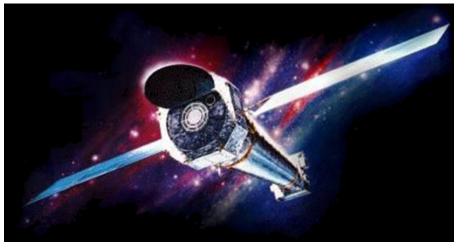

Modeling contamination migration on the Chandra X-ray Observatory — II

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Massachusetts Institute of Technology
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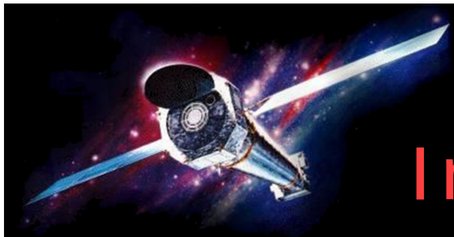
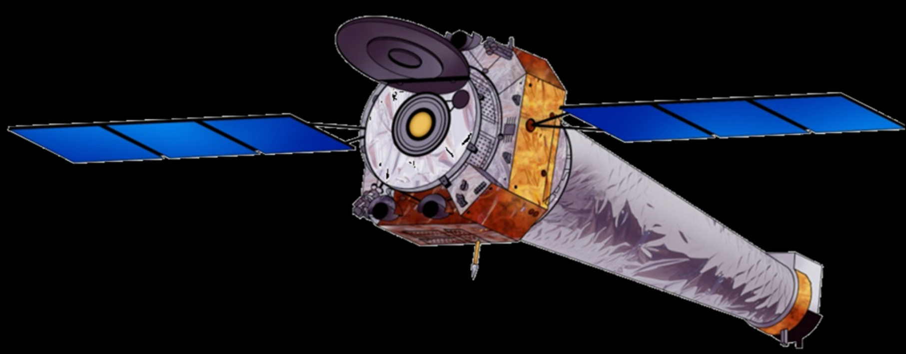
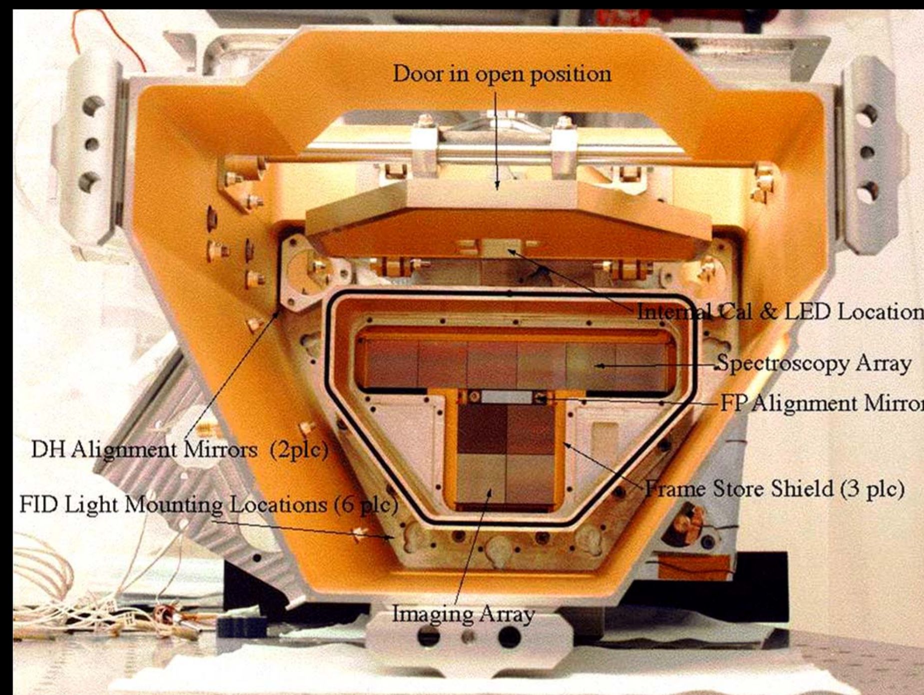


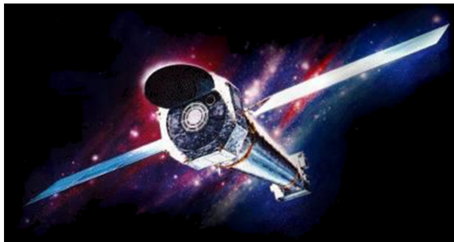
Chandra's Advanced CCD Imaging Spectrometer (ACIS)

- Chandra X-ray Observatory
  - Mirror Assembly
    - Transmission gratings
  - Optical bench
  - Science Instrument Module
    - High-Resolution Camera
    - Advanced CCD Imaging Spectrometer (ACIS)



- ACIS cavity
  - Collimator
  - Snoot and door
  - Camera top and filters

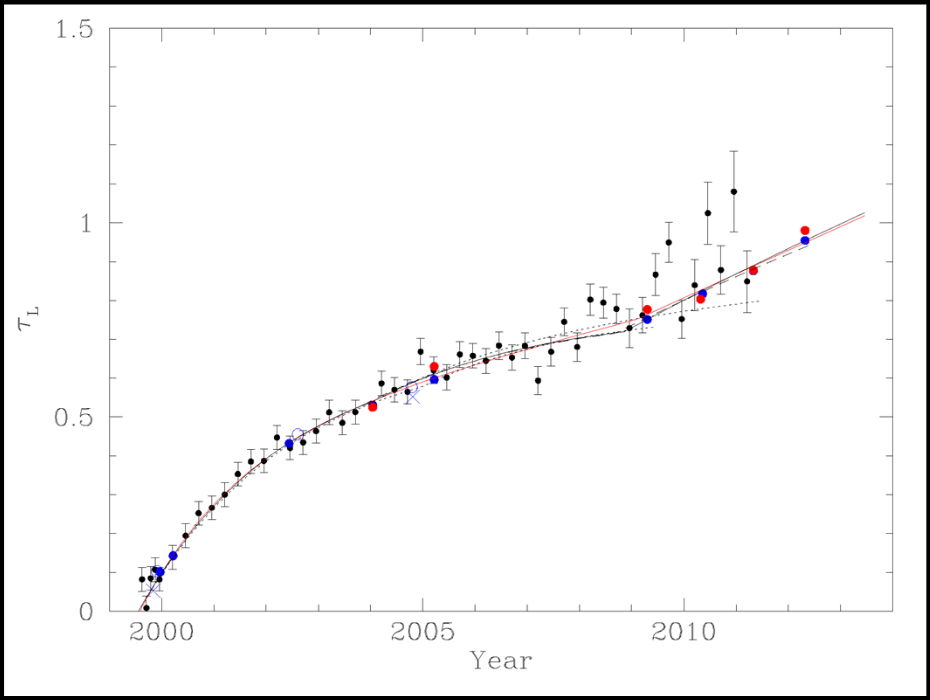


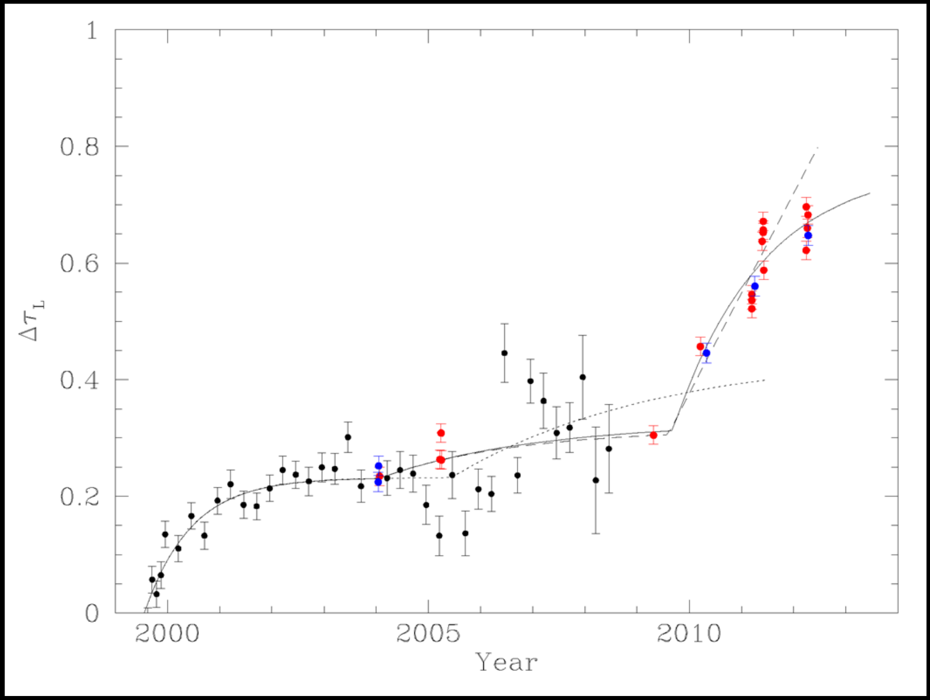


Introduction

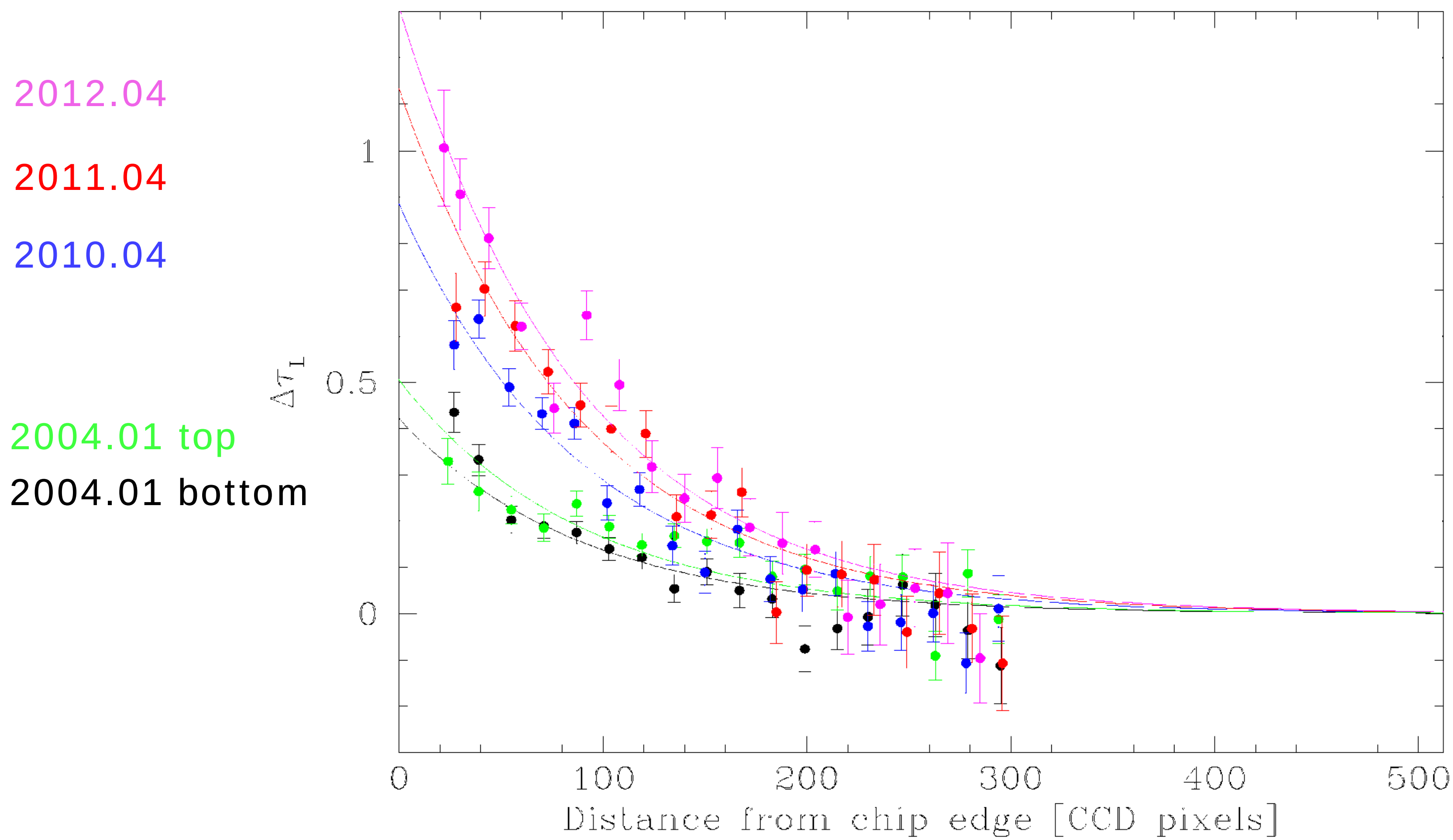
- *Chandra* has 2 focal-plane instruments, each with I & S arrays.
  - High-Resolution Camera (microchannel plates) is at ambient.
  - Advanced CCD Imaging Spectrometer is passively cooled.
    - Heaters on ACIS housing may be set to -60°C during operations.
    - Focal plane is held at -120°C to reduce charge-transfer inefficiency.
- A contaminant has accumulated on the cold optical blocking filters.
  - Measured x-ray attenuation shows a column ≈ 200 μg cm^{-2}.
    - Infer a mass of contaminant ≤ 1 g in entire *Chandra* optical cavity.
    - Accumulation rate is about 30 times pre-flight estimates.
  - High-resolution x-ray spectroscopy provides more information.
    - Contaminant is primarily carbon C/O ≈ 11, C/F ≈ 15, C/N > 30.
    - Based upon EXAFS, nearly all the carbon is aliphatic (single-bond).
  - Molecular weight and vapor pressure remain unknown.

Spatial variation

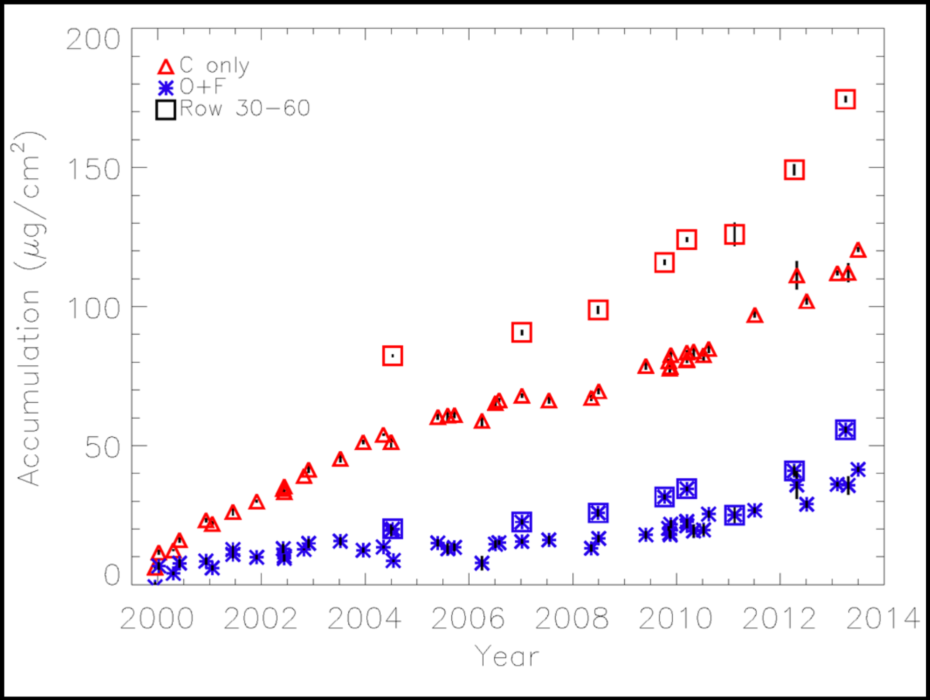


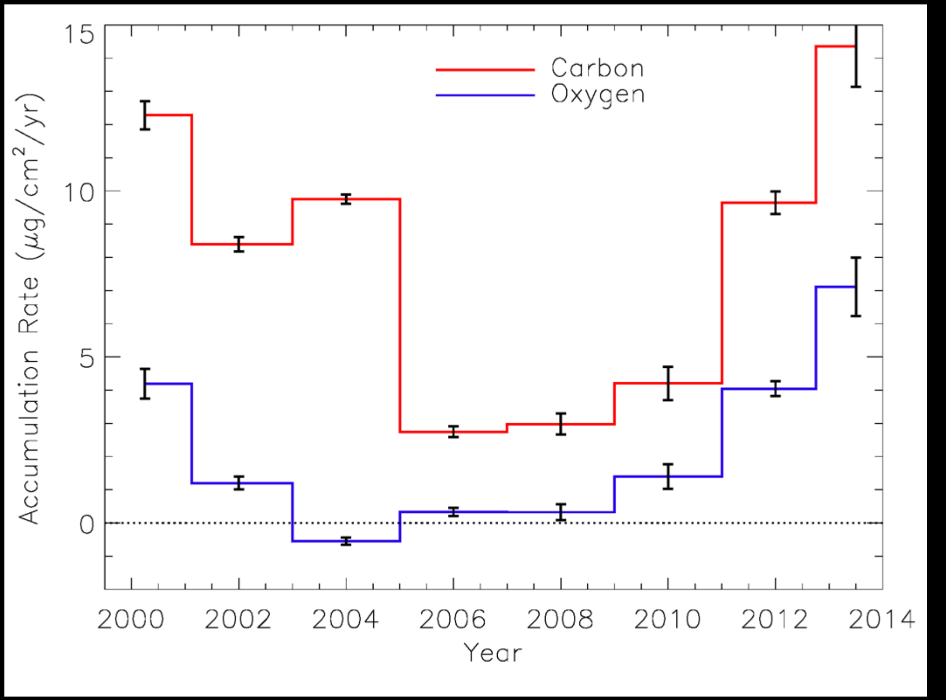


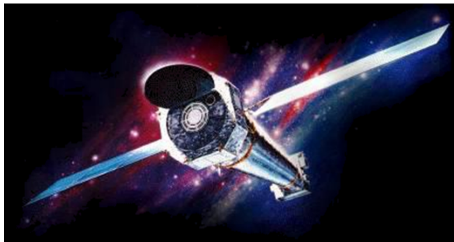
Spatial distribution of contaminant on OBF



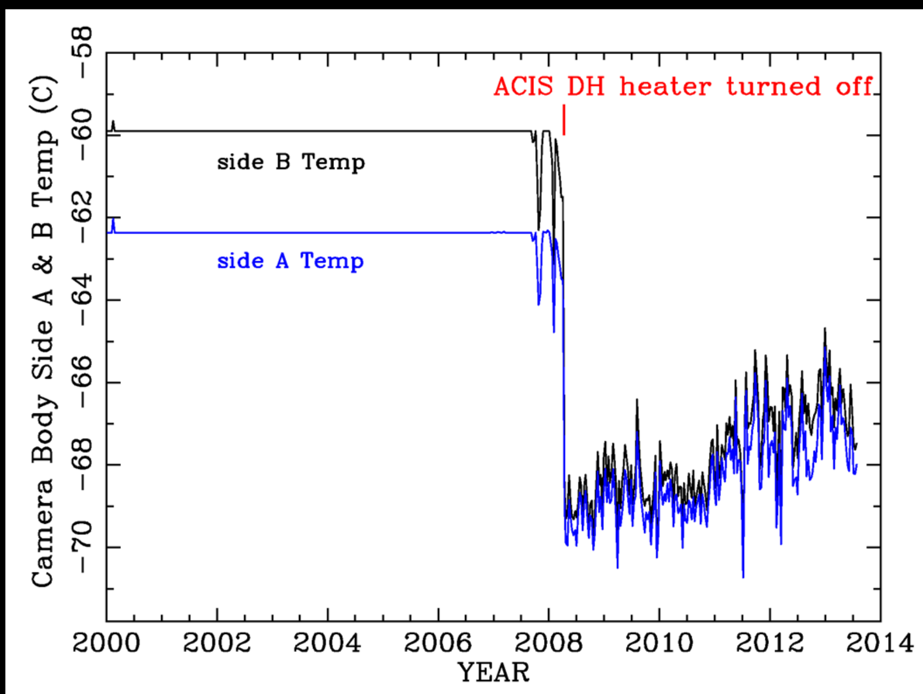
Composition variation

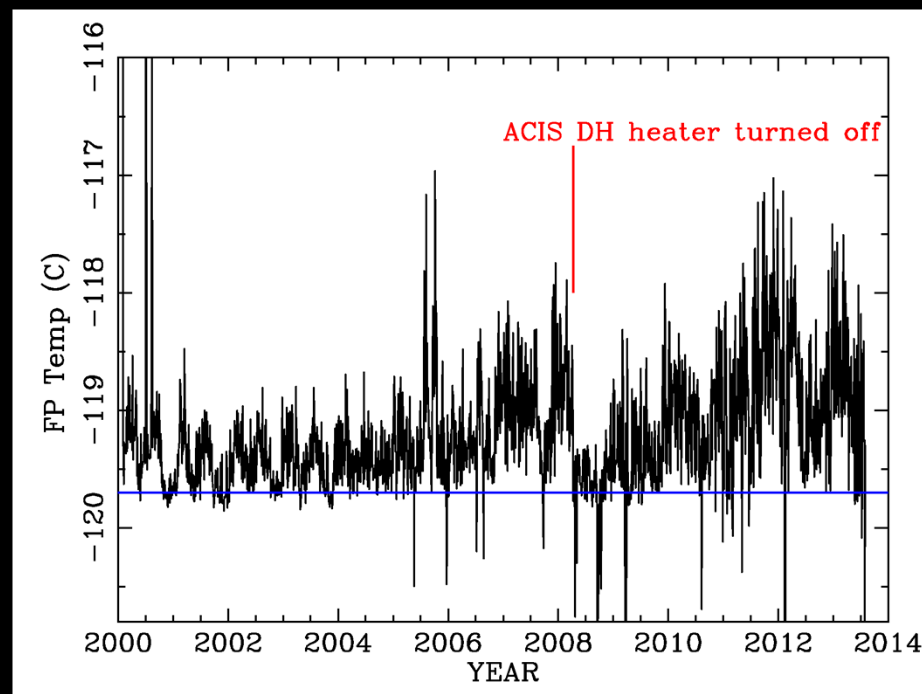




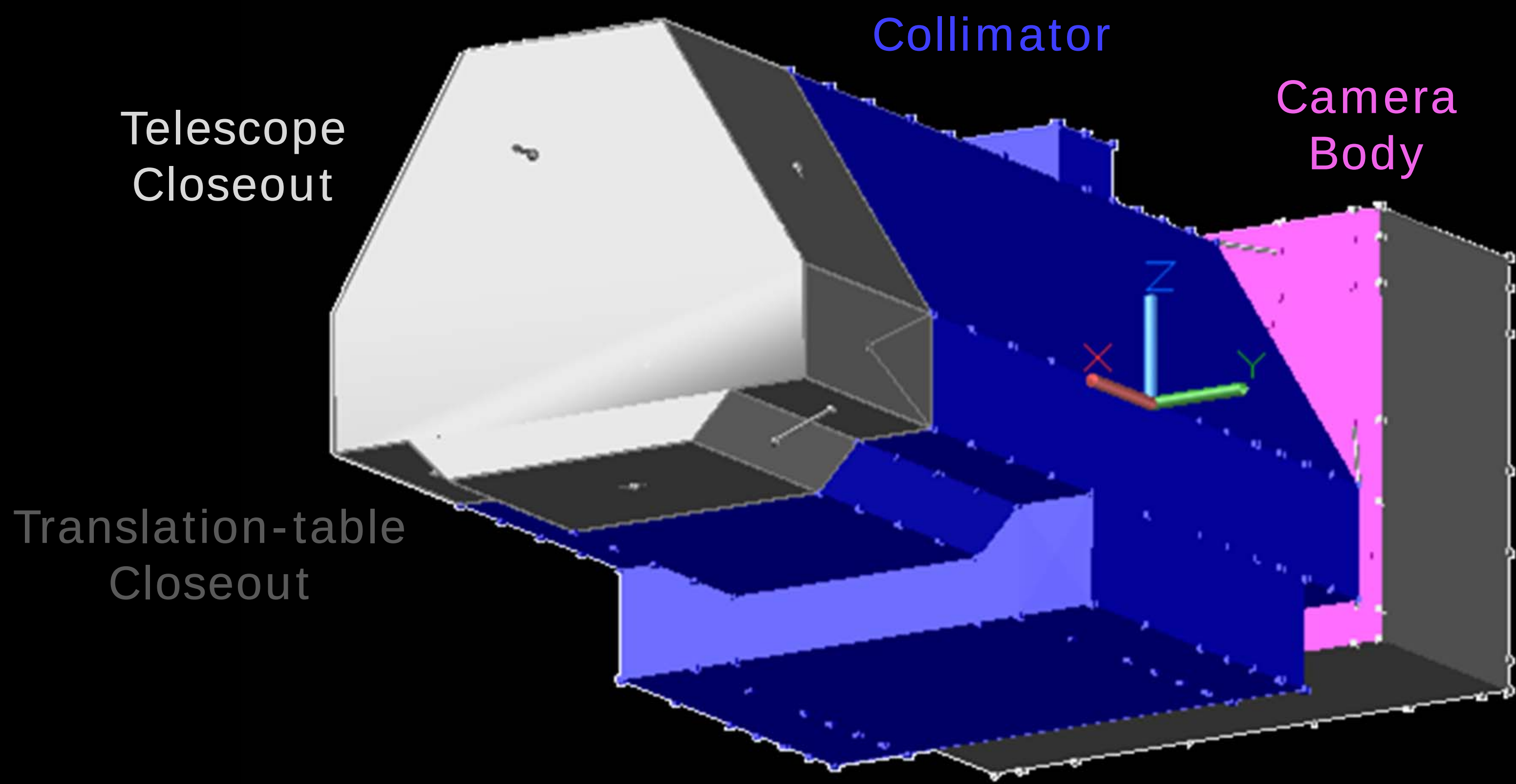


Effects of turning OFF the ACIS housing heater

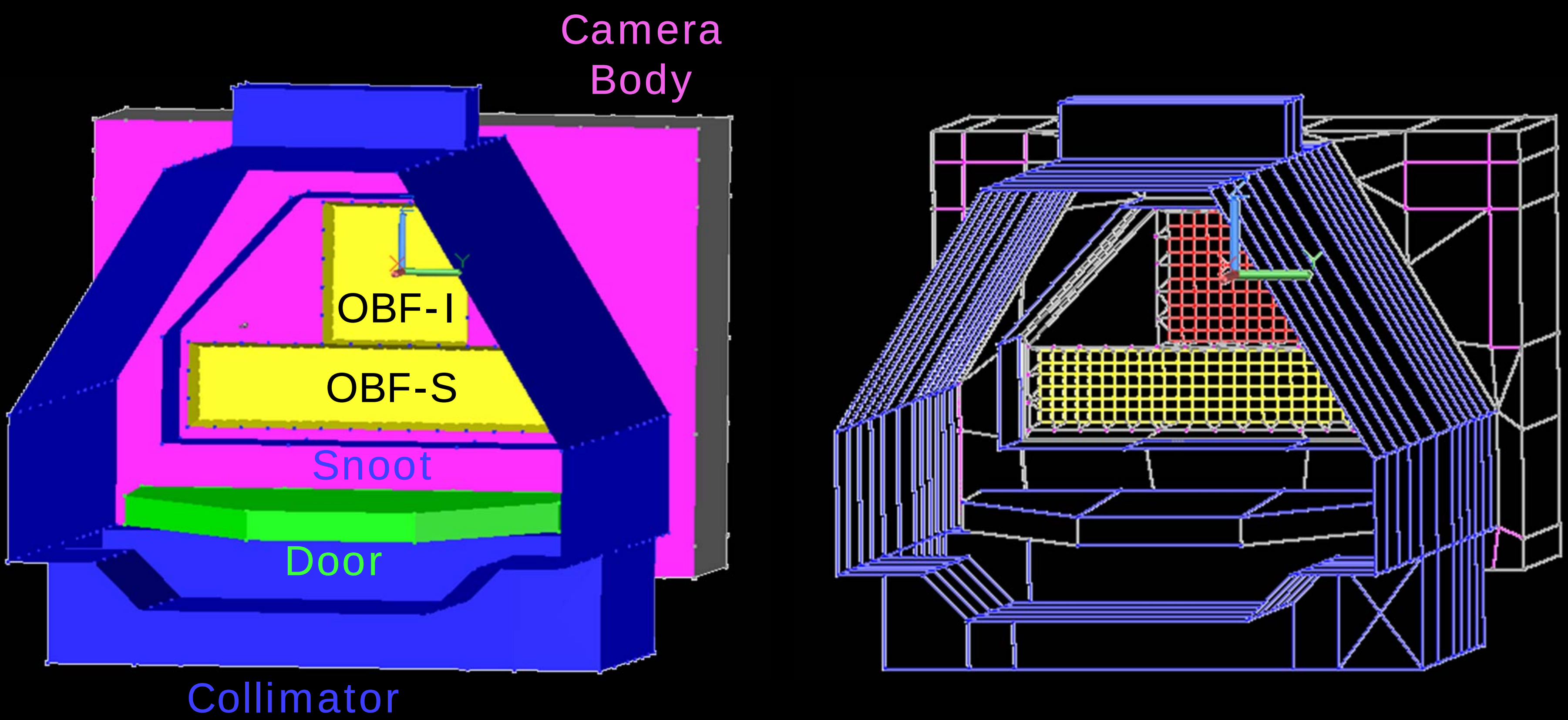




ACIS geometric model (exterior view)

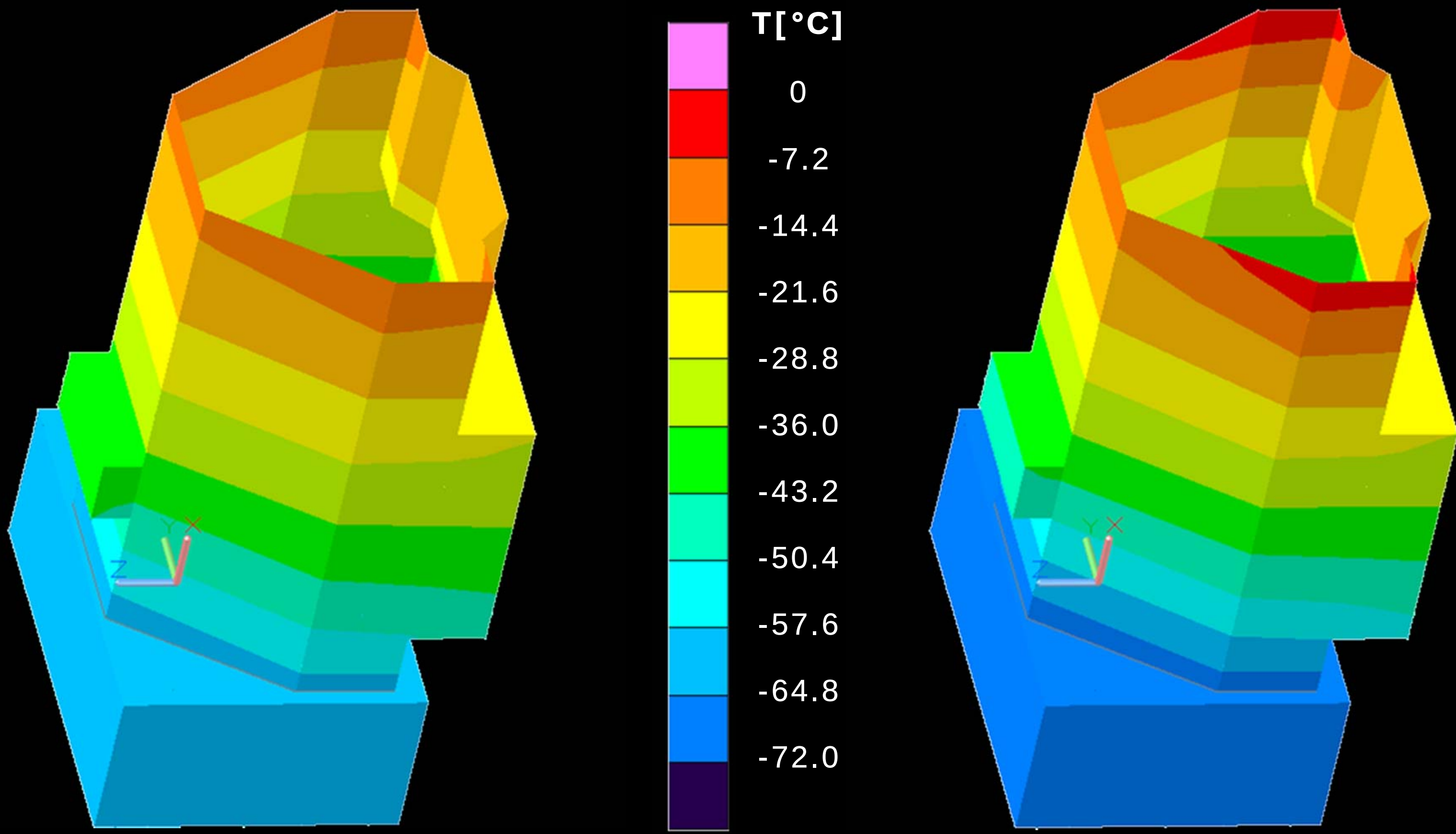


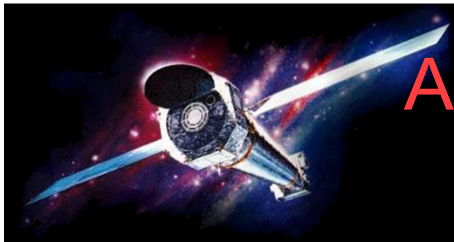
ACIS geometric model (interior view)



ACIS temperature distribution (exterior)

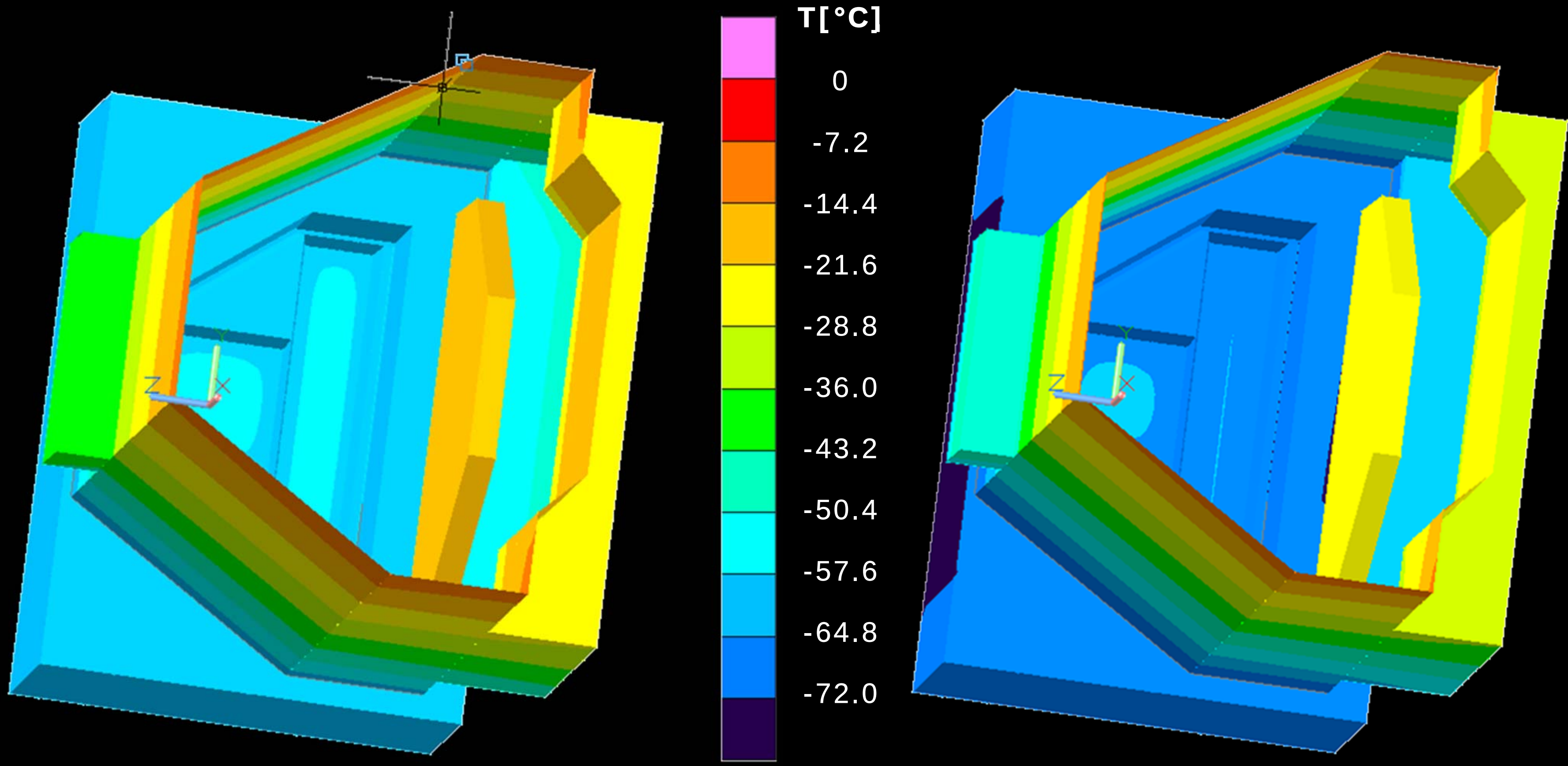
- Early 2008: Housing heater ON
- Late 2008: Housing heater OFF

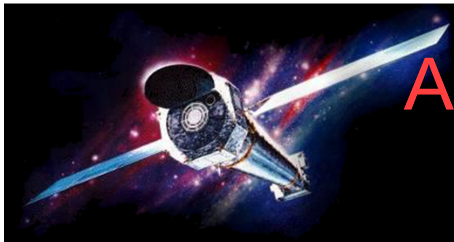




ACIS temperature distribution (interior)

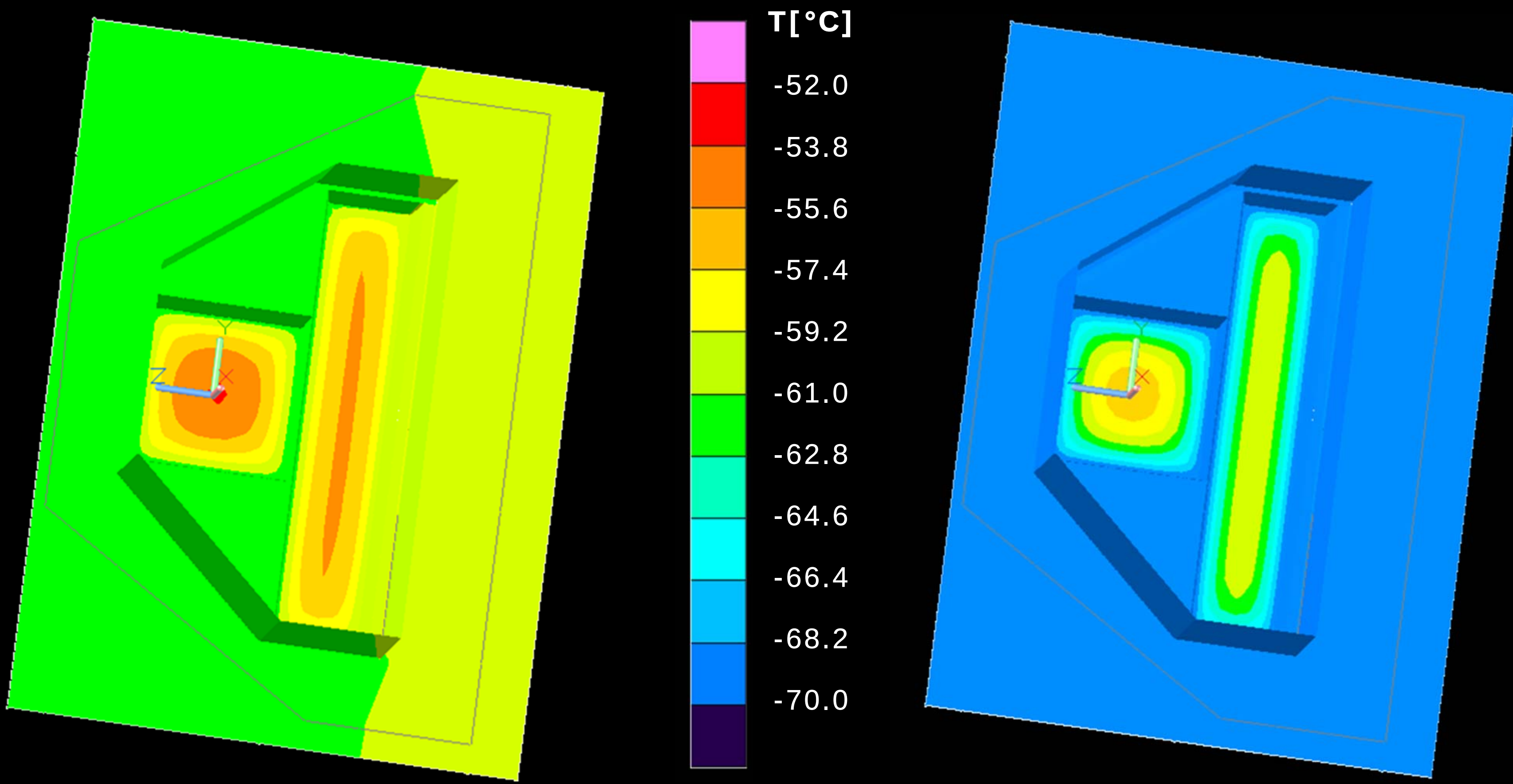
- Early 2008: Housing heater ON
- Late 2008: Housing heater OFF

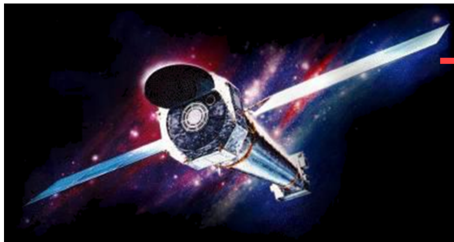




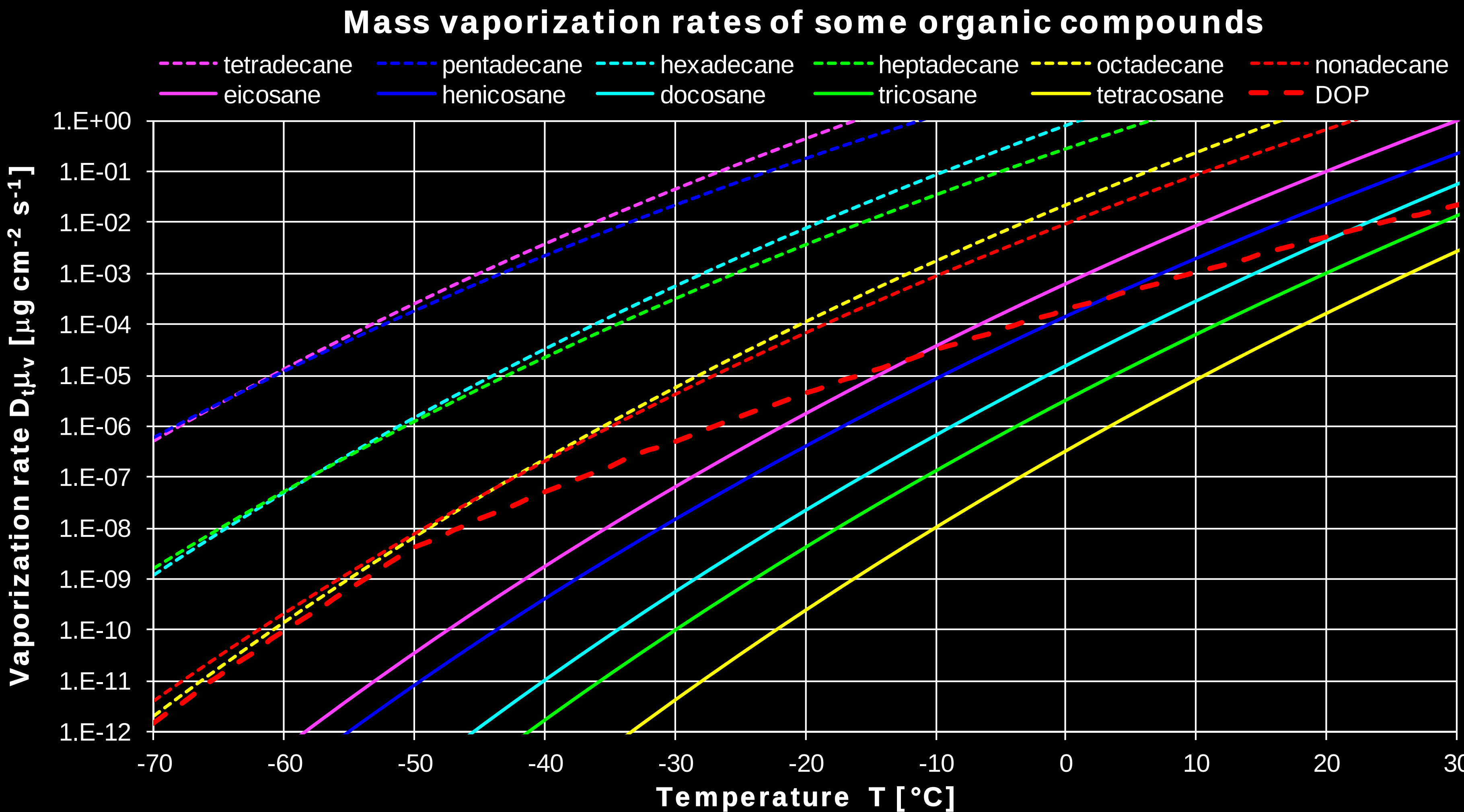
ACIS temperature distribution (camera top and filters)

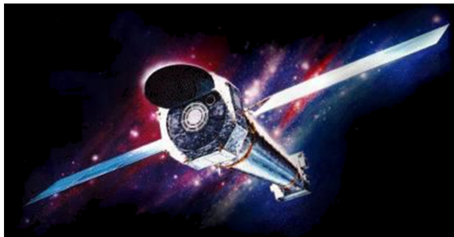
- Early 2008: Housing heater ON
- Late 2008: Housing heater OFF



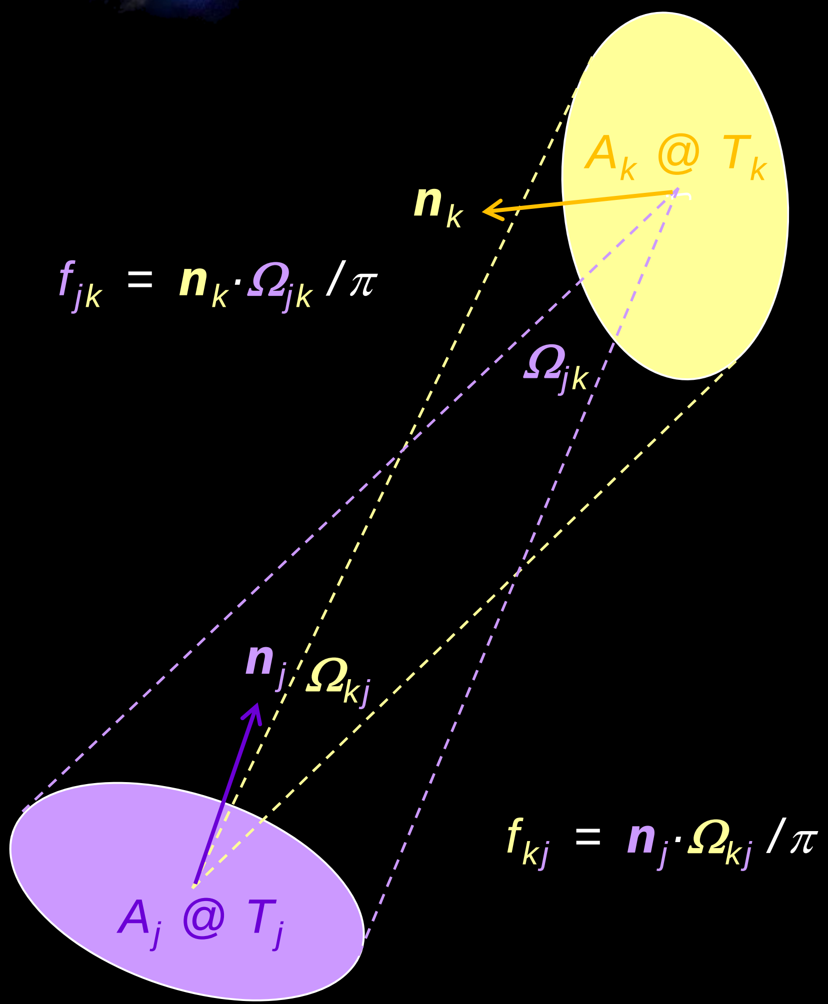


Temperature dependence of mass vaporization rate





Molecular rate equations



- Net mass flux onto node j

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

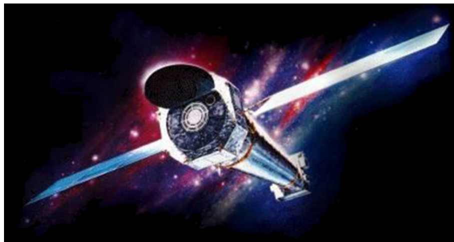
- Mass vaporization rate
  - Related to vapor pressure

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

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

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

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

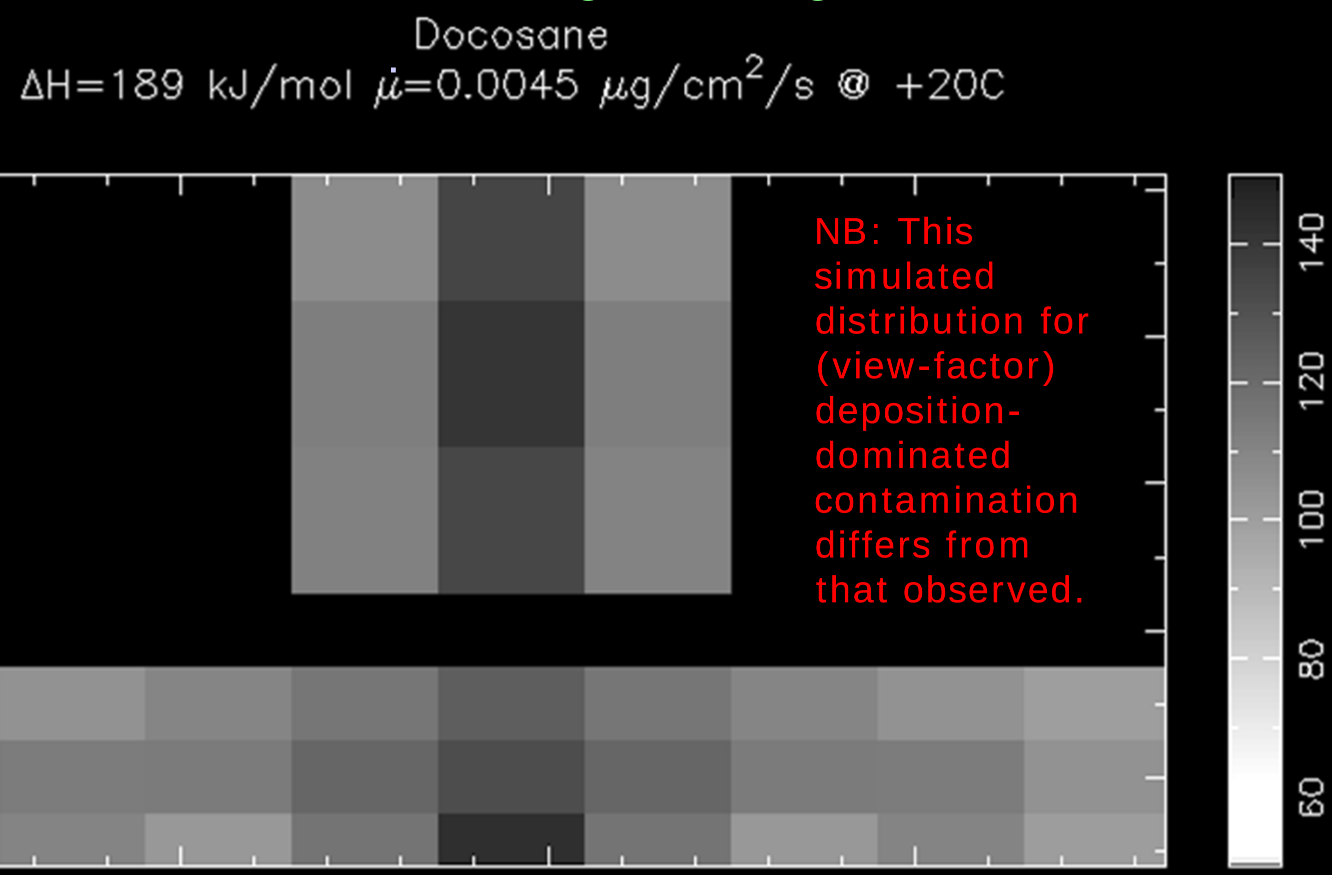


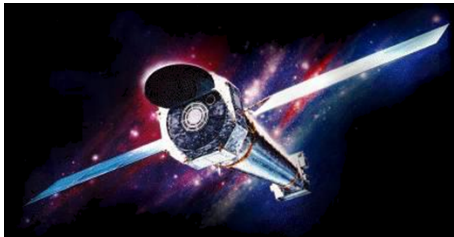
Simulation methodology

- Simulation methodology
  - Solve coupled molecular rate equations to evolve mass column.
    - Contaminant deposits on each surface from source, other surfaces.
    - Contaminant vaporizes from each contaminated surface.
    - If vaporization exceeds deposition, surface cleans and remains so.
  - Input (thermal) geometric model for areas and view factors.
  - Use thermal model to estimate temperatures on surfaces.
    - Use high-resolution thermal model for ACIS cavity.
    - Treat rest of Observatory's optical cavity as warm closeouts.
      - Material leaving ACIS cavity either vents or returns.
  - Specify volatility of contaminant.
    - Assume mass vaporization rate at reference temperature (+20°C).
    - Scale temperature dependence using Clausius–Clapeyron equation.
      - Governing parameter is the enthalpy of vaporization $\Delta_v H$.

Deposition simulation

- Simulate deposition of docosane ($C_{22}H_{46}$) onto OBF at operating T.
  - View factors from contaminating nodes govern distribution.





Summary

- Contamination-migration model has been a useful tool.
  - It predicts the relative likelihood of success for scenarios.
  - Utility for high-fidelity, 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.
      - Contaminant probably comprises multiple molecular species.
      - Thermal emissivity depends upon mass column of contaminant.
        - » Temperature distribution
        - » Mass vaporization rate