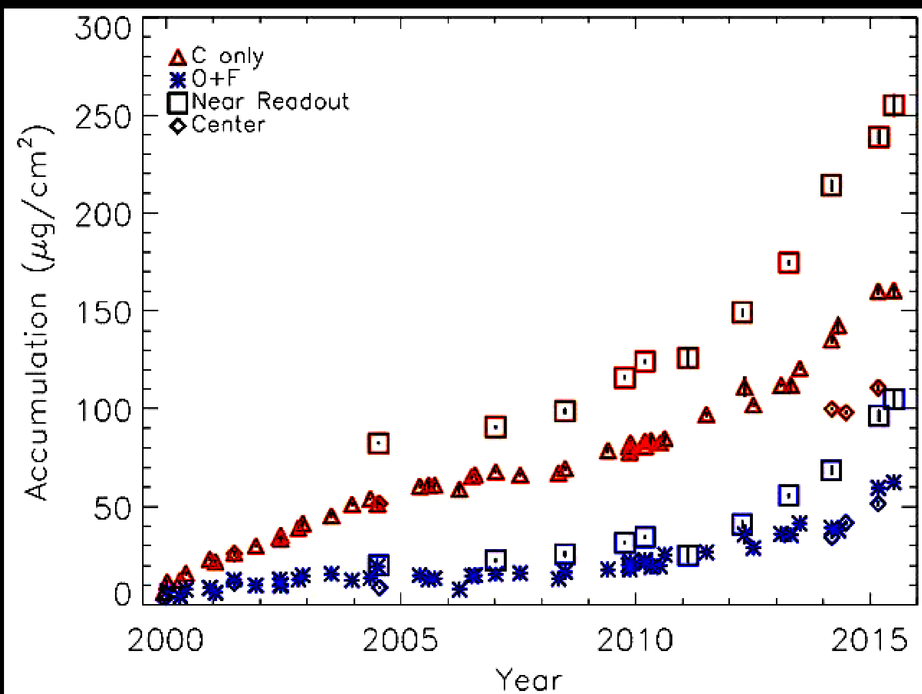
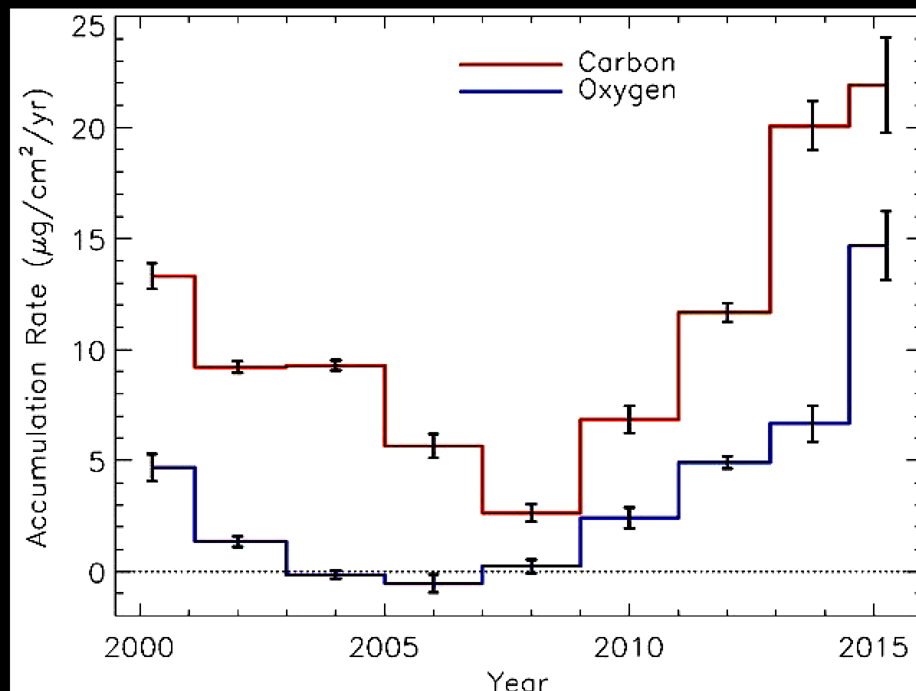
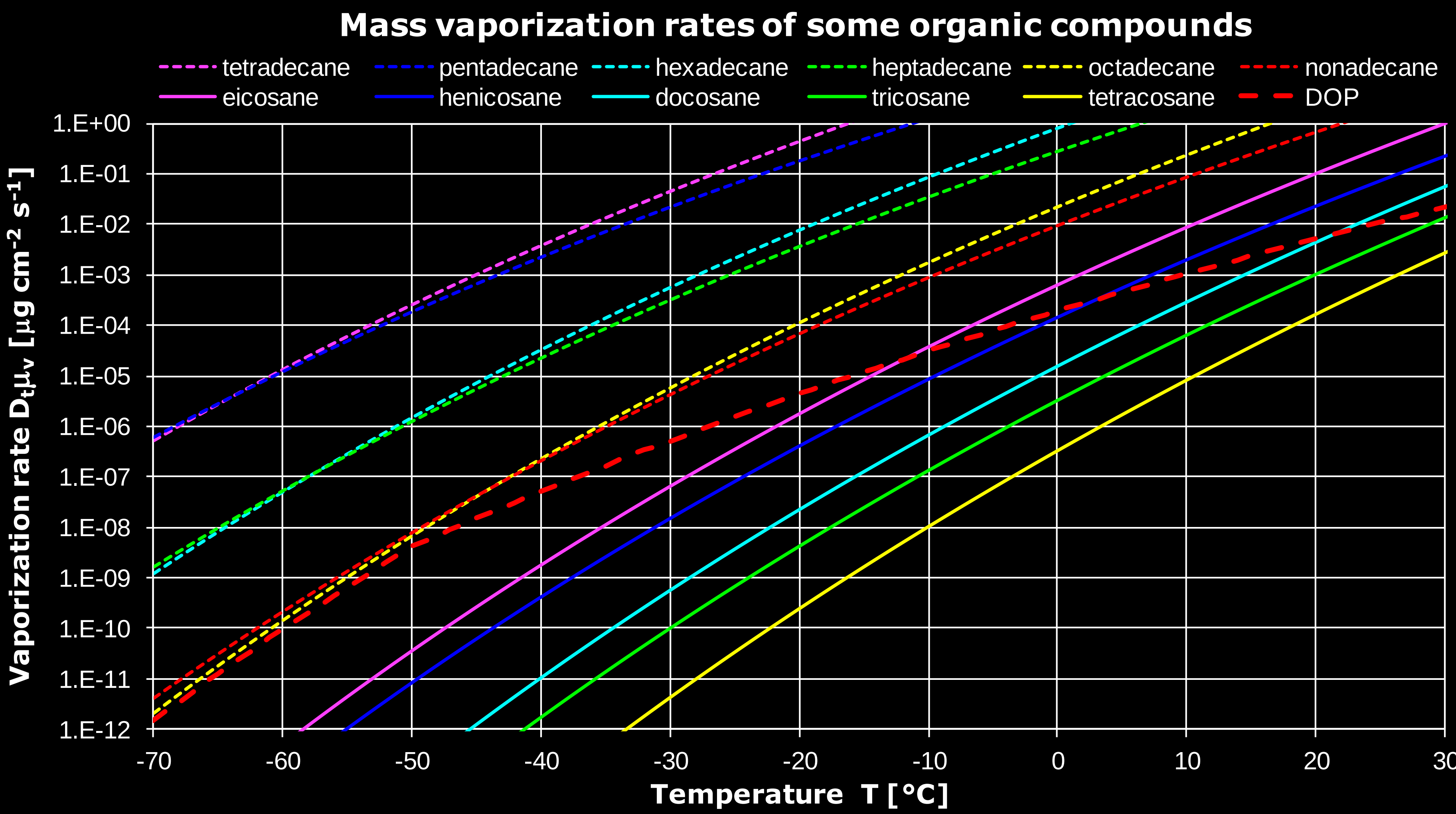
Evolution of mass column, its rate, and composition

- Accumulation of contaminants
  - LETG/ACIS-S spectra
    - Atomic (C,O,F) edge depths
  - Thickest near OBF edges
- Rate fell until about 2009 then started rising.
- Composition changes indicate multiple species.



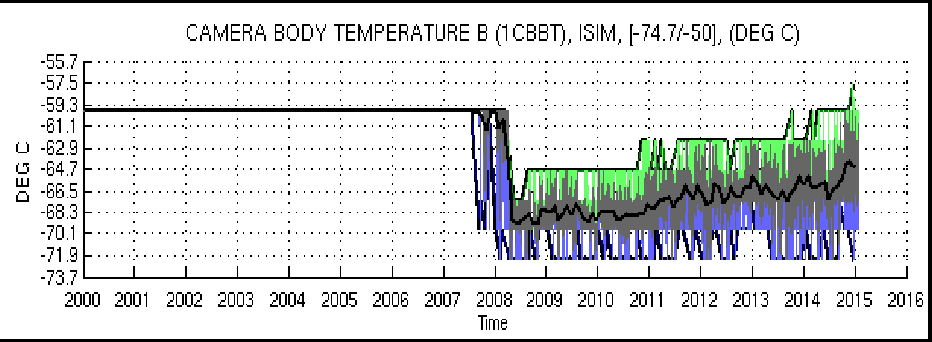


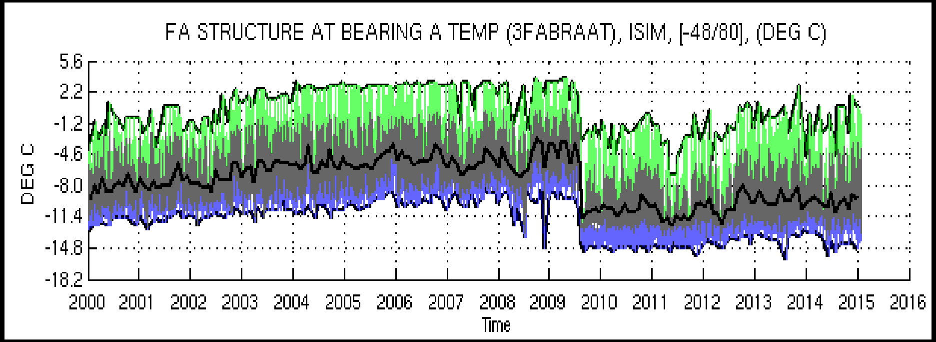
Temperature dependence of mass vaporization rate

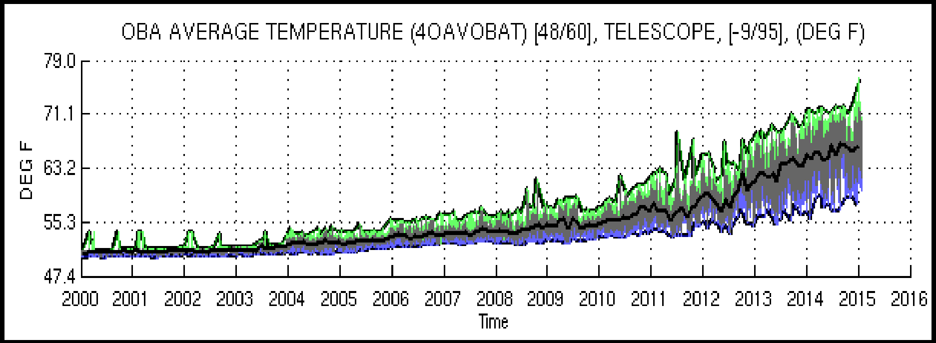


Thermal history

- Most systems are warming.
  - Continuing degradation of external insulation (MLI)
- Strive to keep ACIS focal plane cold to preserve performance.
  - Carefully plan observations.
  - Disabled some heaters.
    - ACIS detector-housing heater (2008 April)
    - A SIM focus-assembly heater (2009 August)
- Optical bench has warmed rapidly since about 2010.
  - New contamination source?







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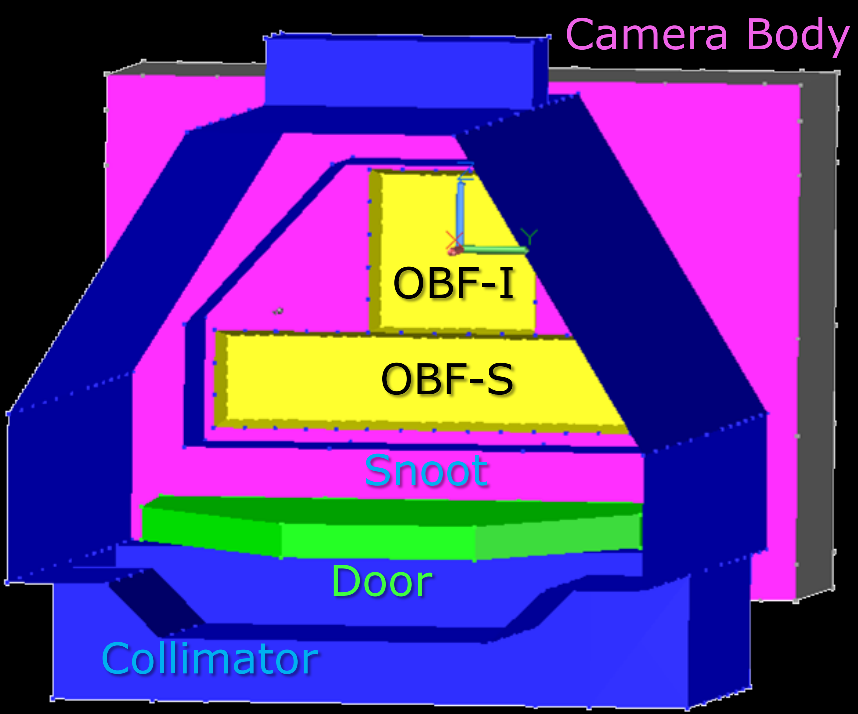
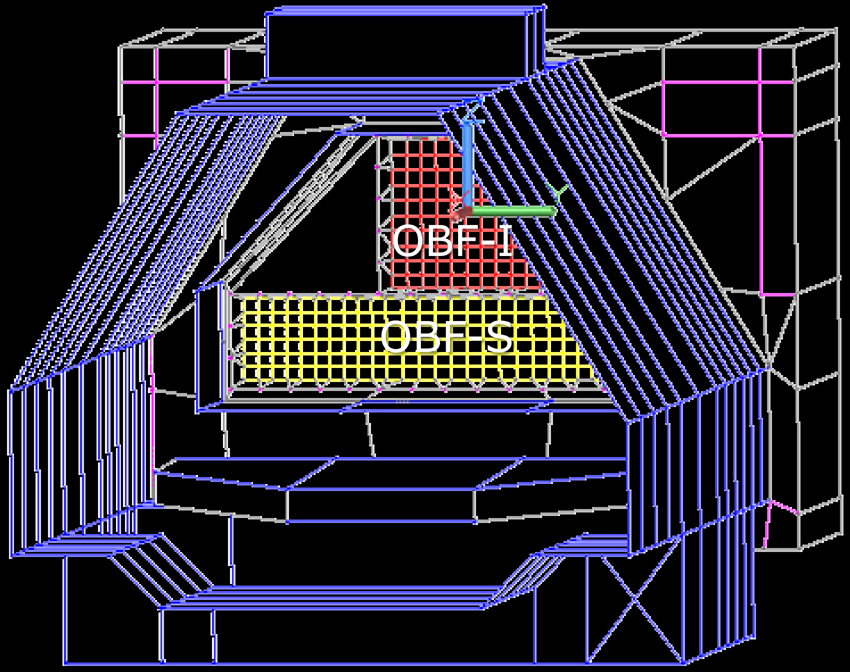
ACIS geometric model (interior view)

- Interior view of ACIS cavity
  - Snoot & door inside collimator
  - Camera top with OBFs

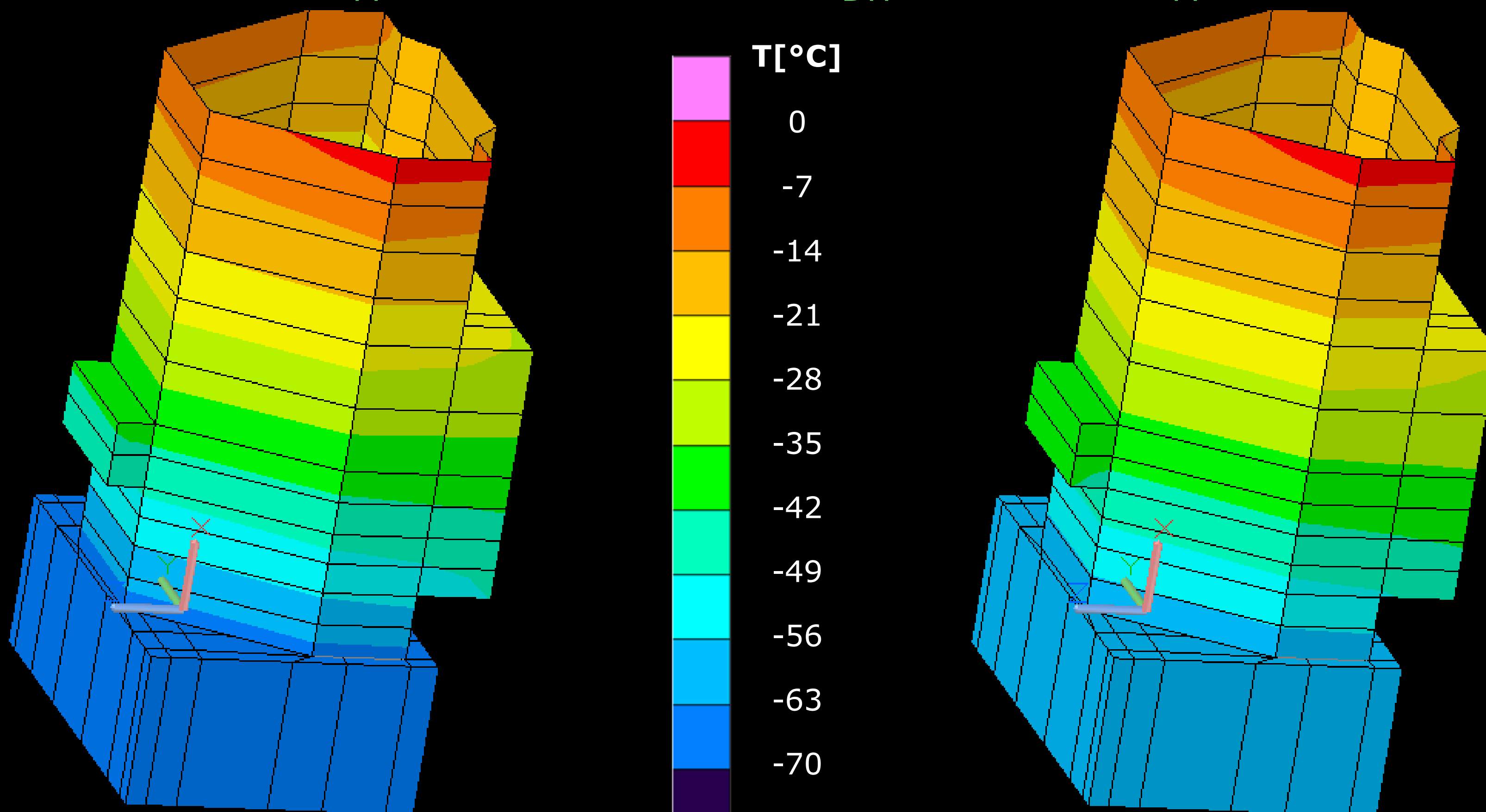
- High-resolution model maps temperature gradients
  - OBF: 121 I & 203 S nodes
  - Collimator: 12 axial zones





ACIS temperature distribution (operational conditions)

- DH heater OFF, T_{FP} = -120°C
- T_{DH} = -60°C, T_{FP} = -120°C



ε_{OBF} = 0.40 ε_{OBF} = 0.40

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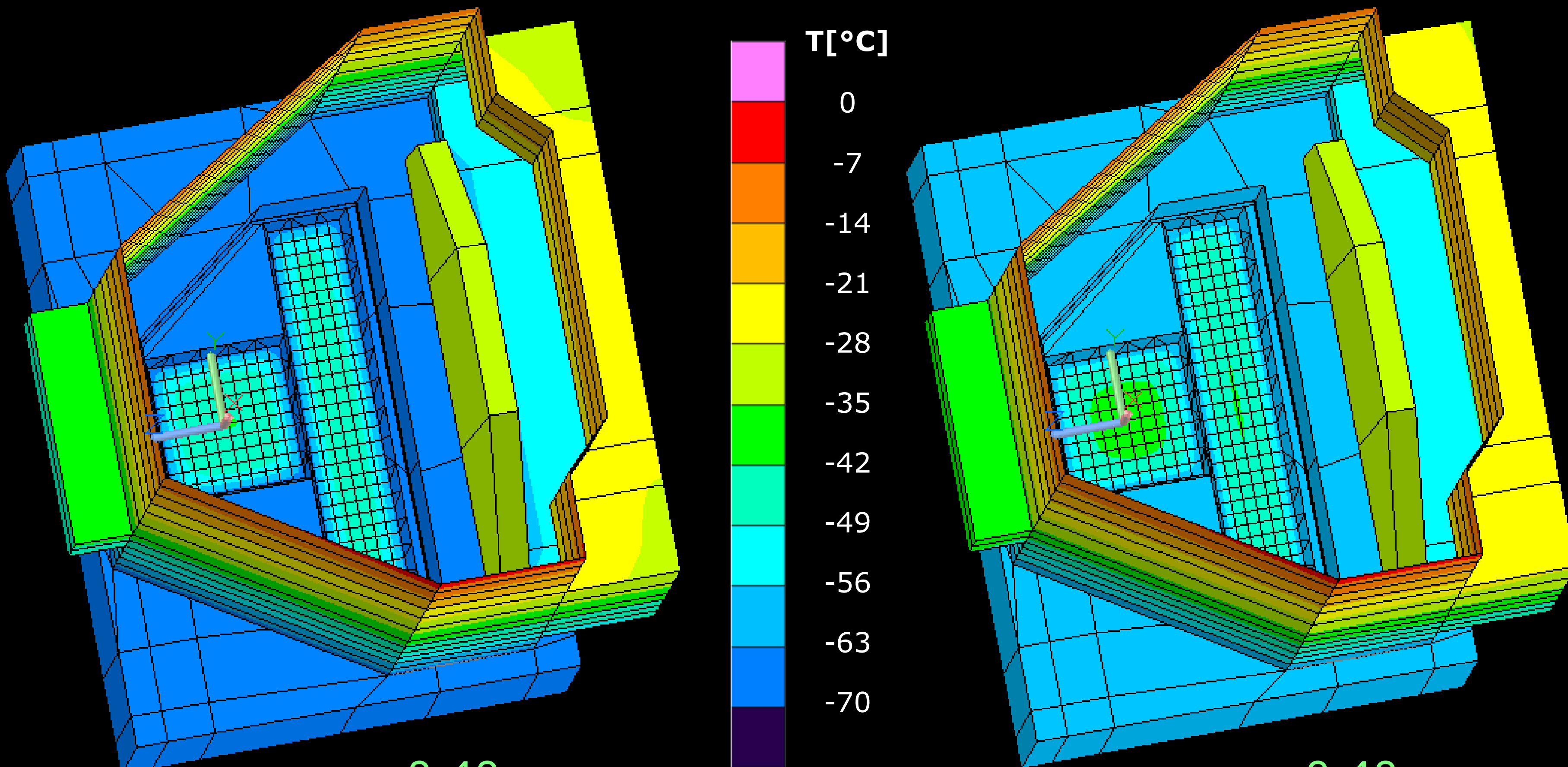

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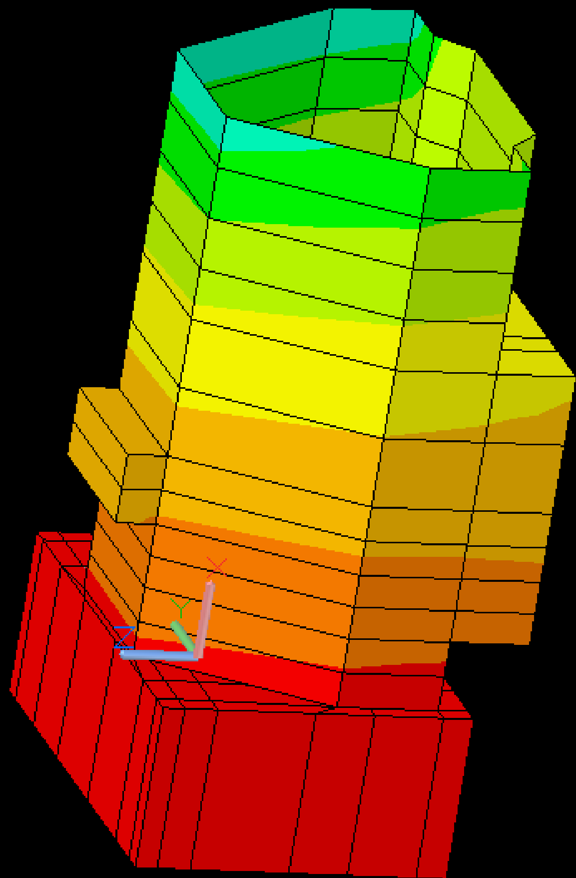
ACIS temperature distribution (bake-out conditions)

- T_{DH} = +25°C, T_{FP} = -60°C
- T_{DH} = +25°C, T_{FP} = +25°C



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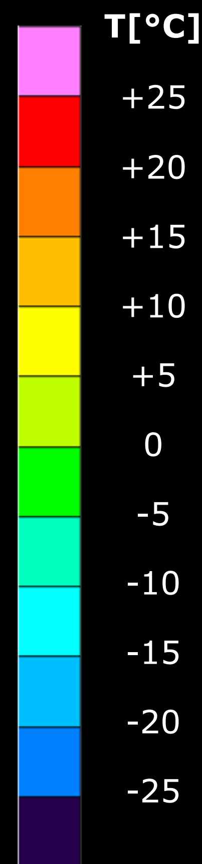

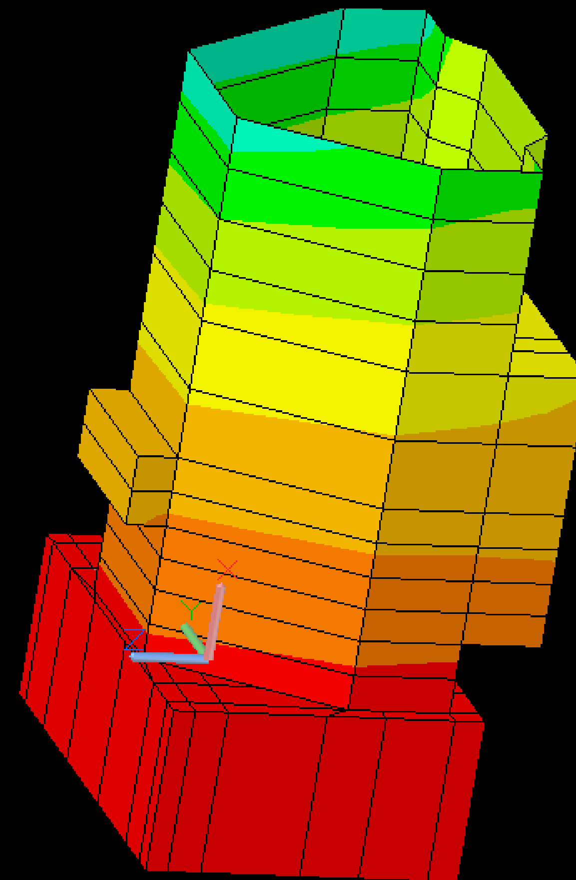

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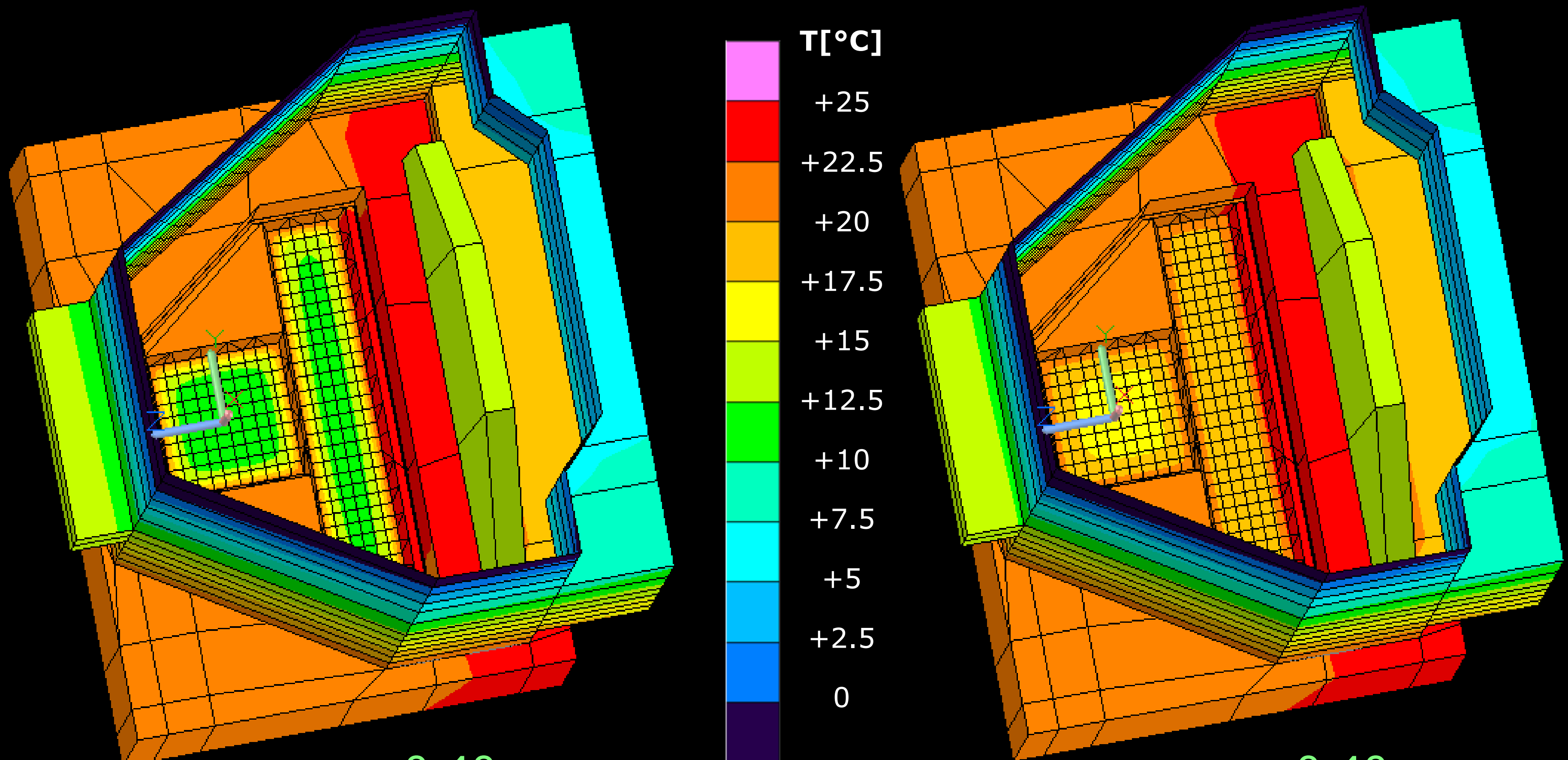

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Molecular flux equations and geometric view factors

- Net mass flux onto node j

$$\frac{d\mu_j}{dt} = -\dot{\mu}_v(T_j)\Theta(\mu_j) + \sum_k \dot{\mu}_v(T_k)\Theta(\mu_k)\ f_{jk}\ \frac{A_k}{A_j}$$

- Mass vaporization flux
  - Related to vapor pressure

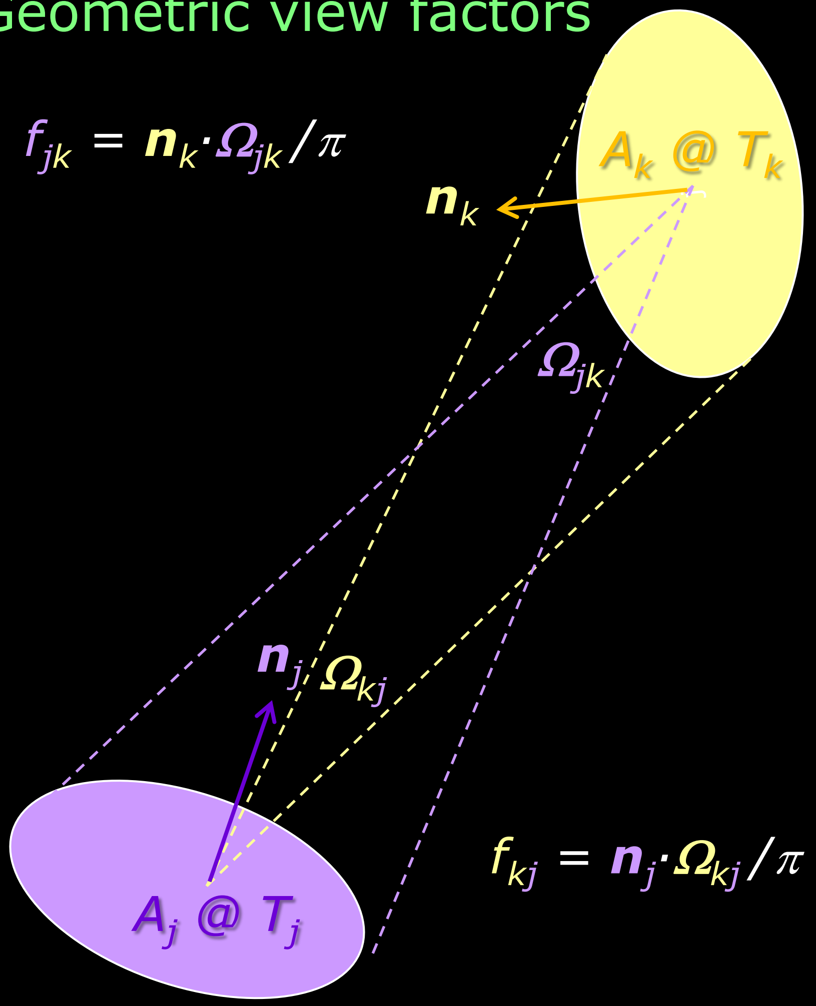
$$\dot{\mu}_v(T) = \frac{P_v(T)}{\sqrt{2\pi\ RT/M}}$$

- Clausius–Clapeyron relation
  - Temperature dependence
  - Vaporization enthalpy $\Delta_v H$

$$P_v(T) = P_v(T_\circ)\ \mathrm{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$

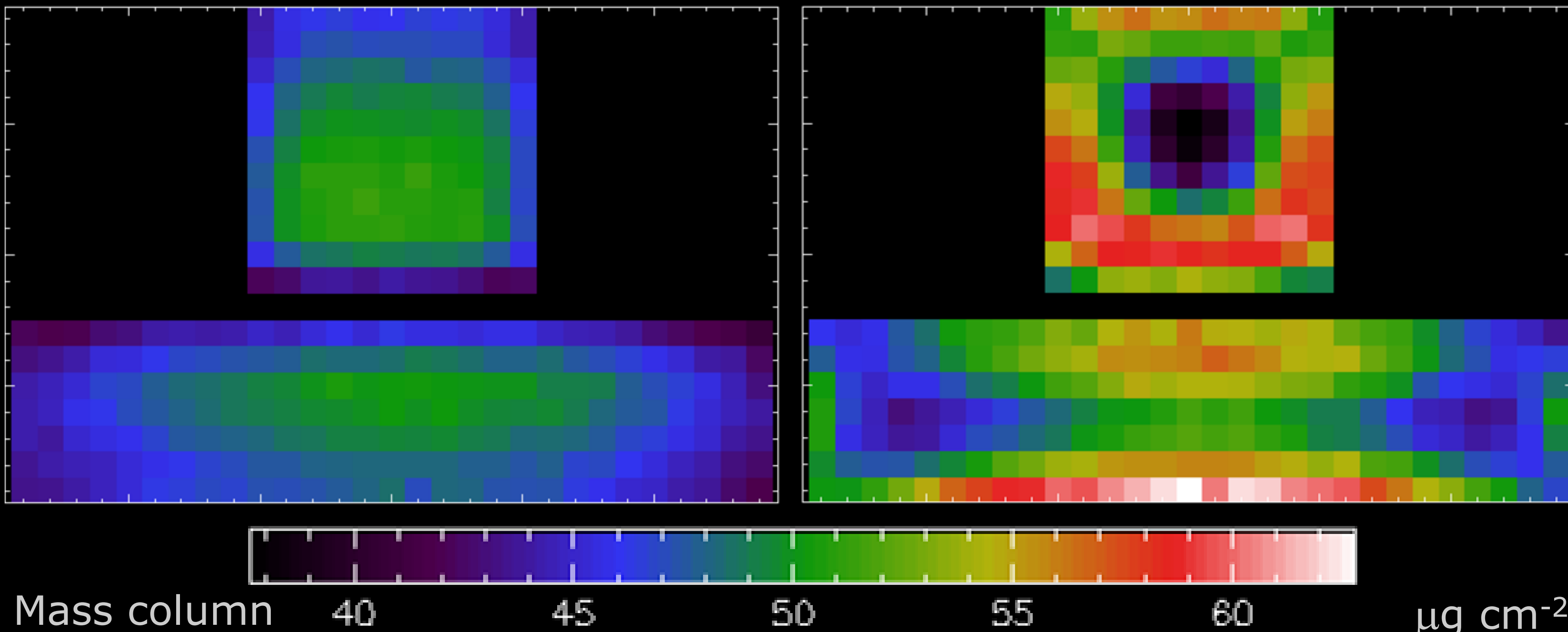
$$\dot{\mu}_v(T) = \dot{\mu}_v(T_\circ)\sqrt{\frac{T_\circ}{T}}\ \mathrm{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$

- Geometric view factors



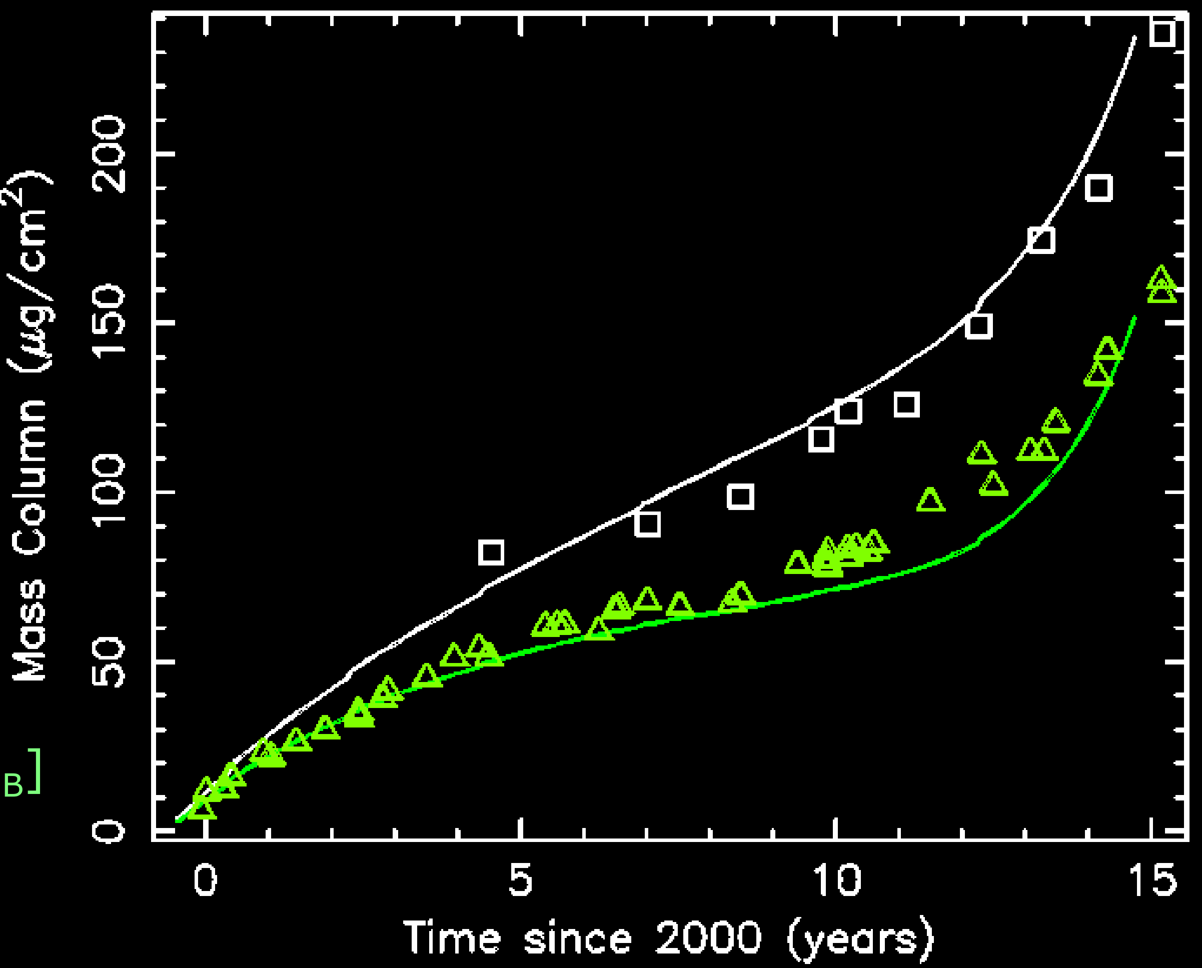
Simulations of contaminant accumulation onto ACIS OBFs

- Lower volatility contaminant
  - Deposition dominates.
    - Accumulates most at center.
- Higher volatility contaminant
  - Vaporization is significant.
    - Accumulates most at edges.

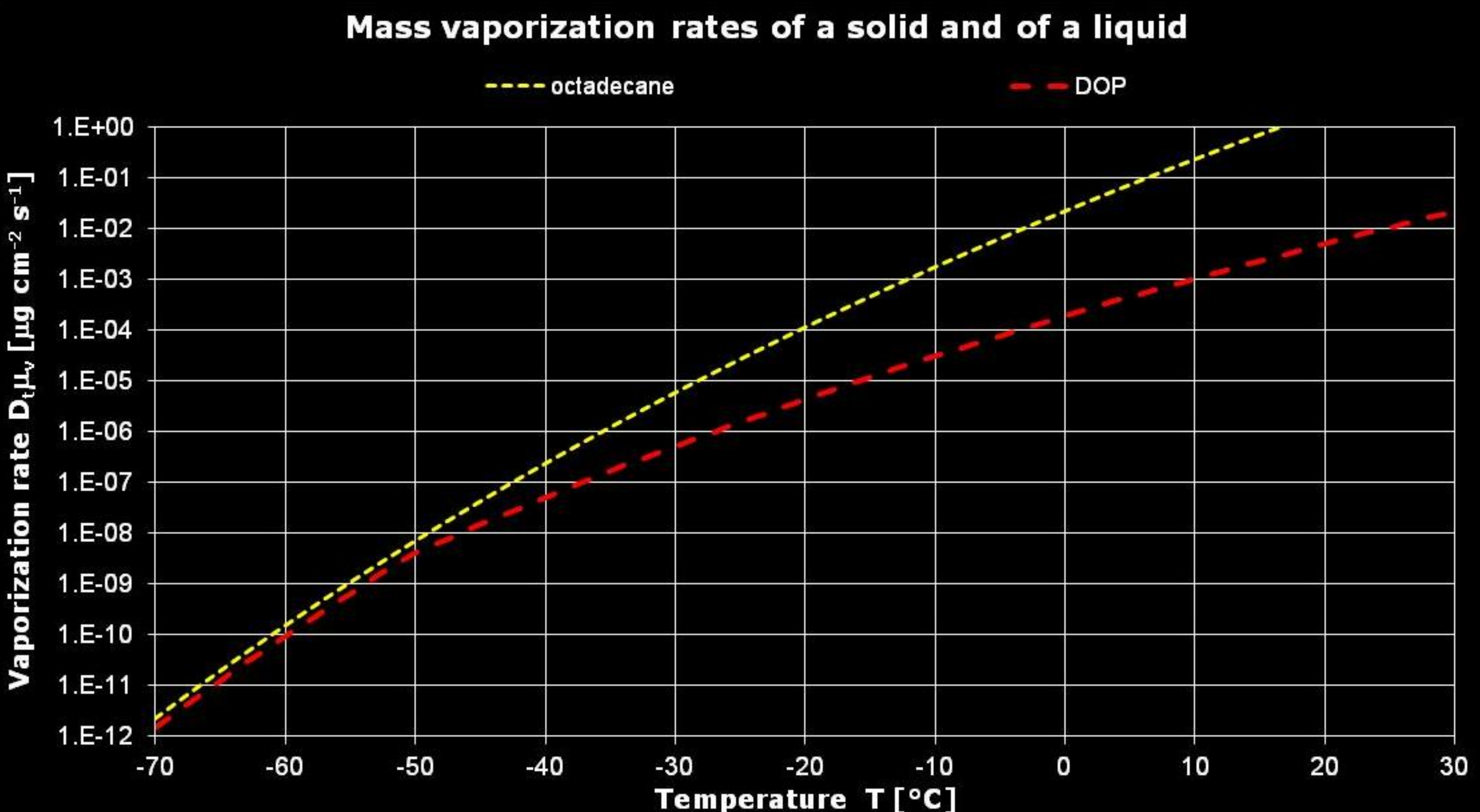


Accumulation simulation: two components

- Low-volatility component
  - Source rate drops exponentially due to depletion.
    - 3.7-year timescale
- Medium-volatility component
  - Source rate rises with increasing optical-bench T_{OB}.
    - $\propto$ Exp[-constant/T_{OB}]
    - Rises until source depletion occurs.

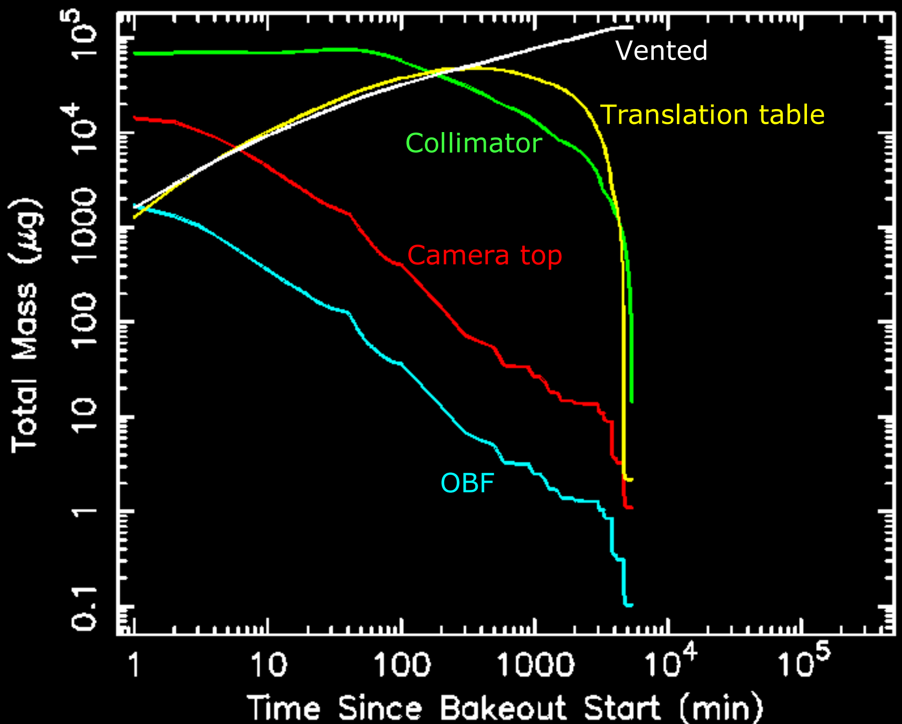


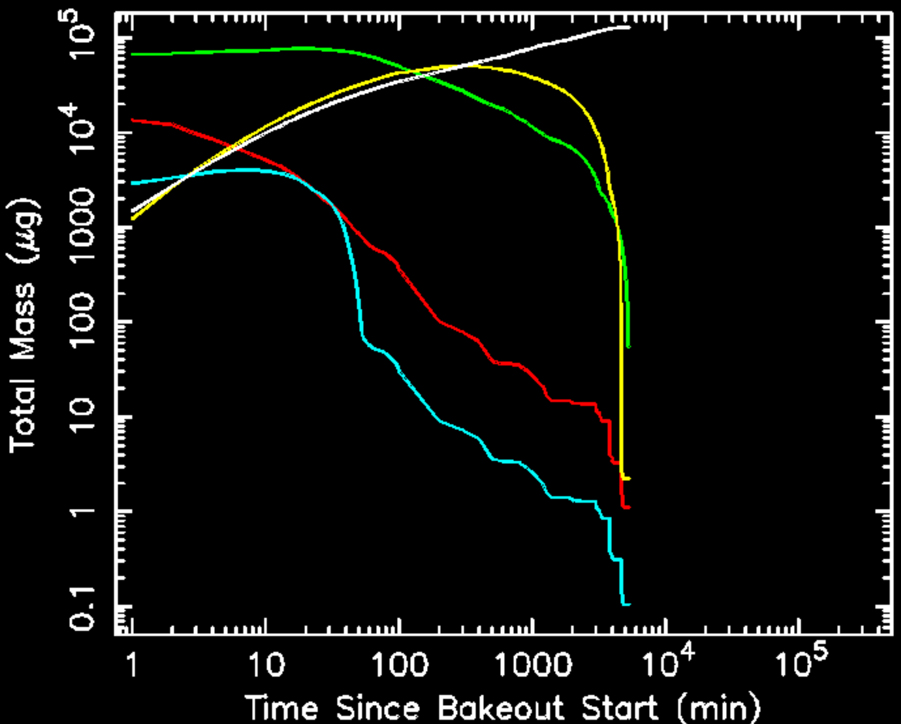
Vaporization rate: Dependence upon phase state

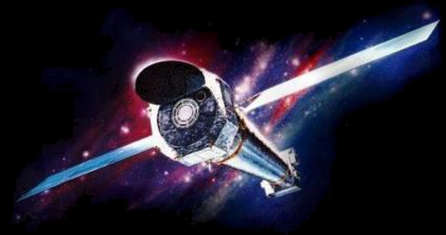


Bake-out simulation: Octadecane mass

- Warm focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = +25°C$
- Cool focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = -60°C$

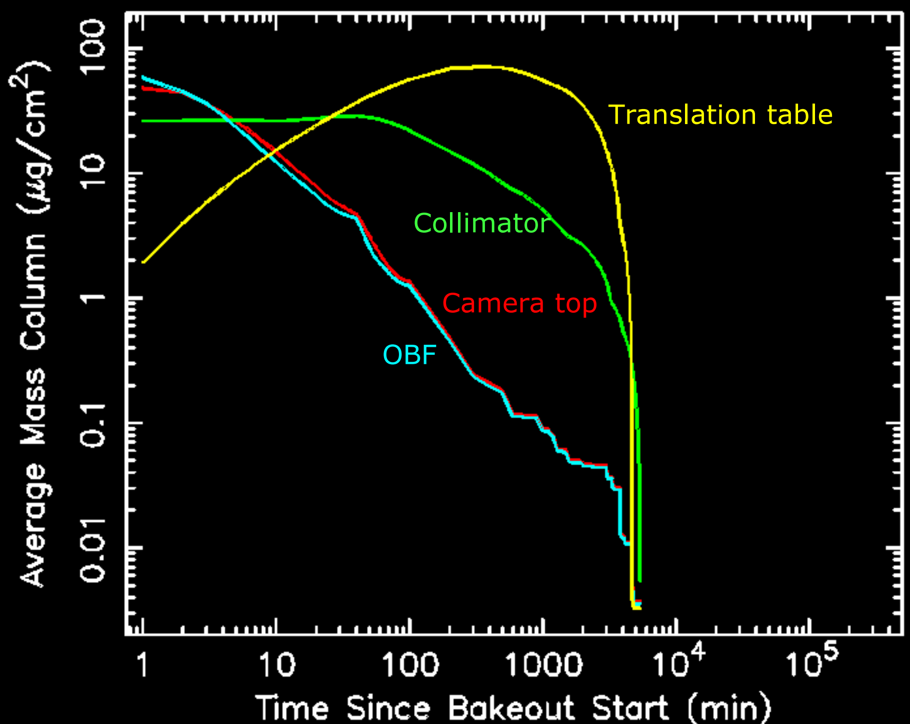




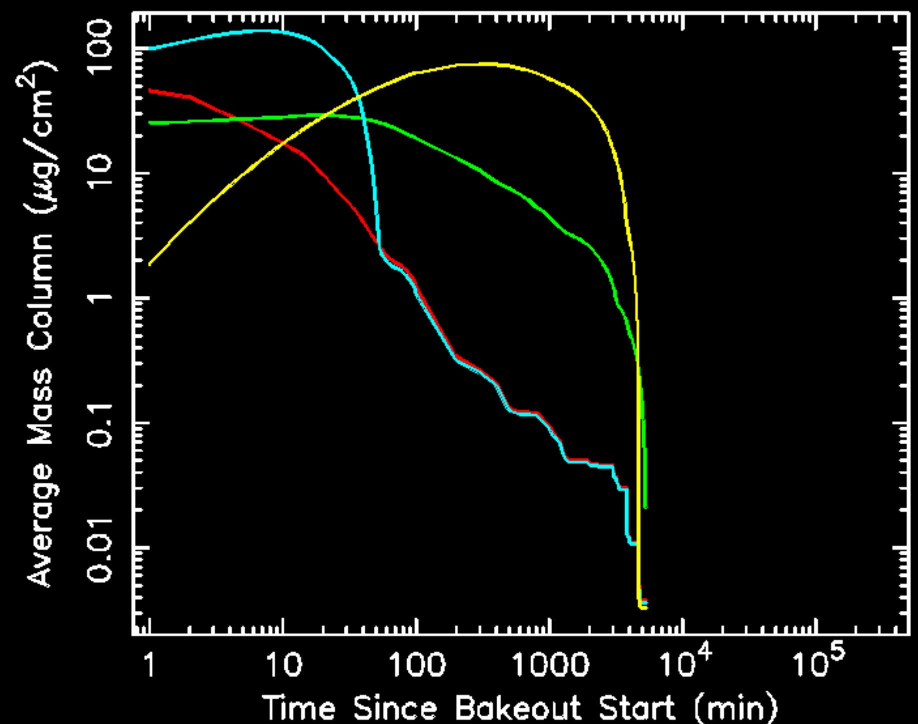


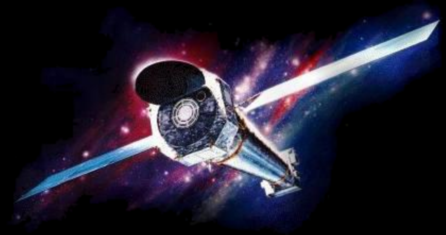
Bake-out simulation: Octadecane column

- Warm focal plane
  - T_{DH} = +25°C
  - T_{FP} = +25°C



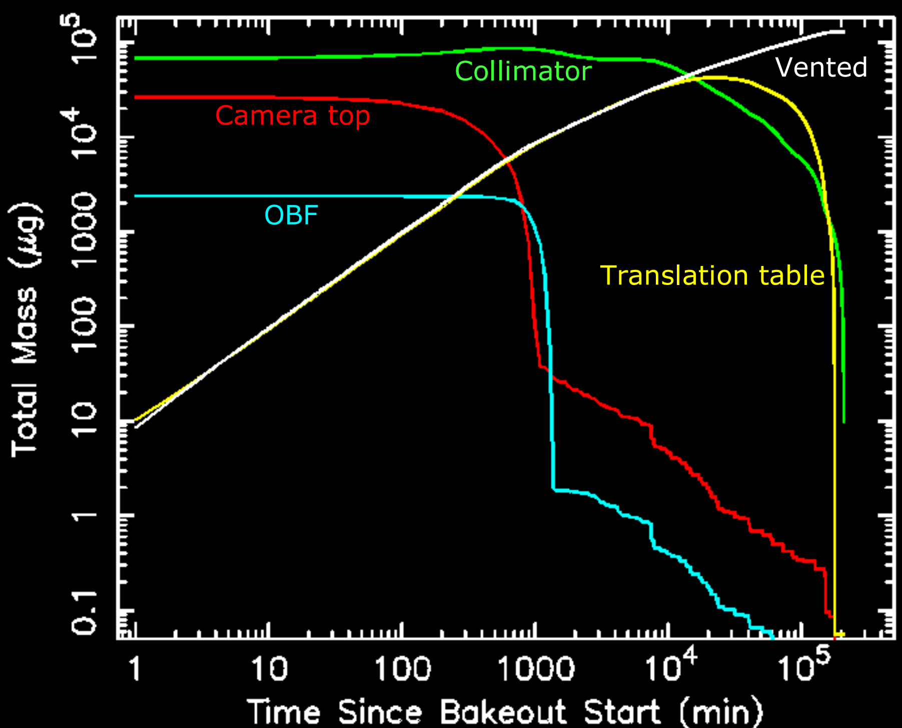
- Cool focal plane
  - T_{DH} = +25°C
  - T_{FP} = -60°C

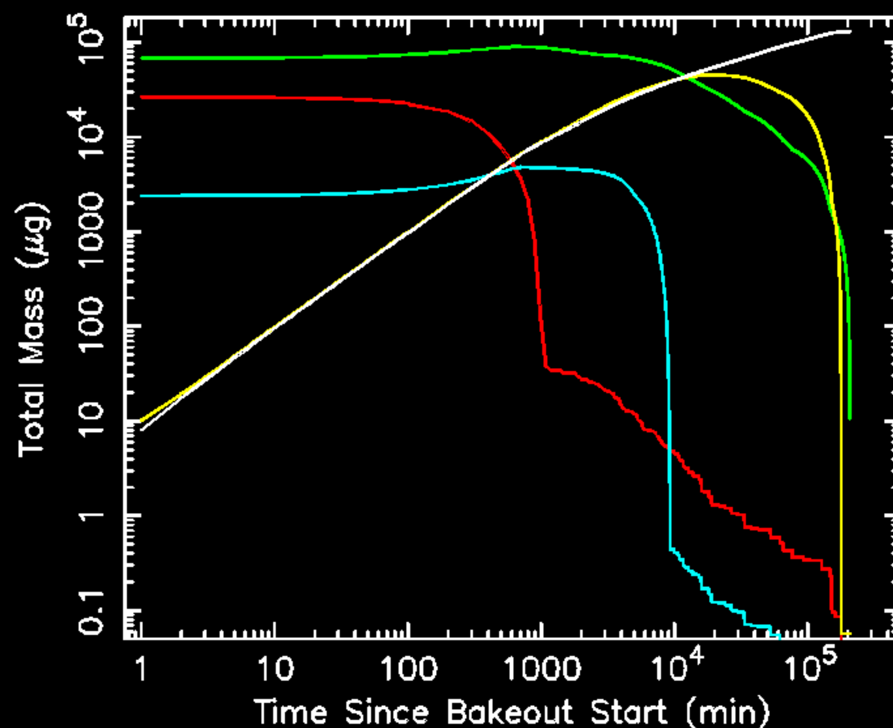


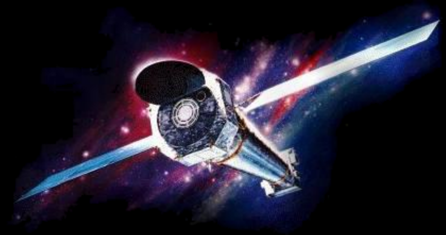


Bake-out simulation: Dioctyl phthalate mass

- Warm focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = +25°C$
- Cool focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = -60°C$

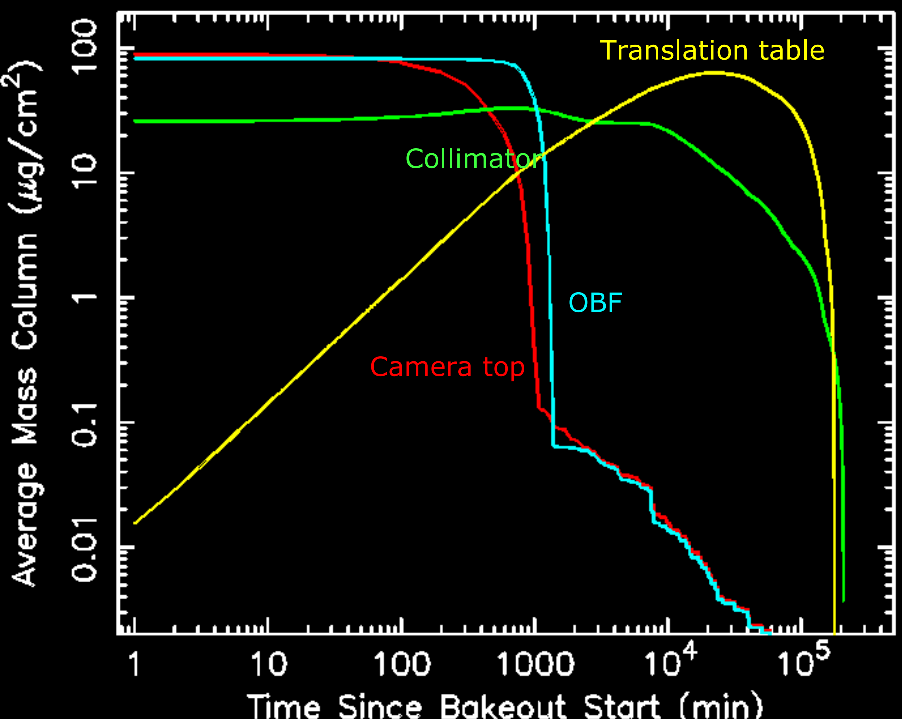


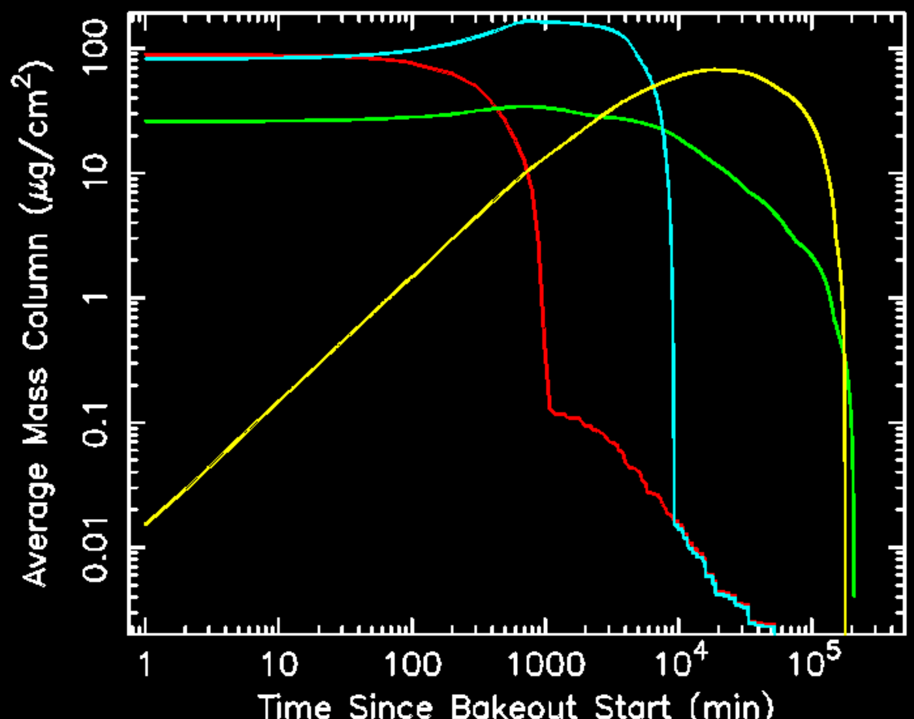




Bake-out simulation: Dioctyl phthalate column

- Warm focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = +25°C$
- Cool focal plane
  - $T_{DH} = +25°C$
  - $T_{FP} = -60°C$





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Summary

- Contamination-migration simulation provides a useful tool.
  - Utility for absolute predictions is still limited.
    - Absolute predictions require knowledge of contaminant’s volatility.
    - Uncertainty in temperatures propagates exponentially to rate error.
  - Model may require additional physics.
    - Treatment of multiple molecular species
    - Dependence of thermal emissivity upon contaminant mass column
      - Affects temperature distribution and thus mass vaporization rate
    - Surface redistribution, especially for a liquid contaminant
- Will use model to provide input for a bake-out decision.
  - Constrain properties of molecular contaminant(s).
  - Simulate contamination migration under potential scenarios.
    - Turning housing heaters back ON
    - Various bake-out conditions for ACIS