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

Steve O’Dell, Doug Swartz, Neil Tice, Paul Plucinsky, Herman Marshall, Akos Bogdan, Catherine Grant, Allyn Tennant, Matt Dahmer

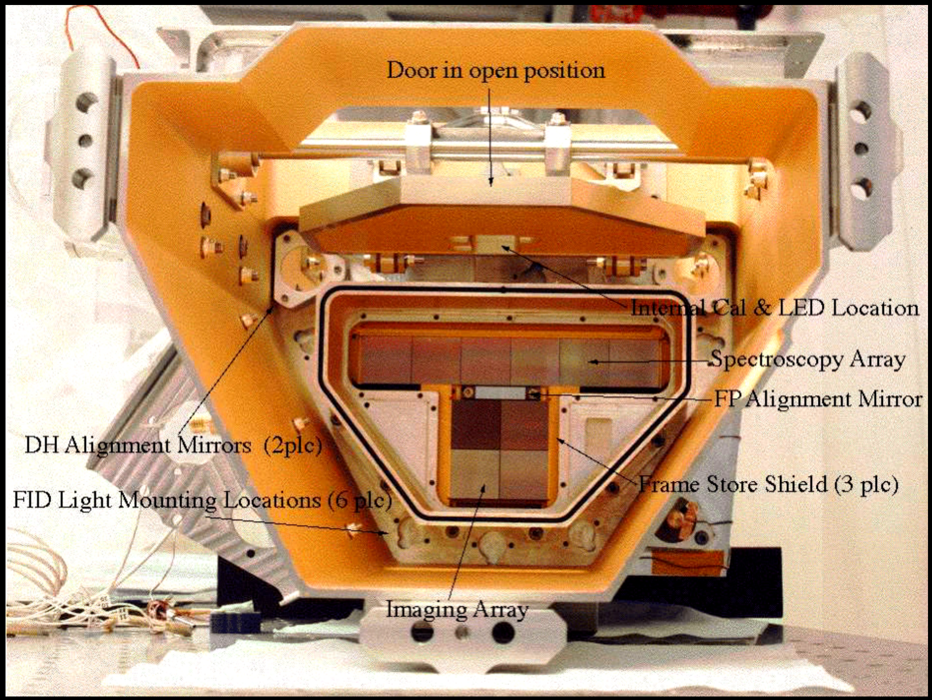
NASA Marshall Space Flight Center
Universities Space Research Association
Massachusetts Institute of Technology
Smithsonian Astrophysical Observatory
Northrop Grumman

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)

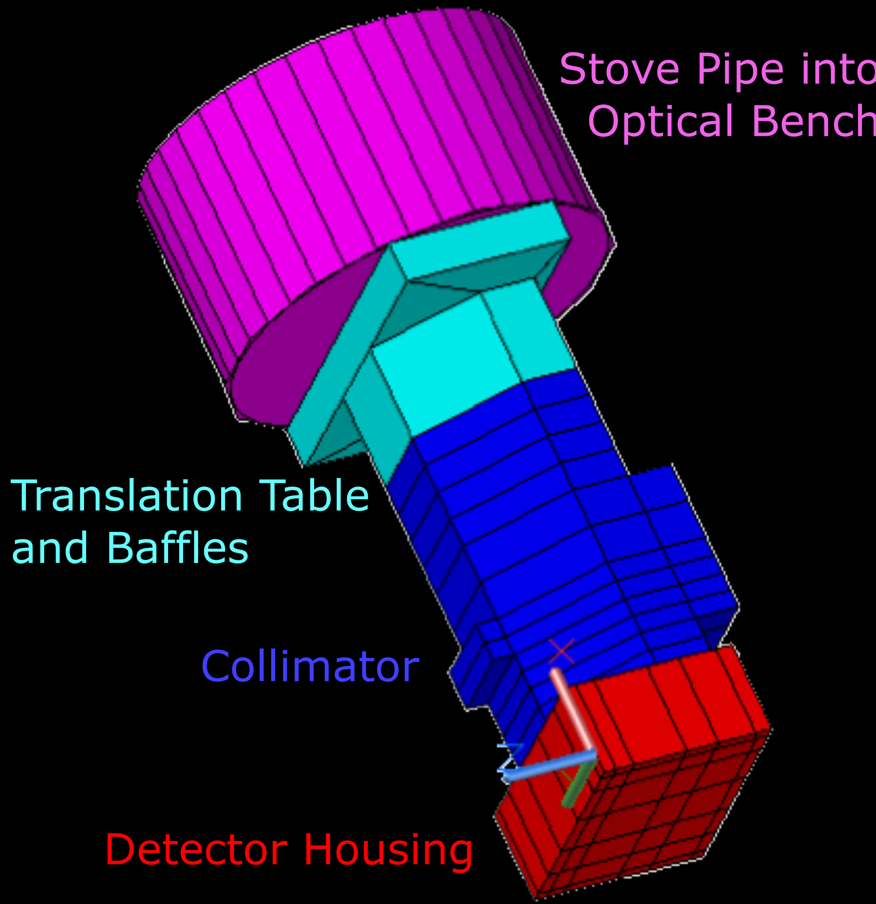


- ACIS operating temperatures
  - Focal plane T_{FP}=-120°C
  - Camera housing T_{DH}=-60°C
    - ≈6°C colder with heaters off
  - Optical blocking filters T_{OBF}
    - ≈T_{DH}≈-60°C near OBF edge
    - 5–20°C warmer near center
- Contamination on cold OBFs
  - Mass column ≈ 200 μg cm^{-2}
    - ≈ 50 × pre-flight estimates
    - ≤ 1 g in entire *Chandra* optical cavity (calculated)
  - Thicker near OBF edge
  - Doubled during 2013–2017

Contamination-migration simulations for Chandra

- 2005 (I)
  - Low-resolution geometric model for ACIS cavity
- 2013 (II)
  - High-resolution geometric model for ACIS cavity
  - Higher emissivity for contaminated surfaces
- 2015 (III)
  - Same model as 2013
- 2017 (IV)
  - Extend geometric model into optical bench

- Geometric model (exterior)



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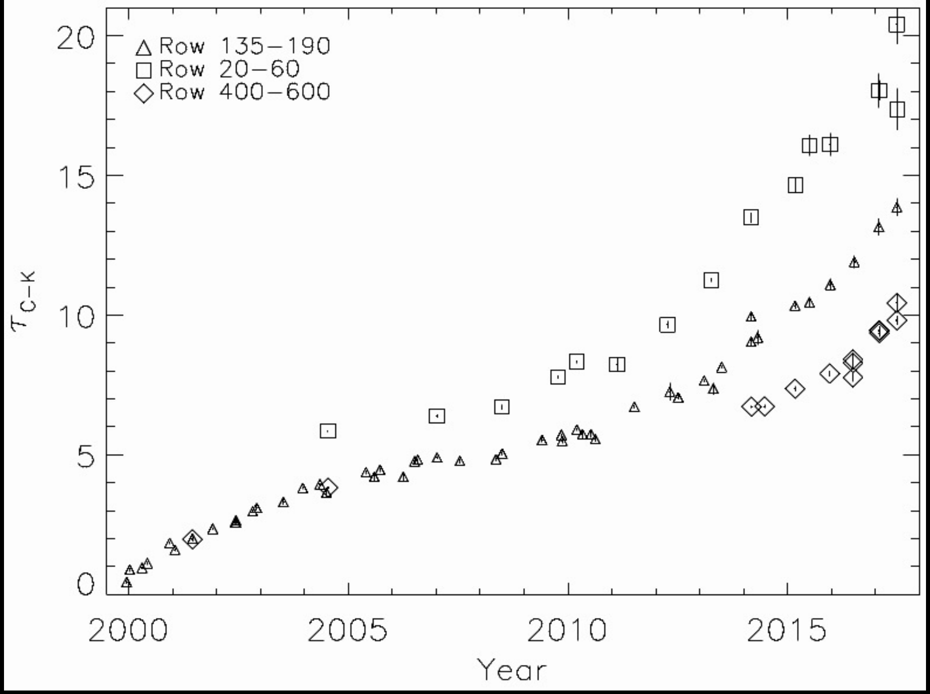
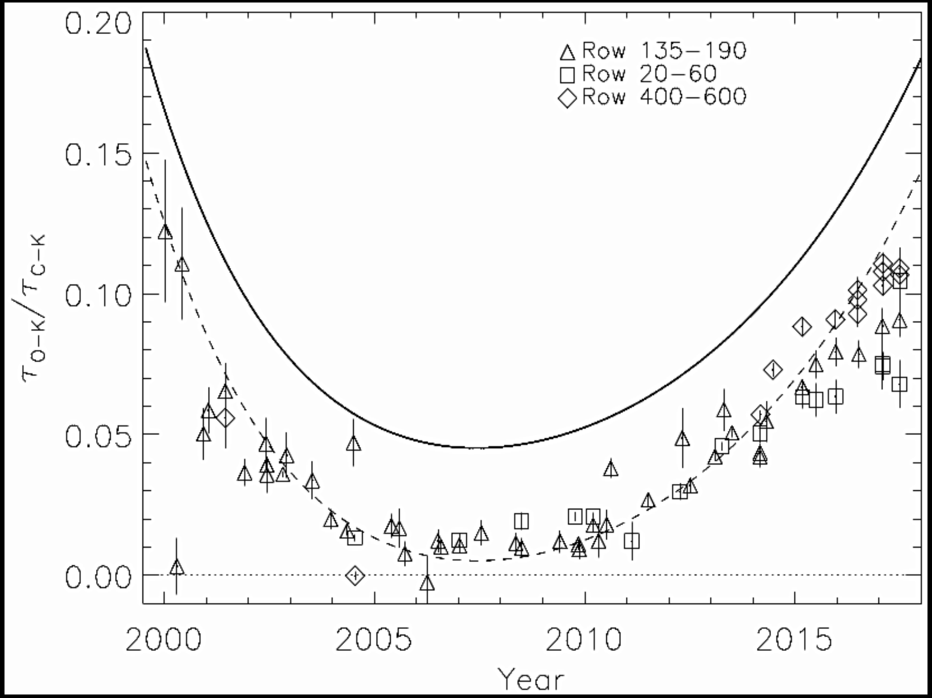
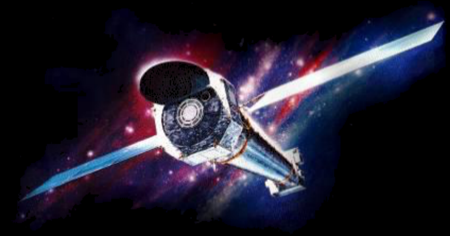
Evolution of mass column, its rate, and composition

- Accumulation of contaminants
  - LETG/ACIS-S spectra
    - Atomic (C,O,F) edge depths
  - Thickest near OBF edges
  - Rate fell until about 2008 then started rising
  - Multiple species

See next presentation by Herman Marshall

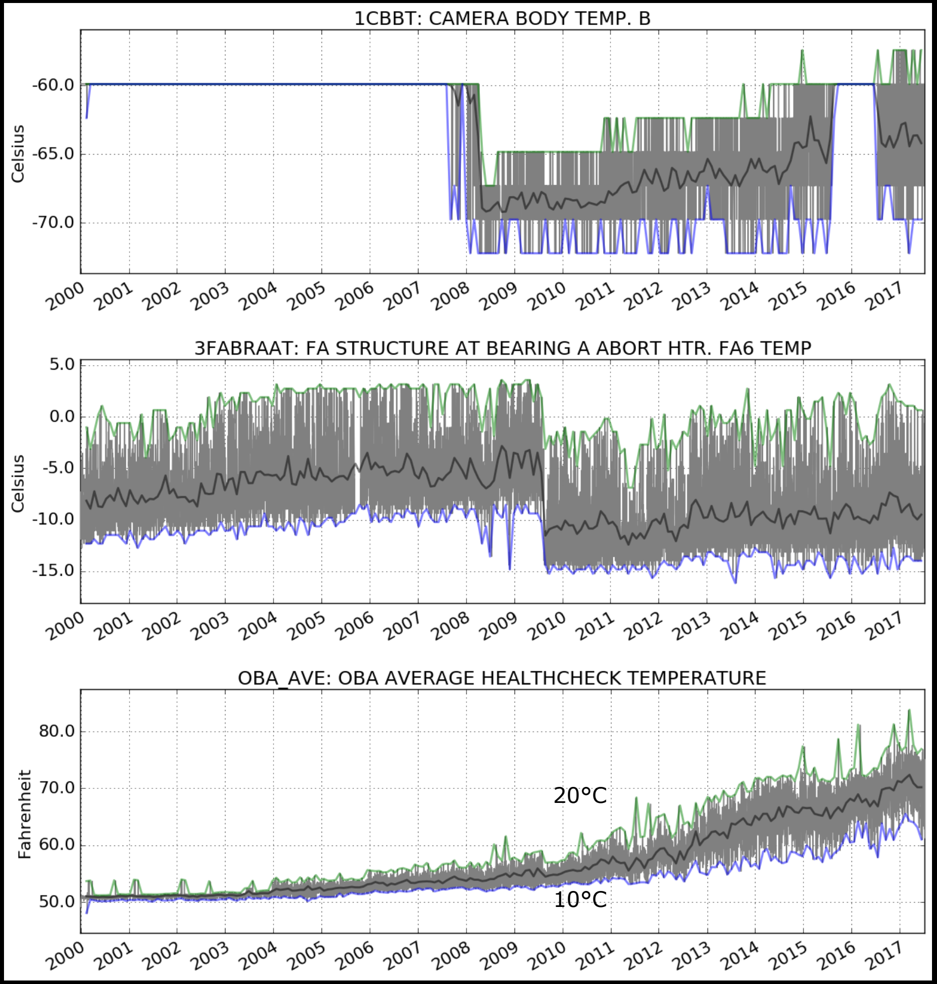






Thermal history

- 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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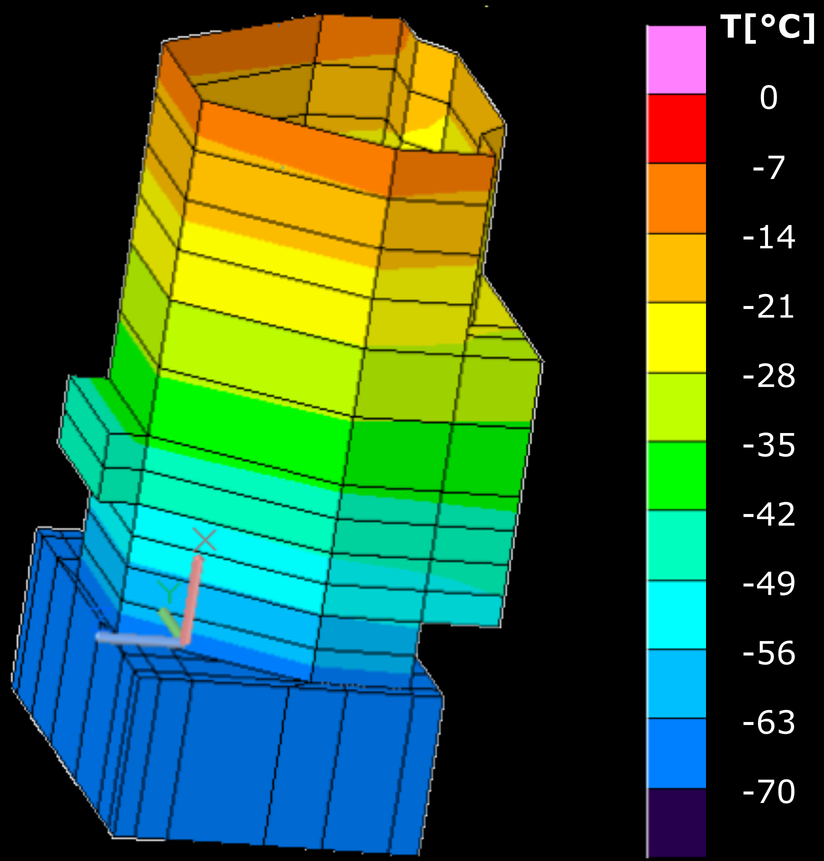
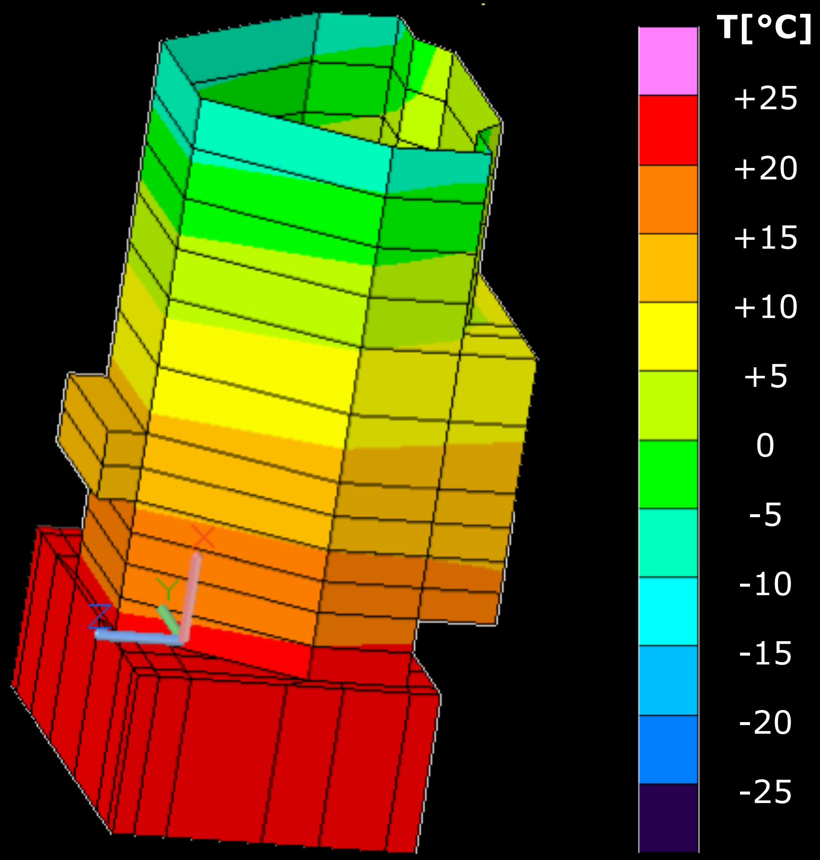
ACIS temperature distribution (exterior)

- DH heater OFF, T_{FP} = -120°C
- T_{DH} = +25°C, T_{FP} = -60°C



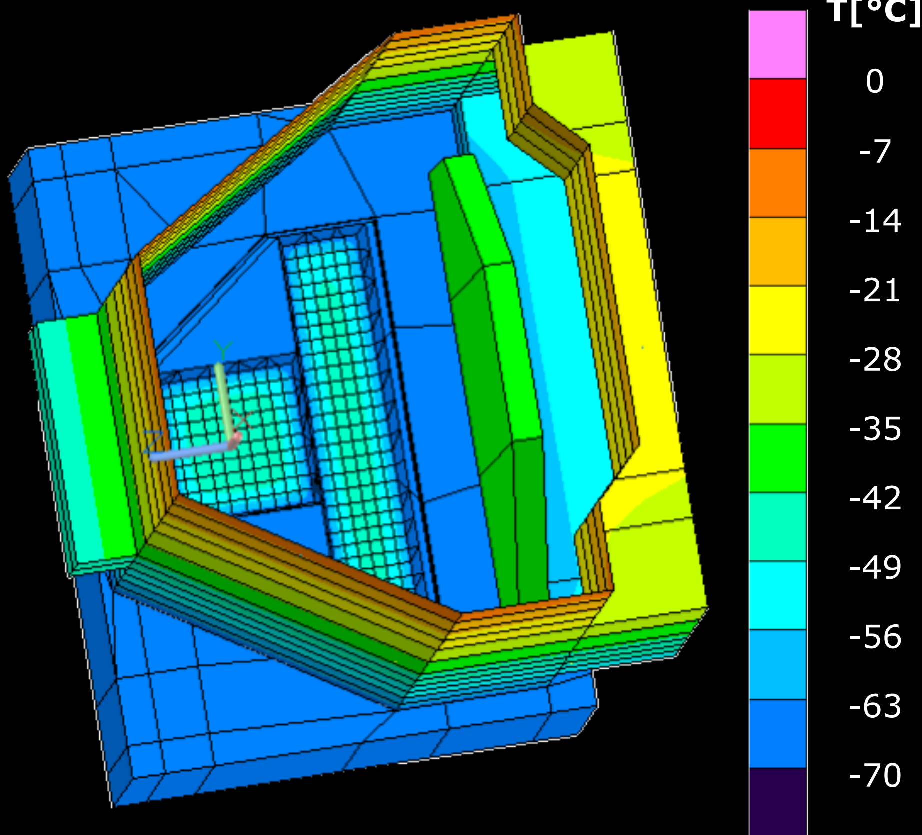
ε_{OBF} = 0.40



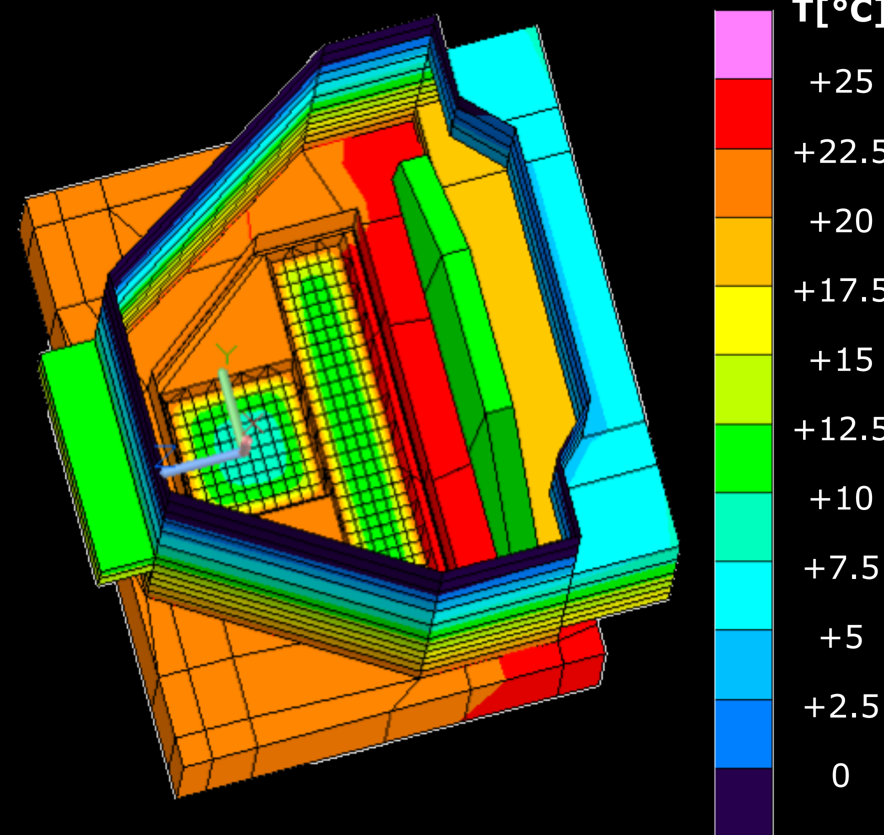
ε_{OBF} = 0.40

ACIS temperature distribution (interior)

- DH heater OFF, T_{FP} = -120°C
- T_{DH} = +25°C, T_{FP} = -60°C



ε_{OBF} = 0.40



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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

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

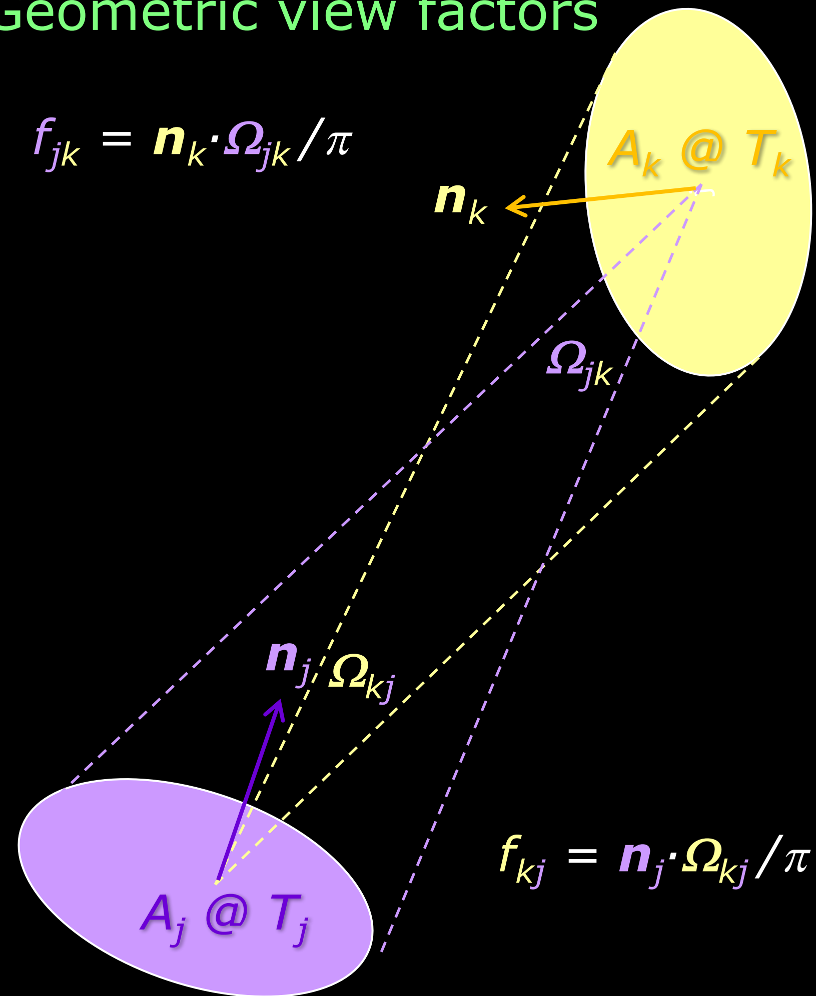
- Clausius–Clapeyron relation
  - Temperature dependence
  - Vaporization enthalpy $\Delta_v H$

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

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

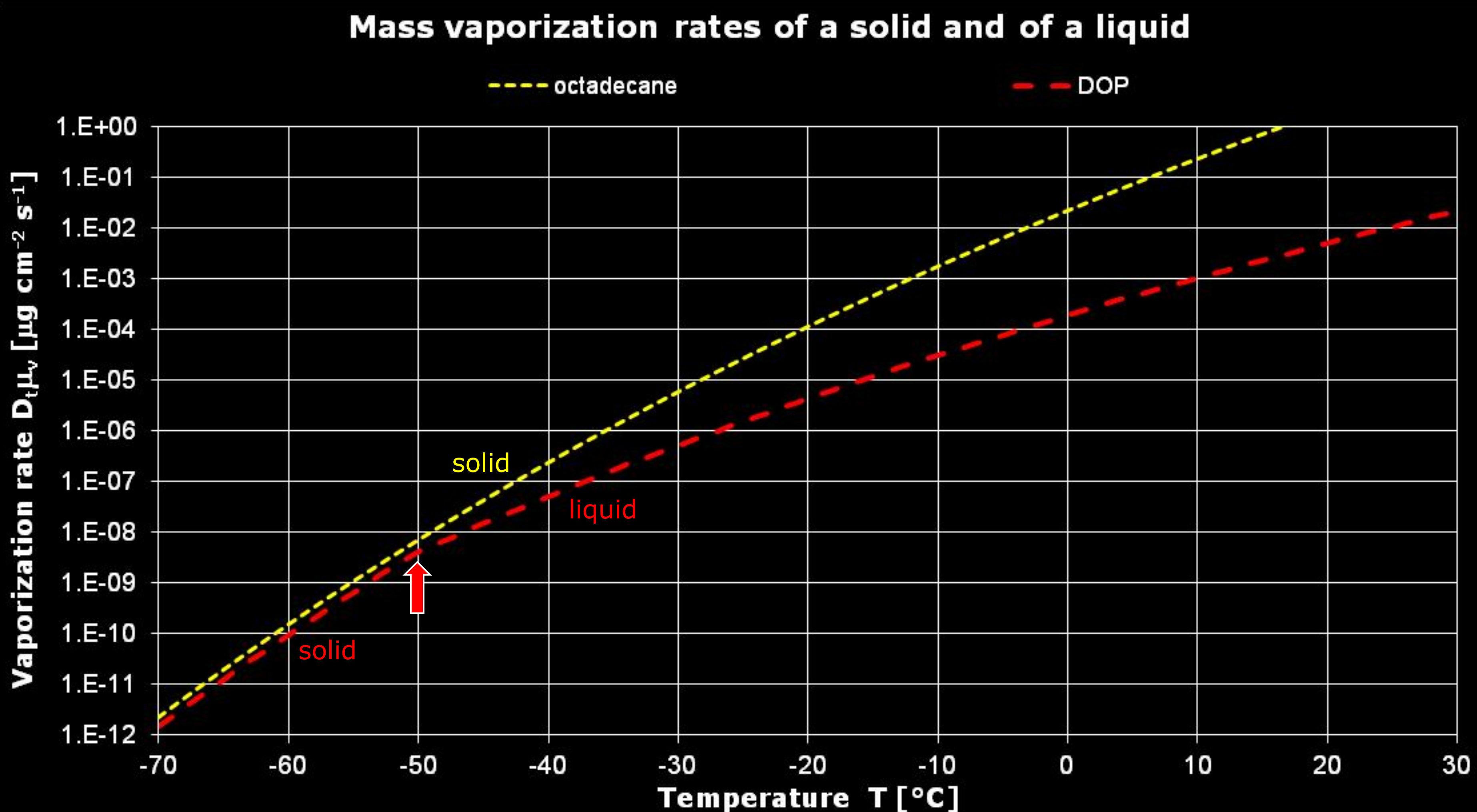
- Geometric view factors

$$f_{jk} = \boldsymbol{n}_k \cdot \Omega_{jk} / \pi$$



$$f_{kj} = \boldsymbol{n}_j \cdot \Omega_{kj} / \pi$$

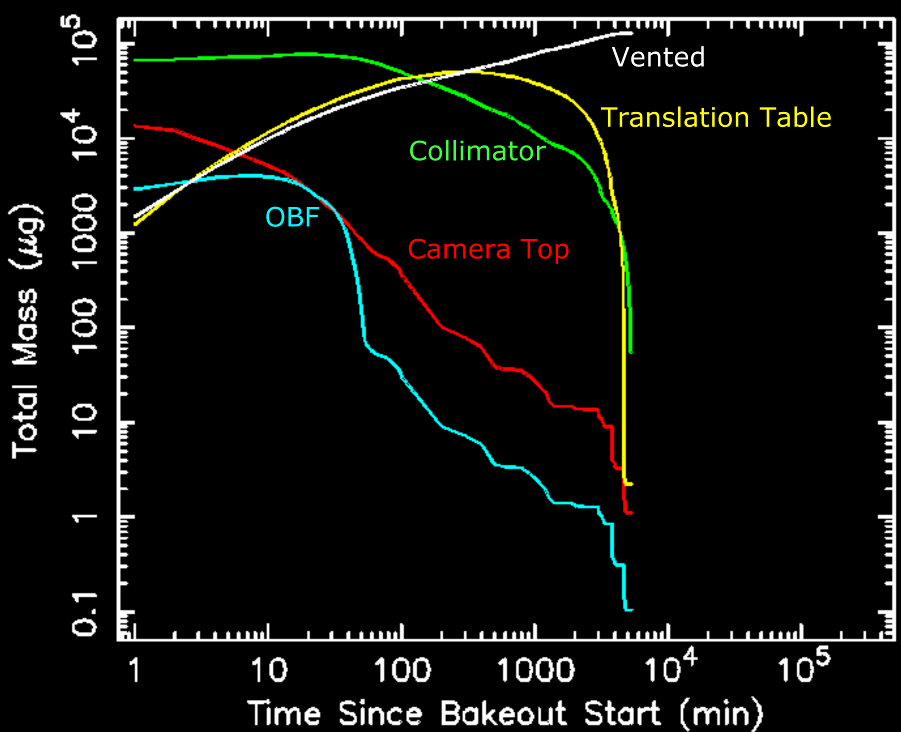
Vaporization rate: Dependence upon phase state



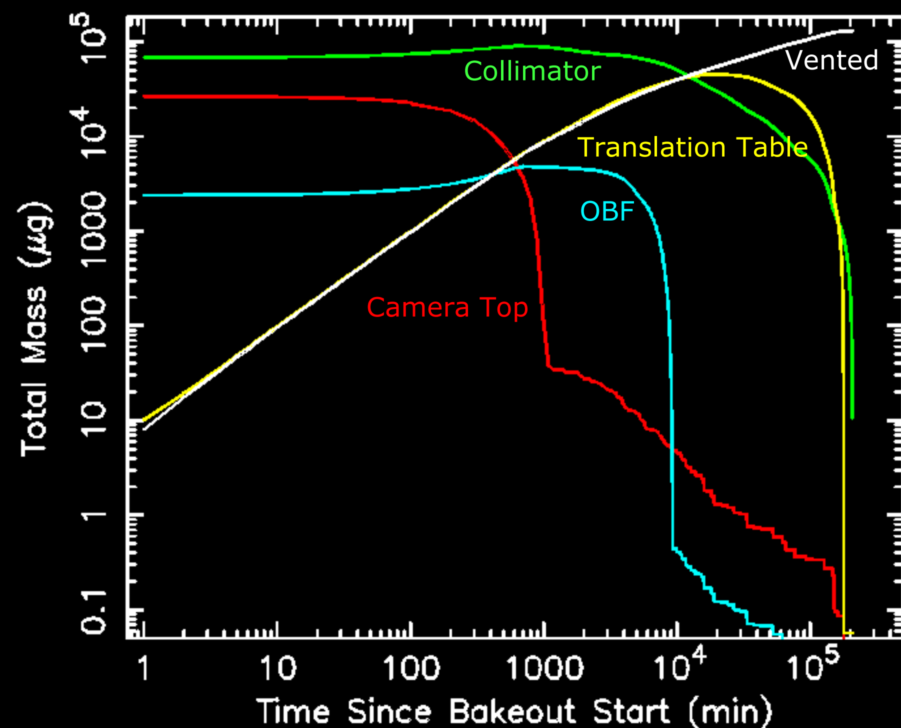
Contaminant mass
Cool bake-out

T_{FP} = -60°C T_{DH} = +25°C T_{OBF} = +10°C T_{TT} = -10°C

- Octadecane



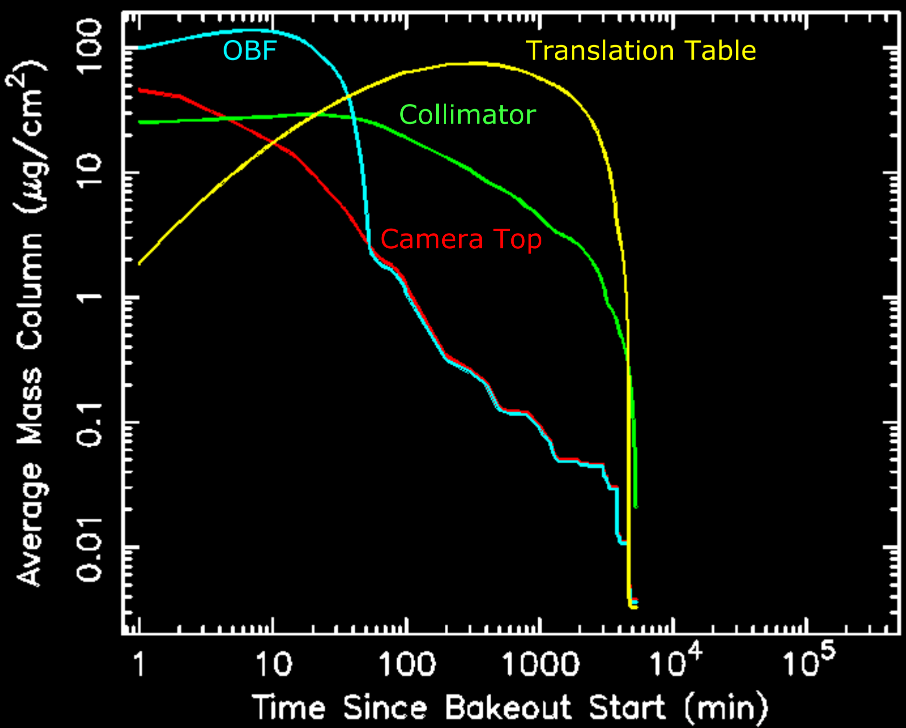
- Dioctyl phthalate (DOP)



Contaminant mass column
Cool bake-out

T_{FP} = -60°C T_{DH} = +25°C T_{OBF} = +10°C T_{TT} = -10°C

- Octadecane



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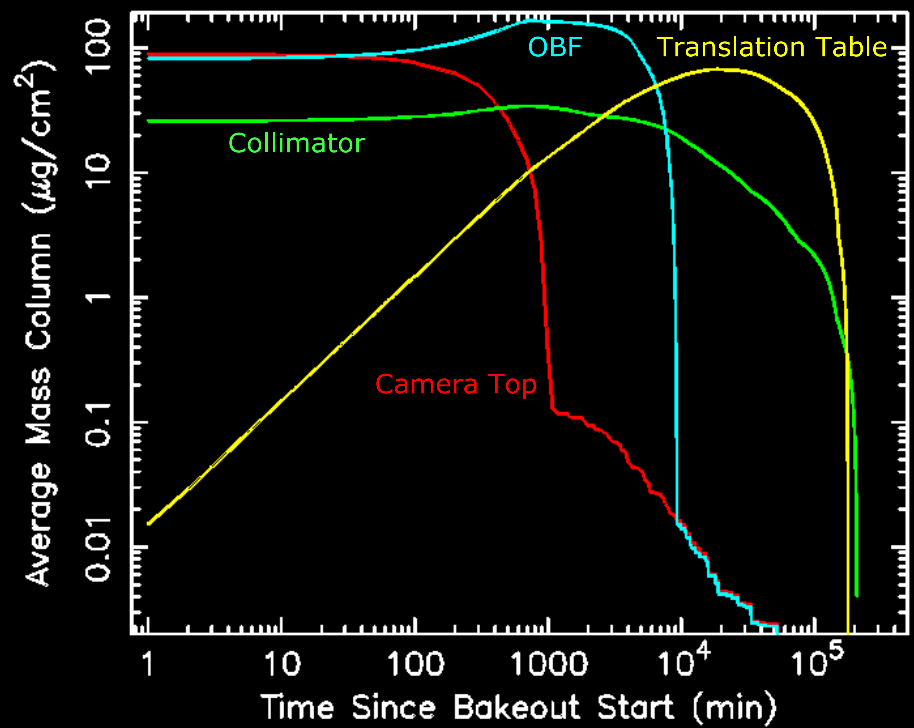
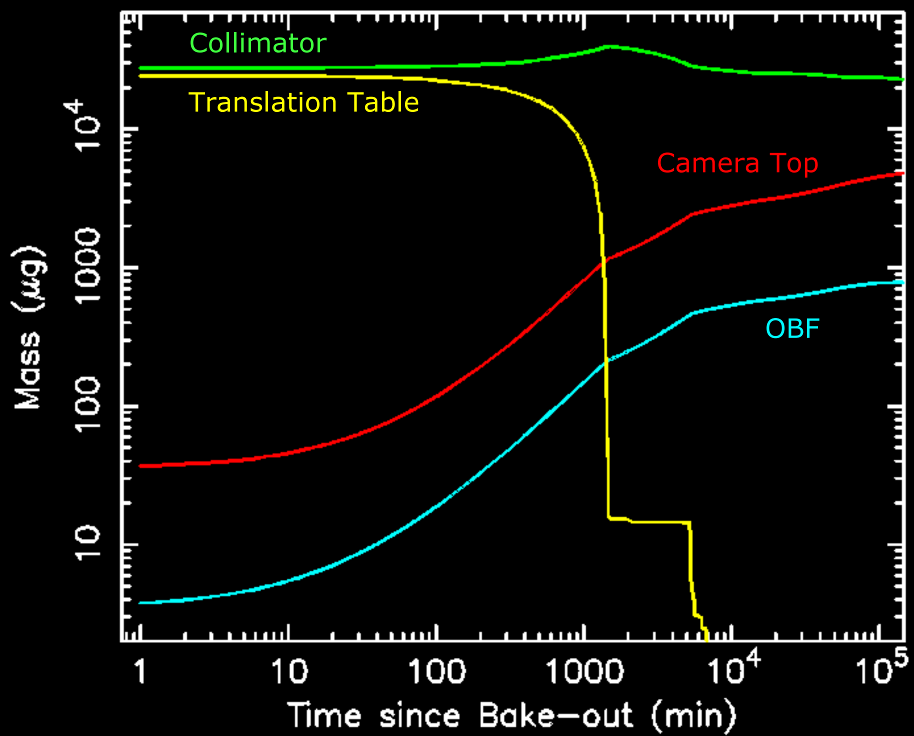


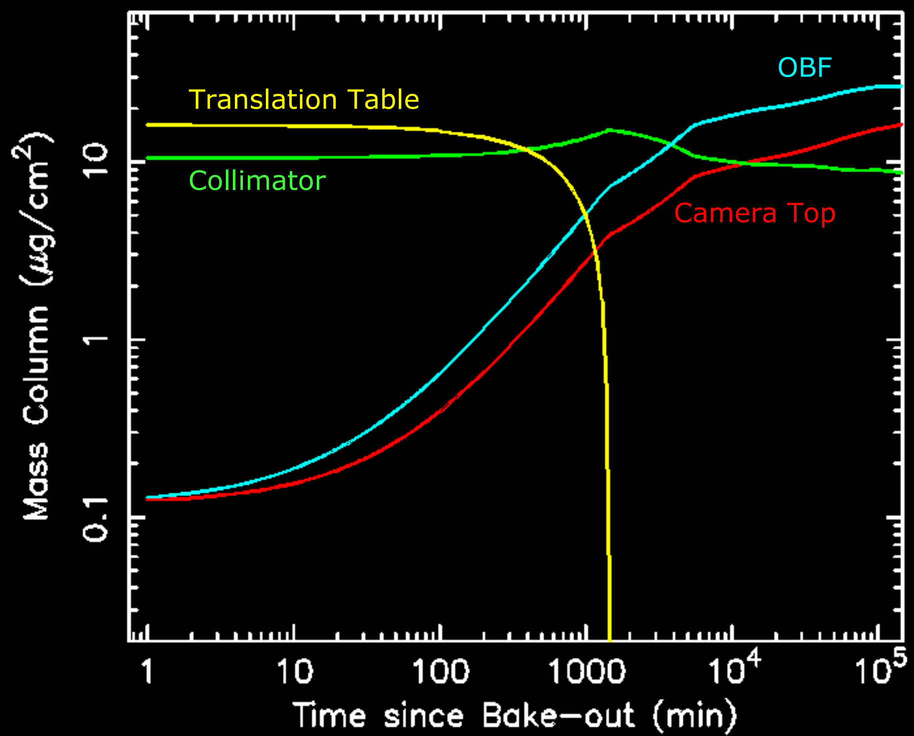
Contaminant re-deposition after (partial) cool bake-out

Octadecane/10

- Mass



- Mass column



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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 is not simple superposition
    - Dependence of thermal emissivity upon contaminant mass column
    - Surface redistribution, especially for a liquid contaminant
- Chandra Team has again deferred a decision to bake-out
  - Scientific productivity continues despite low-energy absorption
    - Observing proposals remain oversubscribed by factor ≈ 5.5
    - Over 400 refereed papers per year, steady over past decade
  - Identified risks of performing bake-out are small but not zero
  - Bake-out might not substantially reduce contamination on OBFs