

Chandra Contaminant Migration Model

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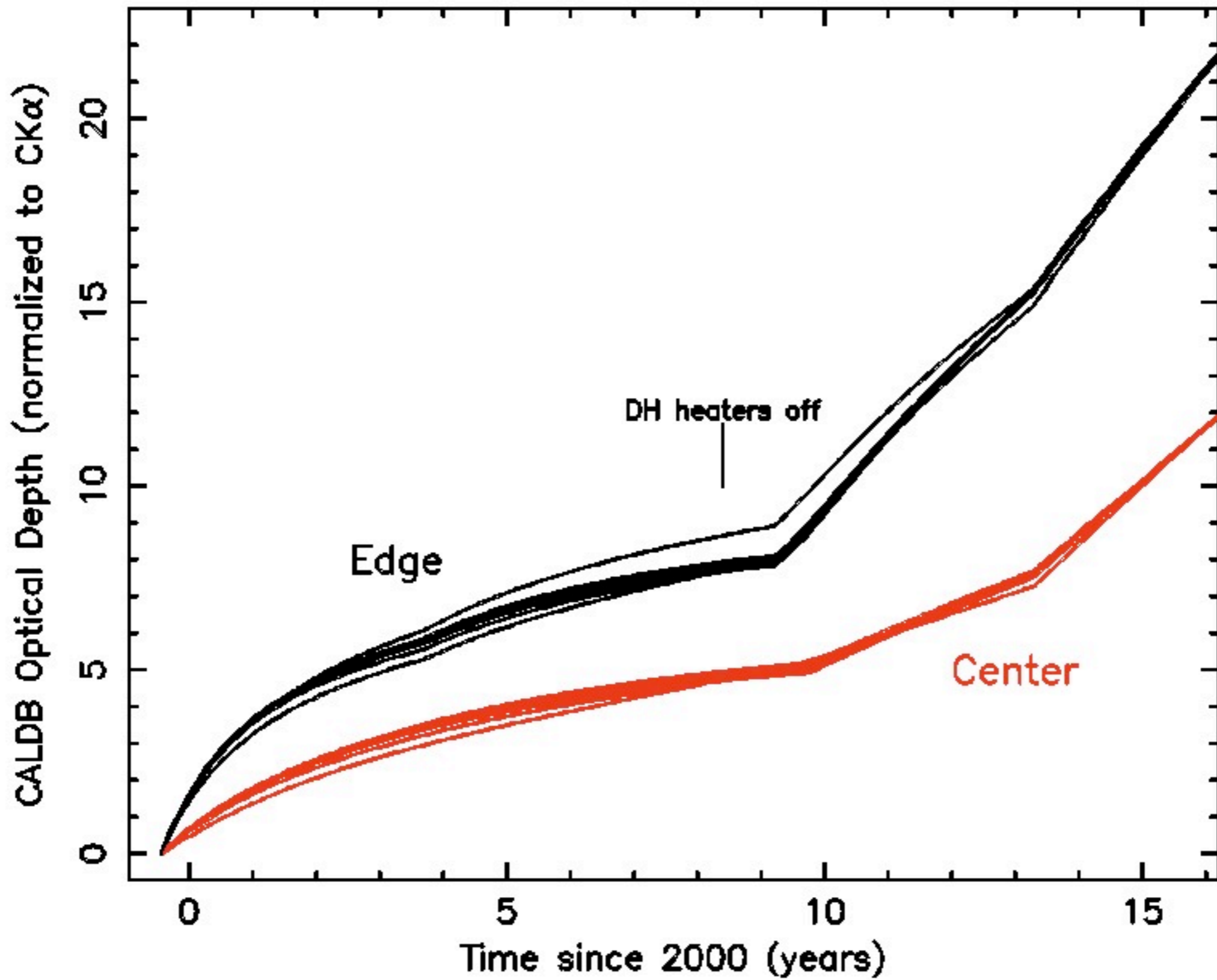
Motivation:

The accelerated accumulation observed since ~2012 cannot be reproduced under the old assumptions of one (or more) gradually depleting contaminant source(s) -- any new paradigm must consider source(s) with rates *increasing* with time (but consistent within S/C trends).

Methods: *(the usual)*

(1) Simulate migration (vaporization/deposition) of potential contaminant(s) by solving a set of 1st order ODEs through explicit (forward) difference scheme and within thermal & geometric model constraints.

(2) Compare time evolution of material mass column density to observations at select locations on OBF filters to identify best candidate contaminant properties.



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Simulation Constraints:

- ◆ Spacecraft geometry (surface areas & view factors) and time-averaged surface temperatures as determined by Neil Tice (LM) using flight data inputs to Thermal DesktopTM RADCAD (geometric) & SINDA FLUINT (radiative/conductive thermal) modules; accounts for effects of DH heaters being turned off ~2008.4 (t~9 yr)
- ◆ X-ray observations of contamination effects throughout the mission as documented in CALDB contamination model N0009 (June 2014); constrains time evolution and spatial distribution of contaminant optical depth, $\tau(t,x,y)$, proportional to the mass surface density, $\mu(t,x,y)$
- ◆ Temperature dependence of vaporization rate follows Clausius-Clapeyron relation $\rho(T) = \rho(T_0) (T/T_0)^{1/2} \exp(-\Delta H(1/T-1/T_0)/R)$
where $\rho(T)$ is the mass vaporization rate at temperature T , ΔH is the vaporization enthalpy, and R the universal gas constant

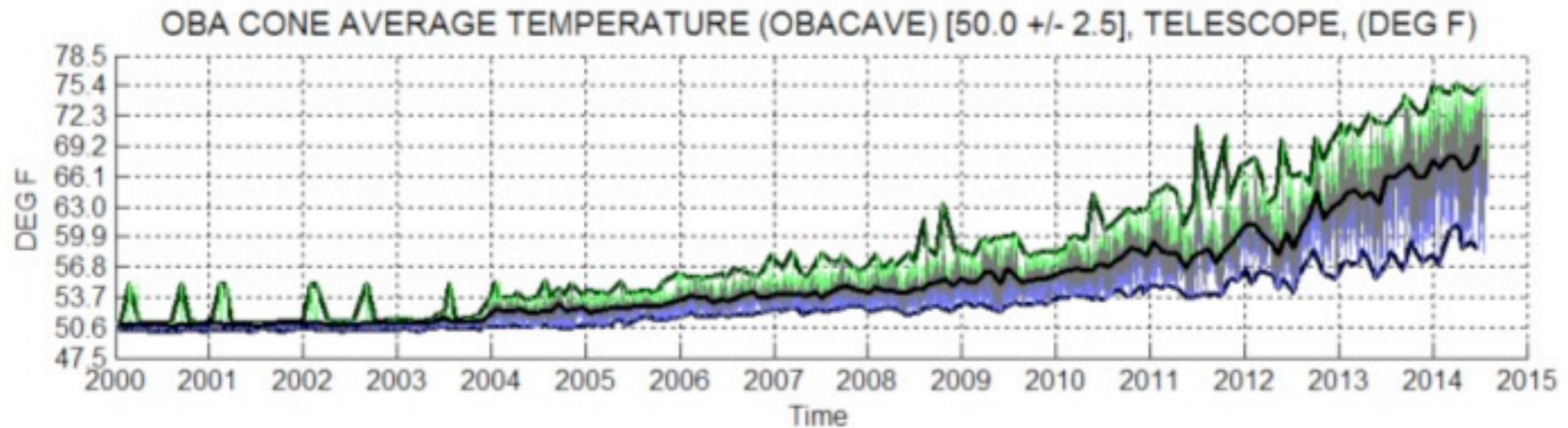
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Simulation Parameters:

- ◆ Material (enthalpy, ΔH , and reference temperature, T_0 , fixed); vaporization rate normalization $\rho(T_0)$ is a free parameter
- ◆ Declining source rate: $S(t) = A(1 + B \cdot \exp(-t/C))$ where A, B & C are chosen to follow the early build-up ($t < 2008$) at the center of S3
- ◆ Rising source rate: $S'(t) \propto A' \exp(-B'(1/T - 1/T_0))$ where the normalization, A' is a free parameter and B' is given by the enthalpy ΔH of the supposed contaminant. Physically, A' includes a multiplicative scale factor representing the outgassing 'escape efficiency'.

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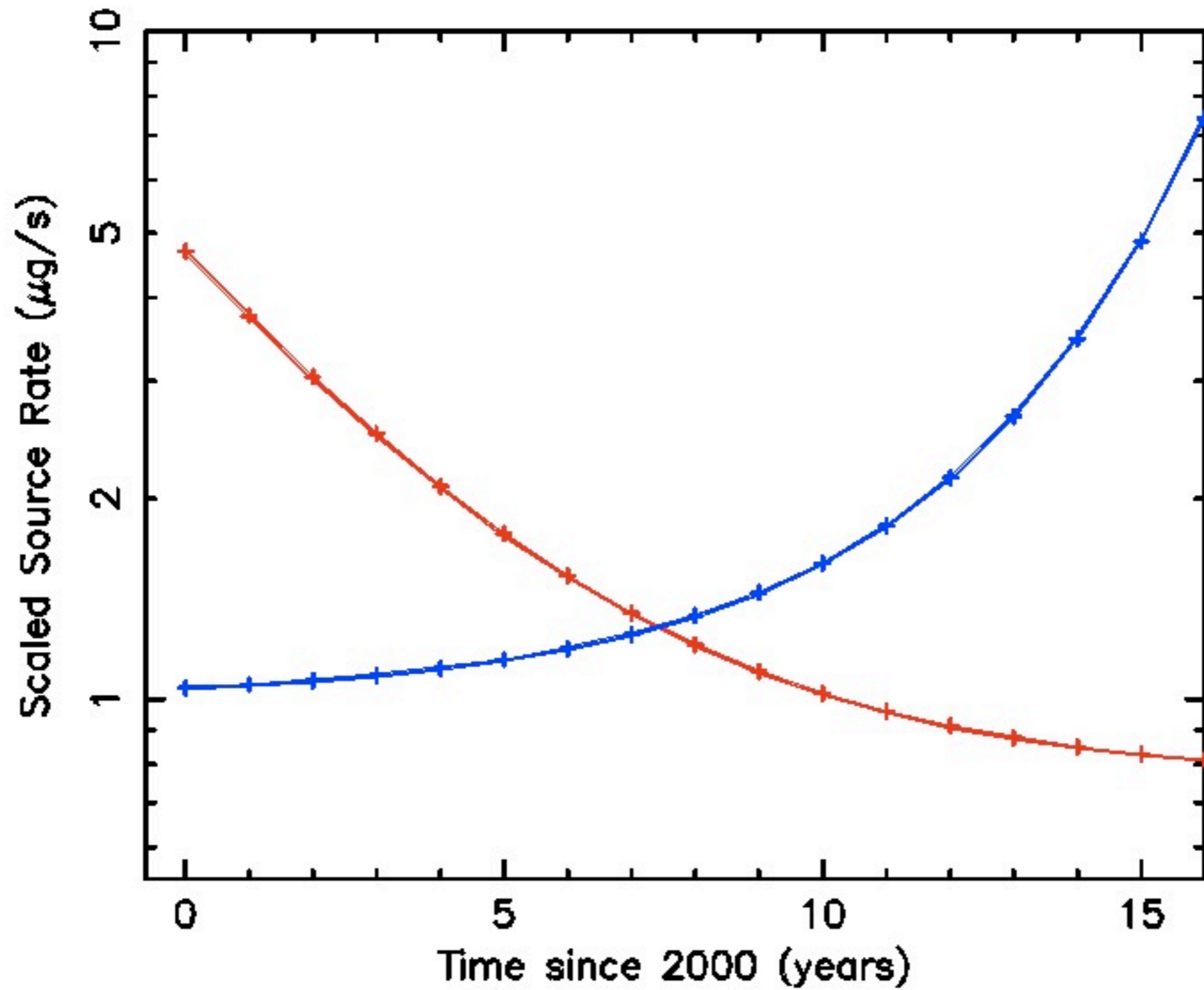
$$T_{\text{OBA}}(t) = T_0 [1 + 0.006 \exp((t-8.1)/4.0)]$$



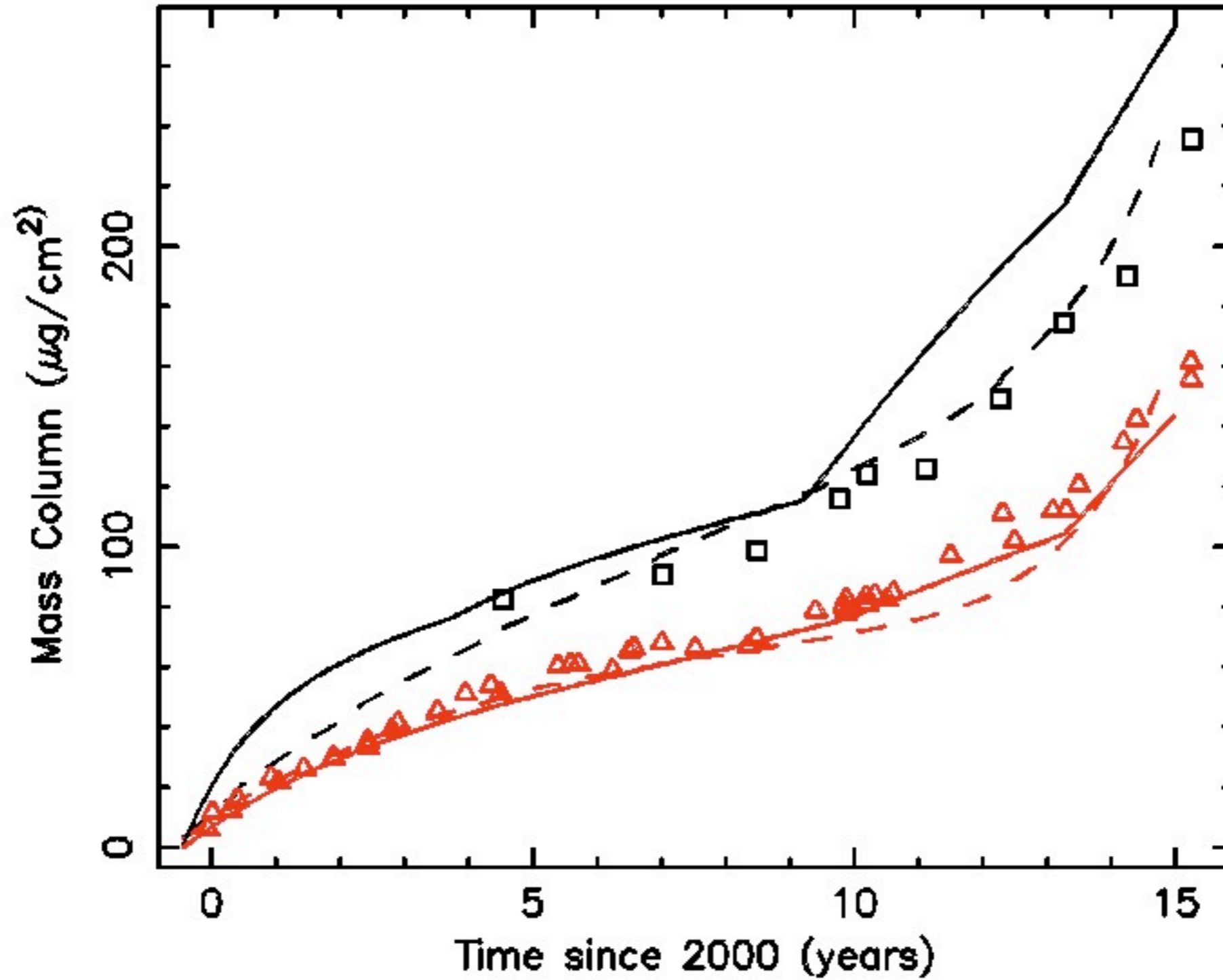
$$S'(t) = S'(T_0) (T_{\text{OBA}}(t)/T_0)^{1/2} \\ * \exp[-\Delta H/RT_0(T_0 - T_{\text{OBA}}(t))/T_{\text{OBA}}(t)]$$

...the Clausius-Clapeyron equation for a time-dependent T_{OBA}
 (ΔH and T_0 are those of the contaminating material)

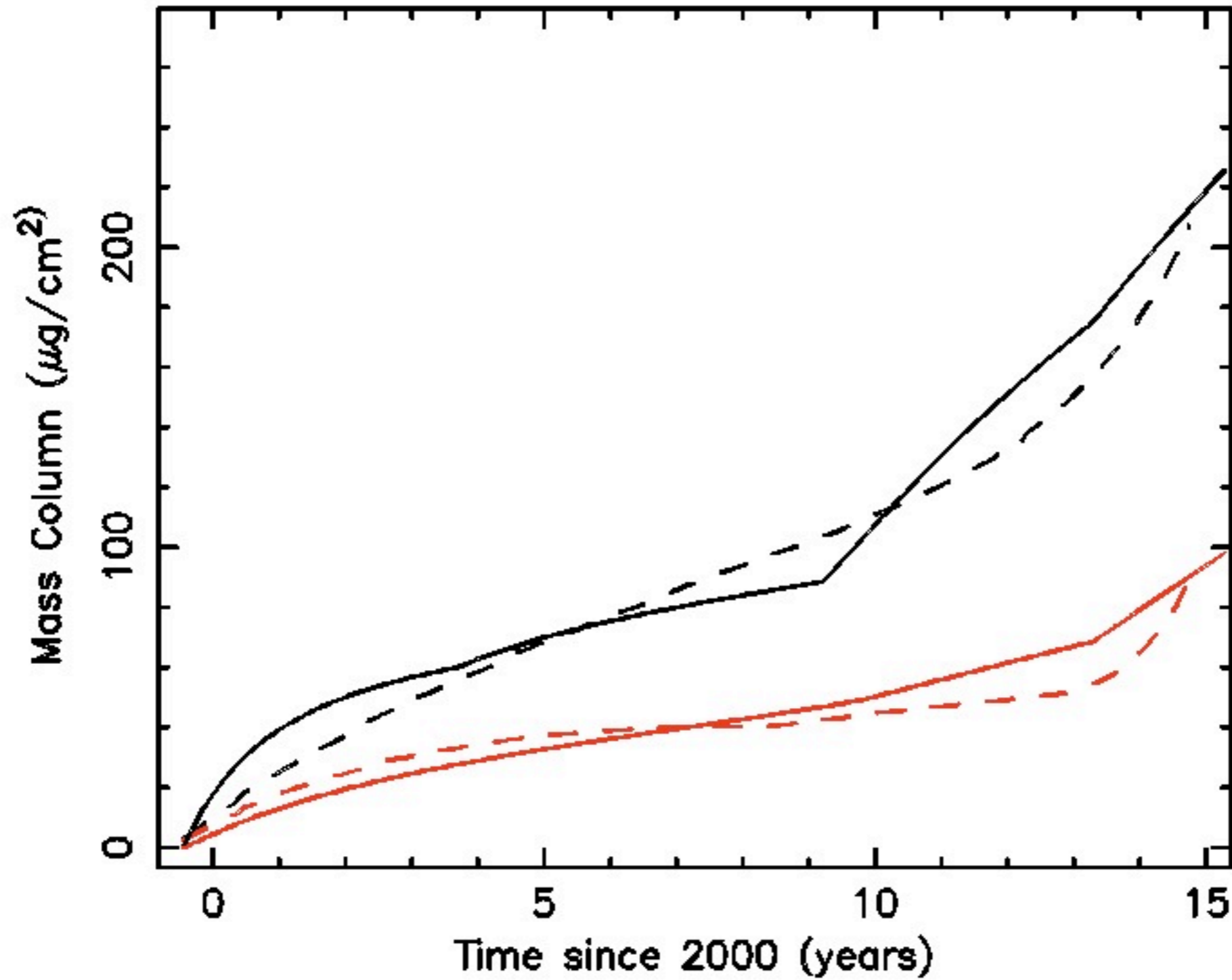
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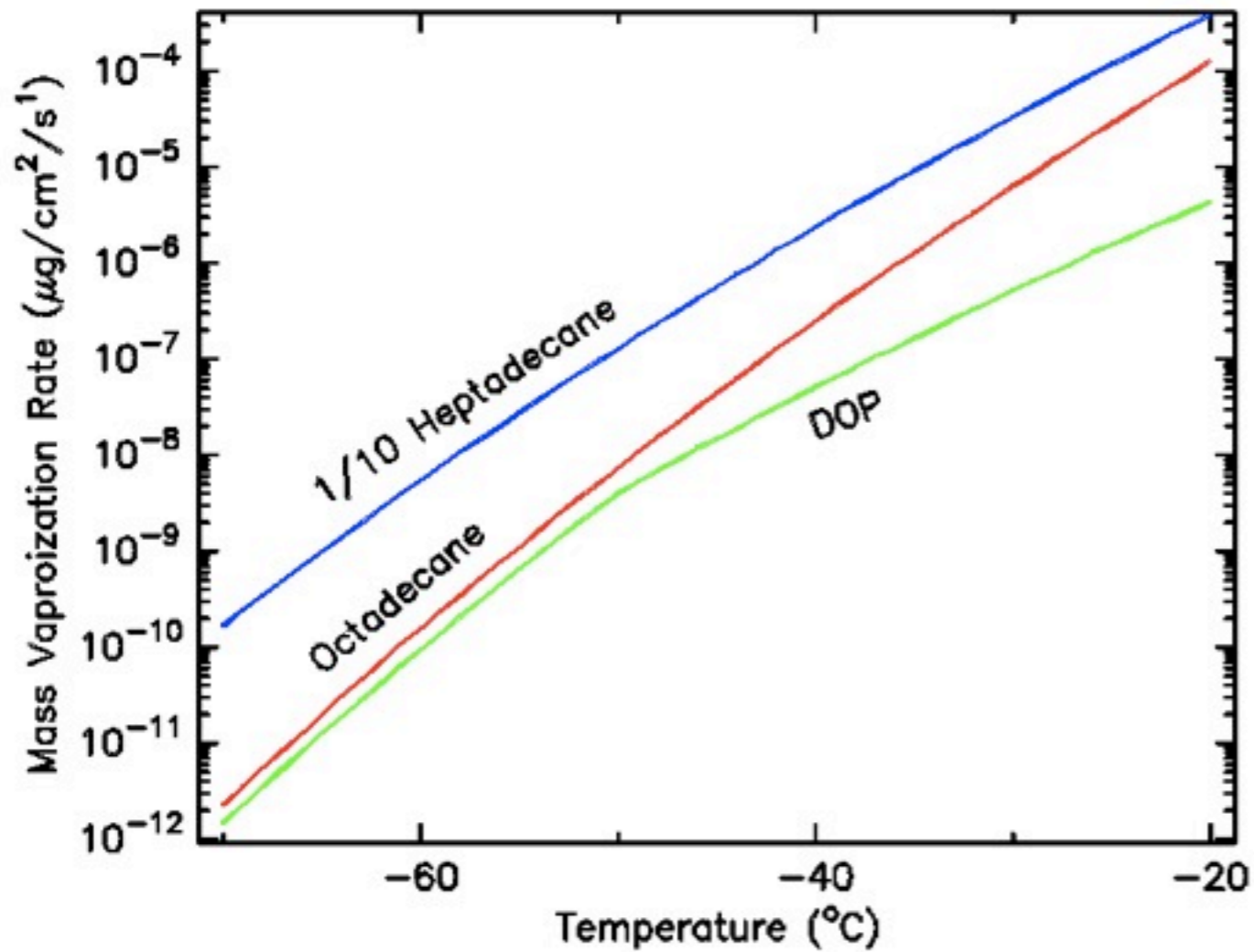
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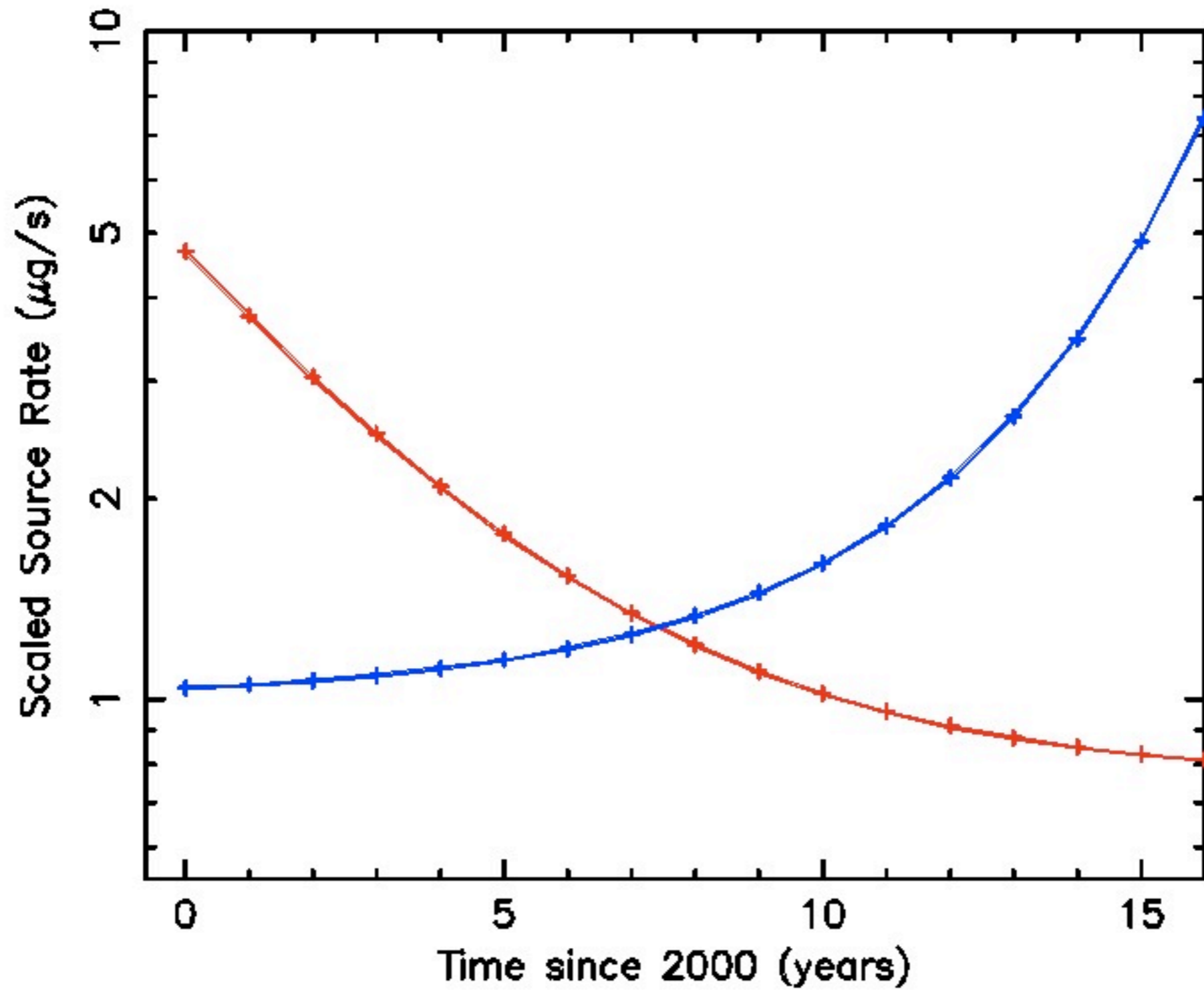


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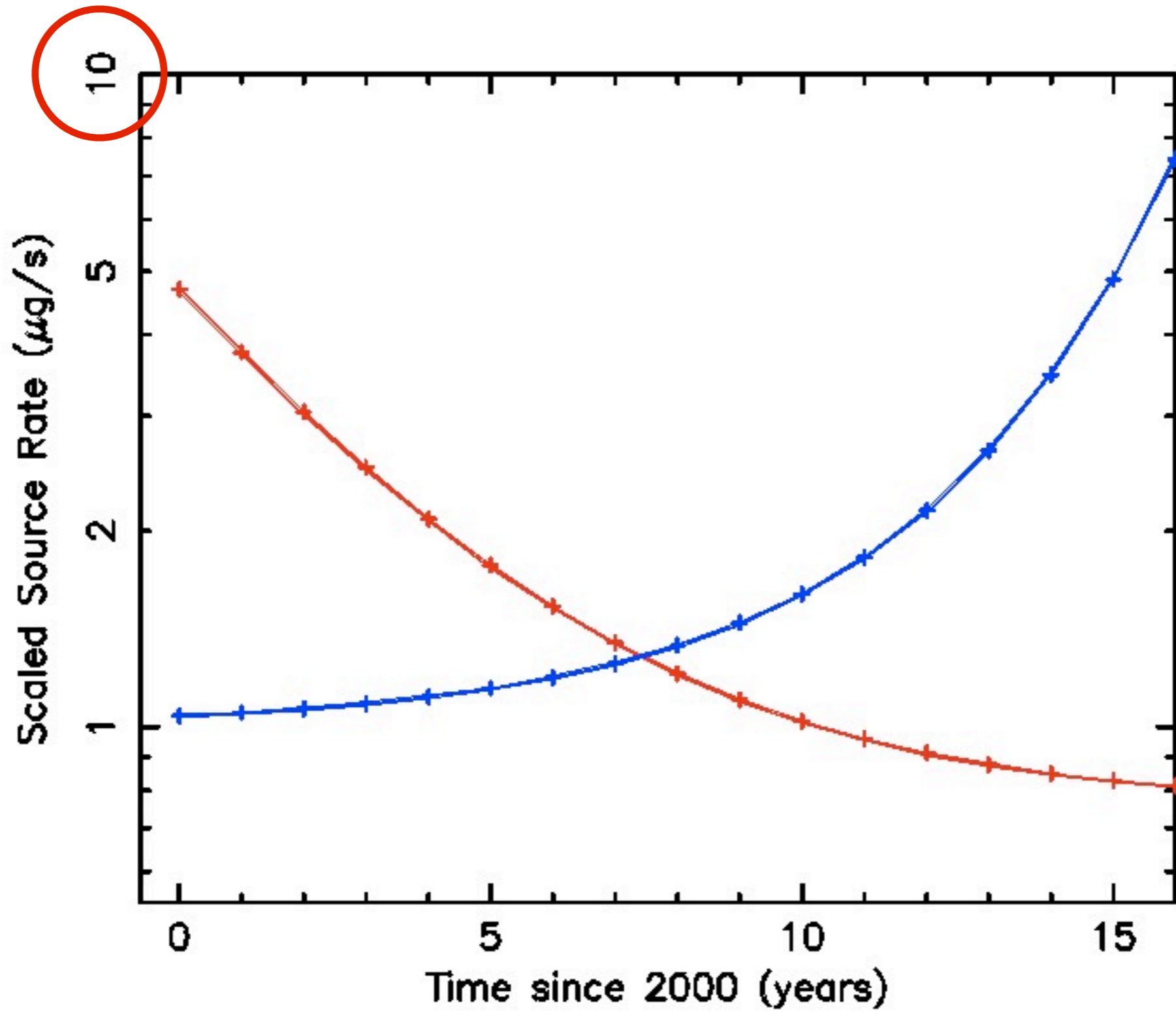


T $^{\circ}\text{C}$	Octadecane	0.1*Hepta-decane
-60	1.6×10^{-10}	5.6×10^{-9}
-40	2.5×10^{-7}	2.4×10^{-6}
+10	0.27	0.21
+20	2.4	1.3

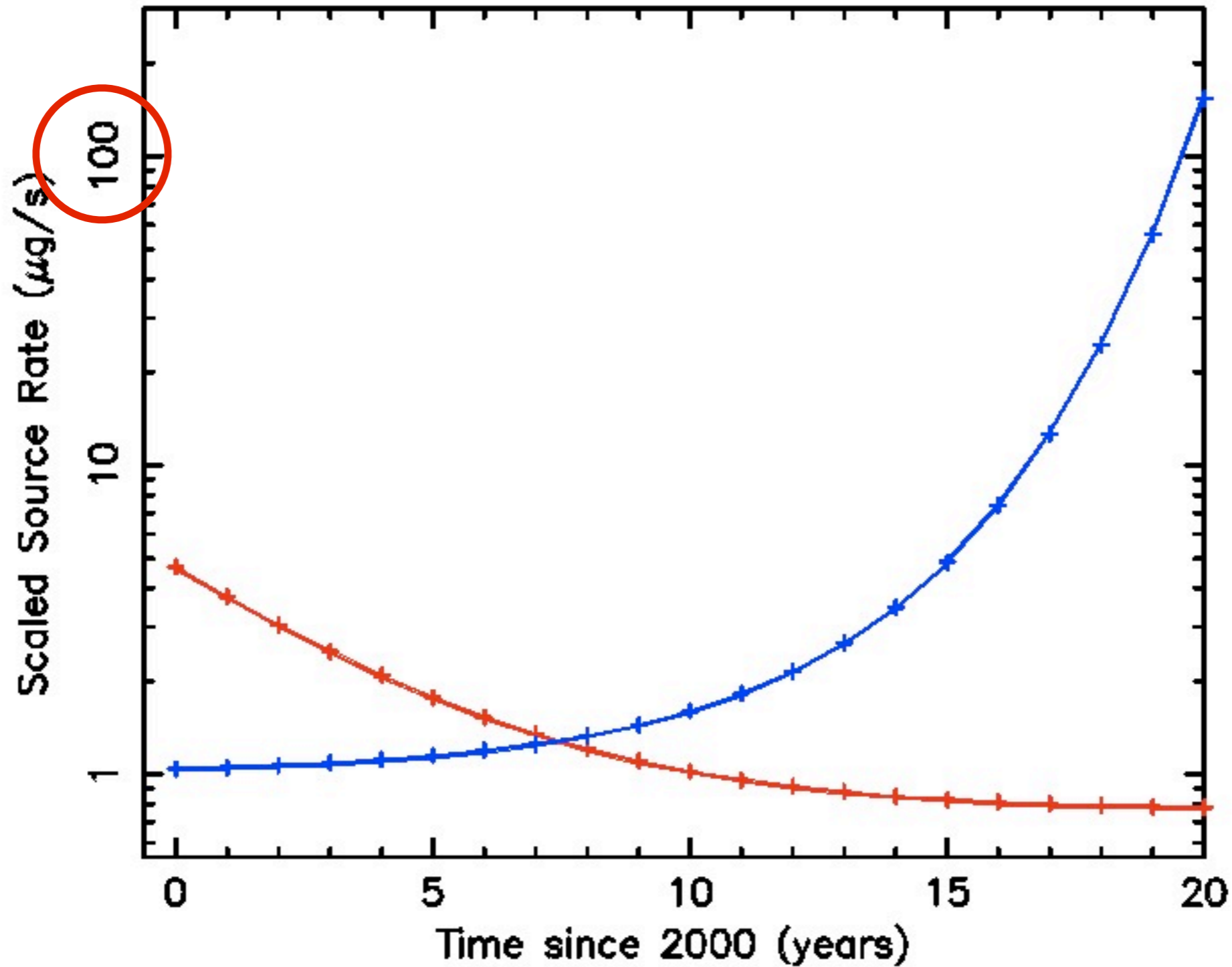
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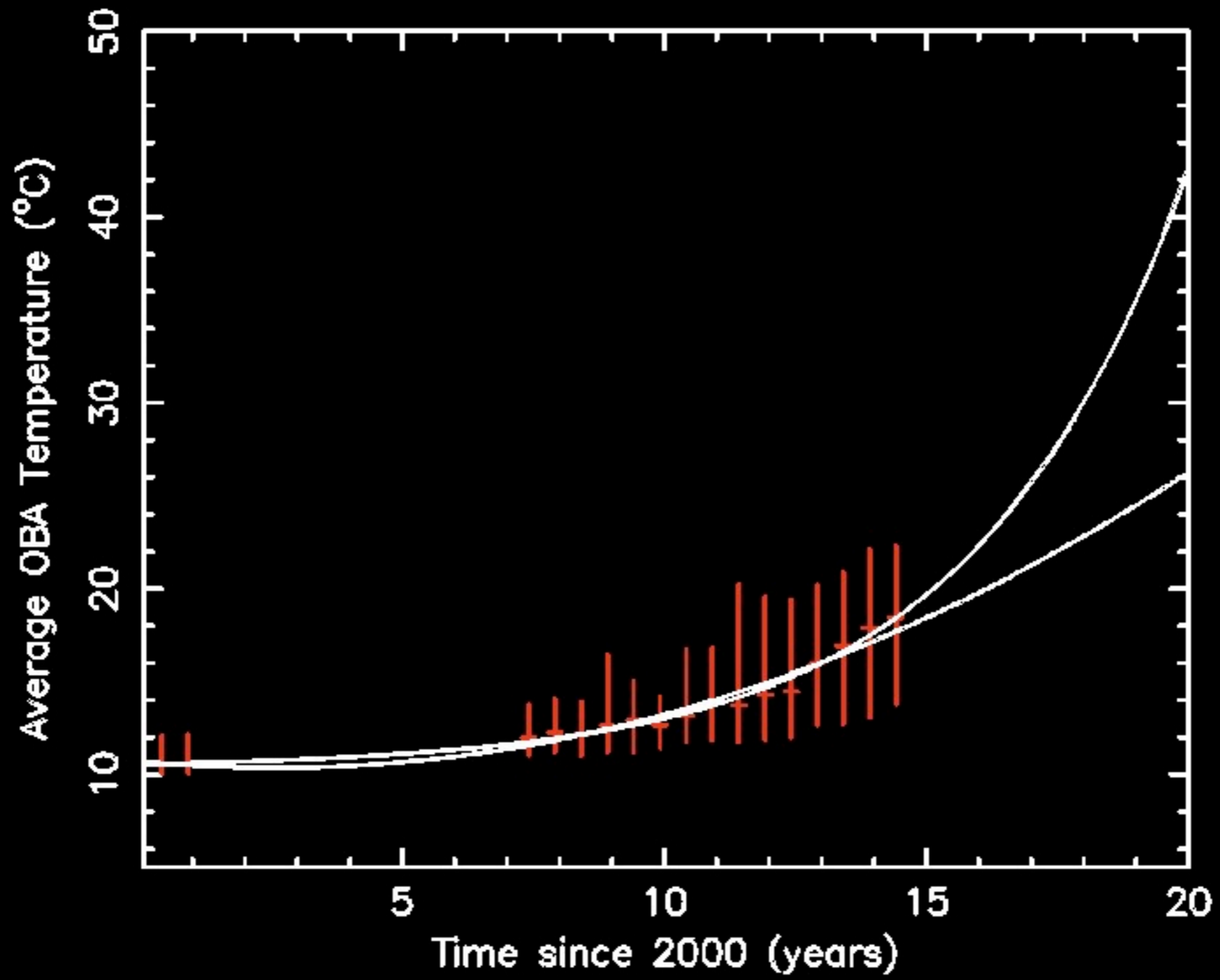


Chandra Contaminant Migration Model

SUMMARY

- ◆ Volatility of contaminants can be tightly constrained by simulations.
- ◆ Accelerated buildup since 2010 has 30* higher volatility at -60°C ; likely to 'clean' readily at elevated temperatures.
- ◆ Current exponentially increasing trend in OBA temperature is predicted to lead to extremely rapid buildup of 'second' contaminant (5*source rate for 10°C increase in 3 yrs; 30* in 5 yr; but polynomial fit implies only 3* in 5 yr).
- ◆ At t~16 yrs, 0.4 grams of contaminant is within the S/C with only 5% (20mg) on OBFs (~270 $\mu\text{g}/\text{cm}^2$).

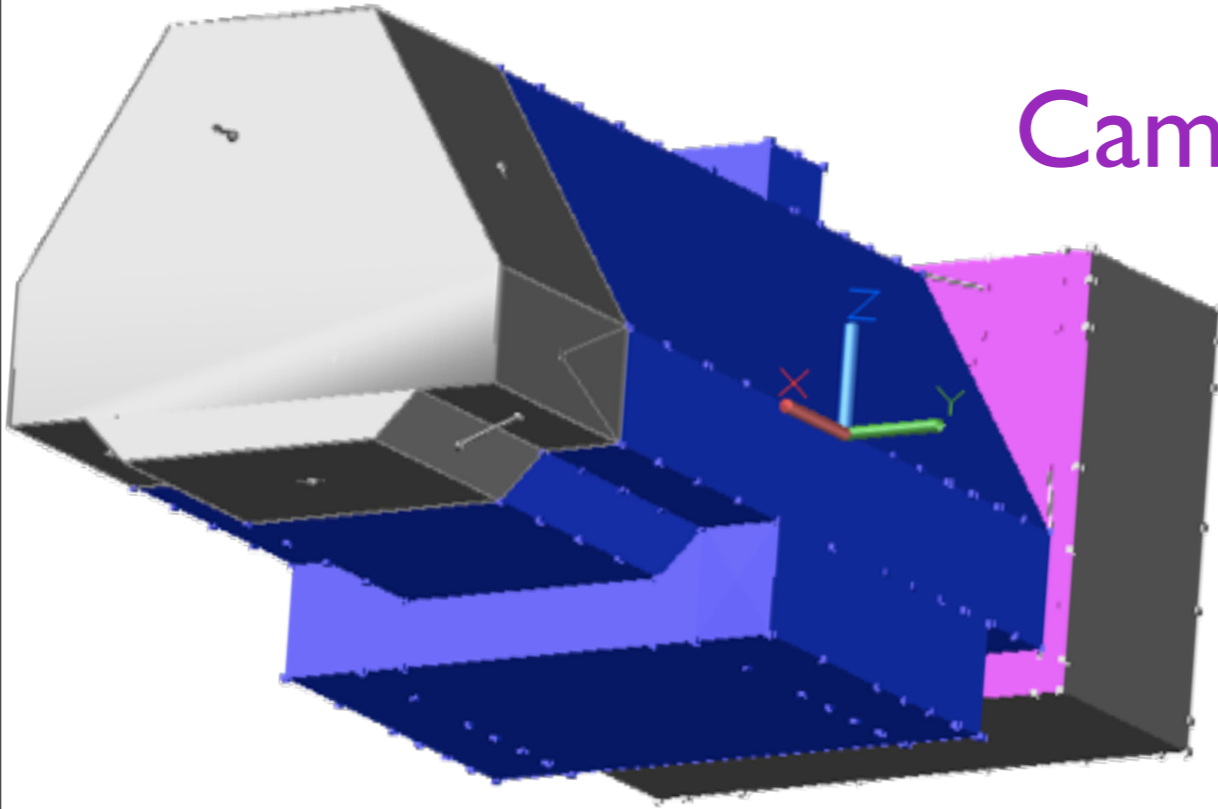
backup slides



Optical Bench Closeout

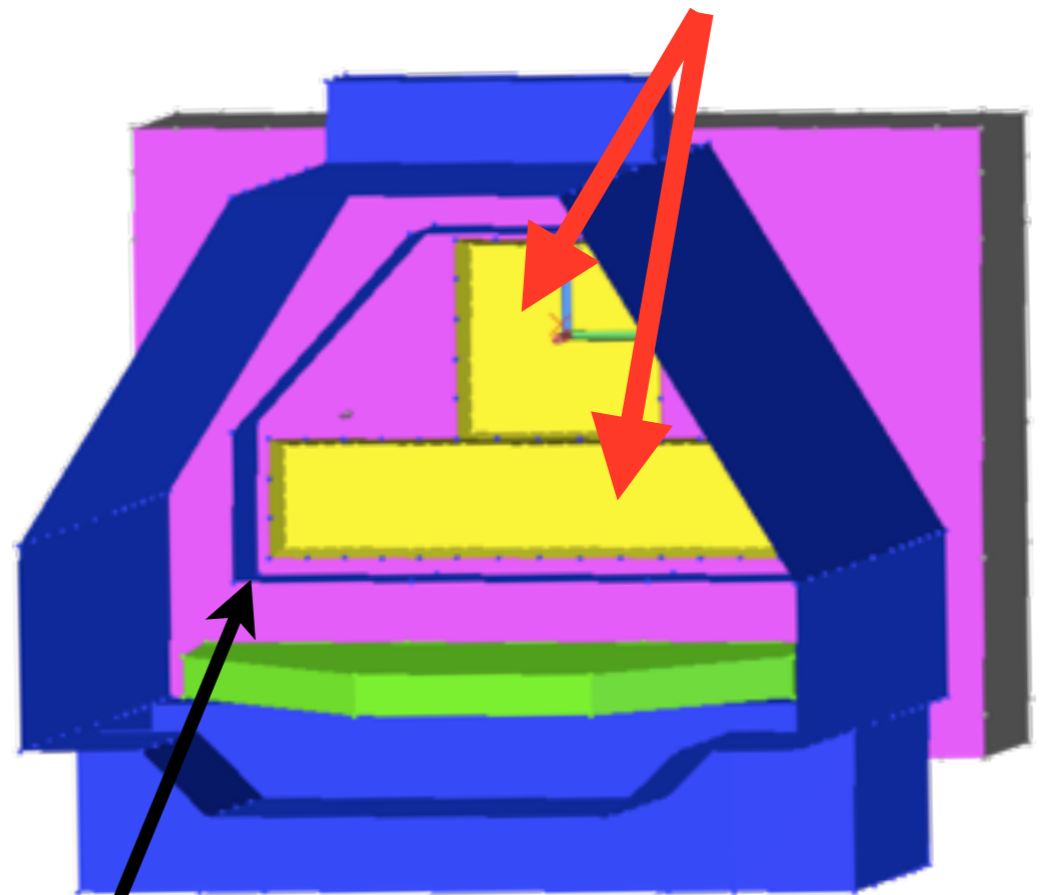
Collimator

Camera Body
(ACIS Housing)



Geometry Model

OBF-I & S



Snoot

ACIS Door

From Neil Tice/LMC

Thermal Desktop (finite element):

RADCAD

to calculate geometric view factors

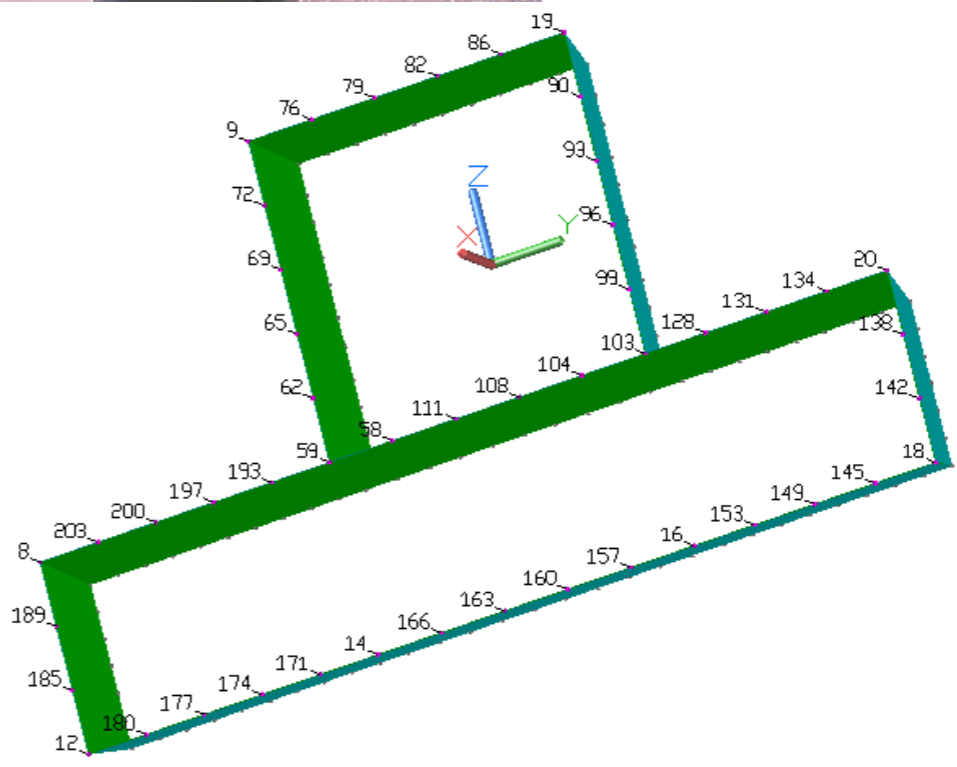
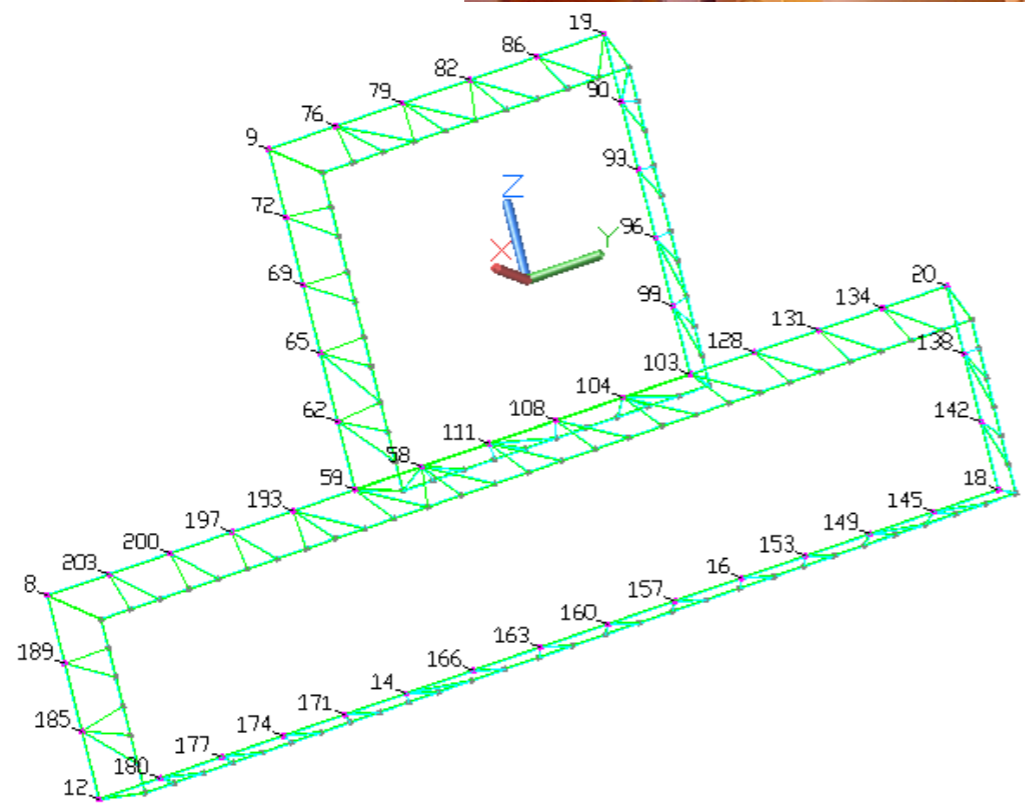
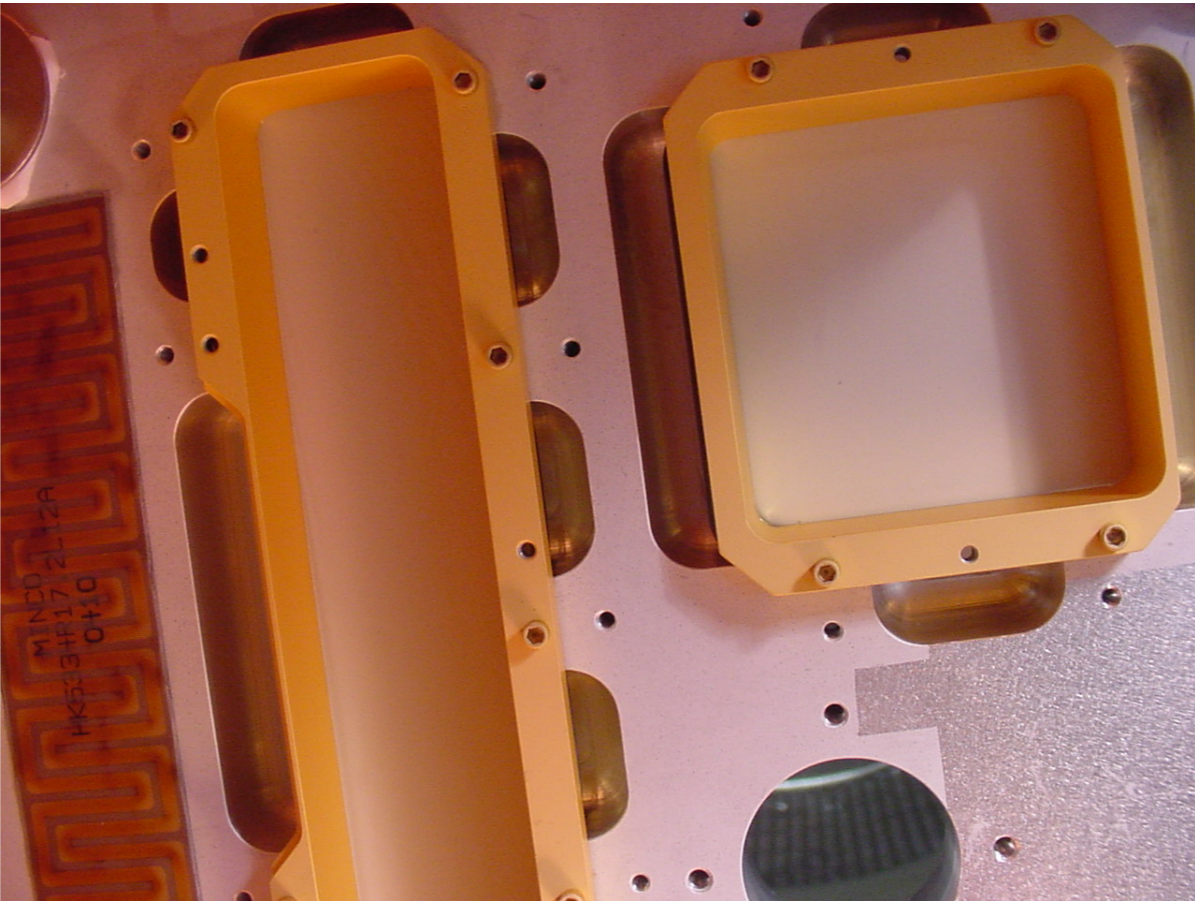
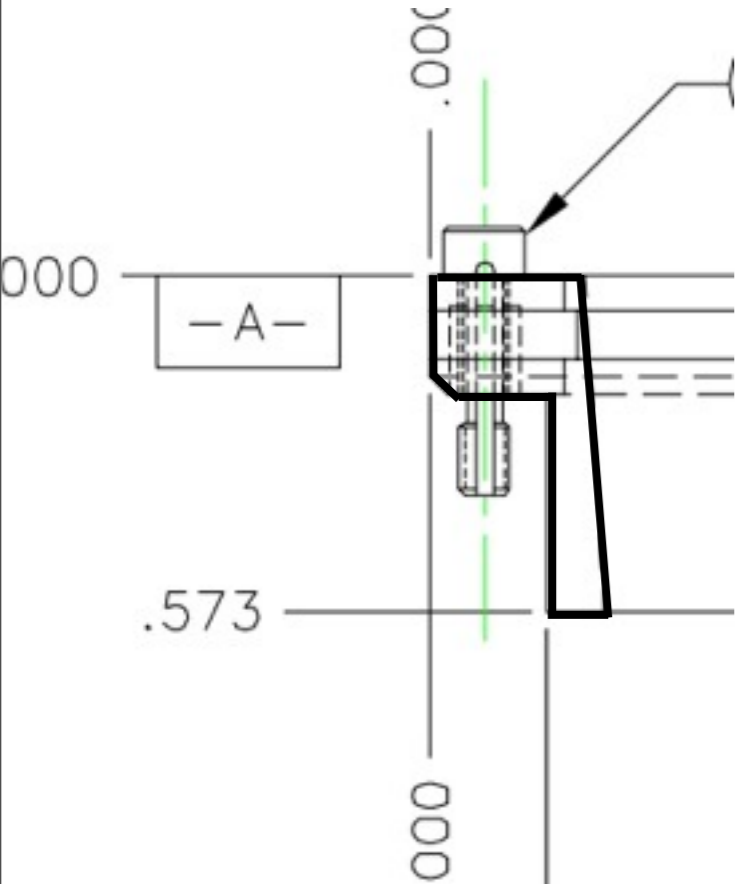
SINDA FLUINT

to calculate temperatures

738 nodes, 121 OBF-I, 203 OBF-S

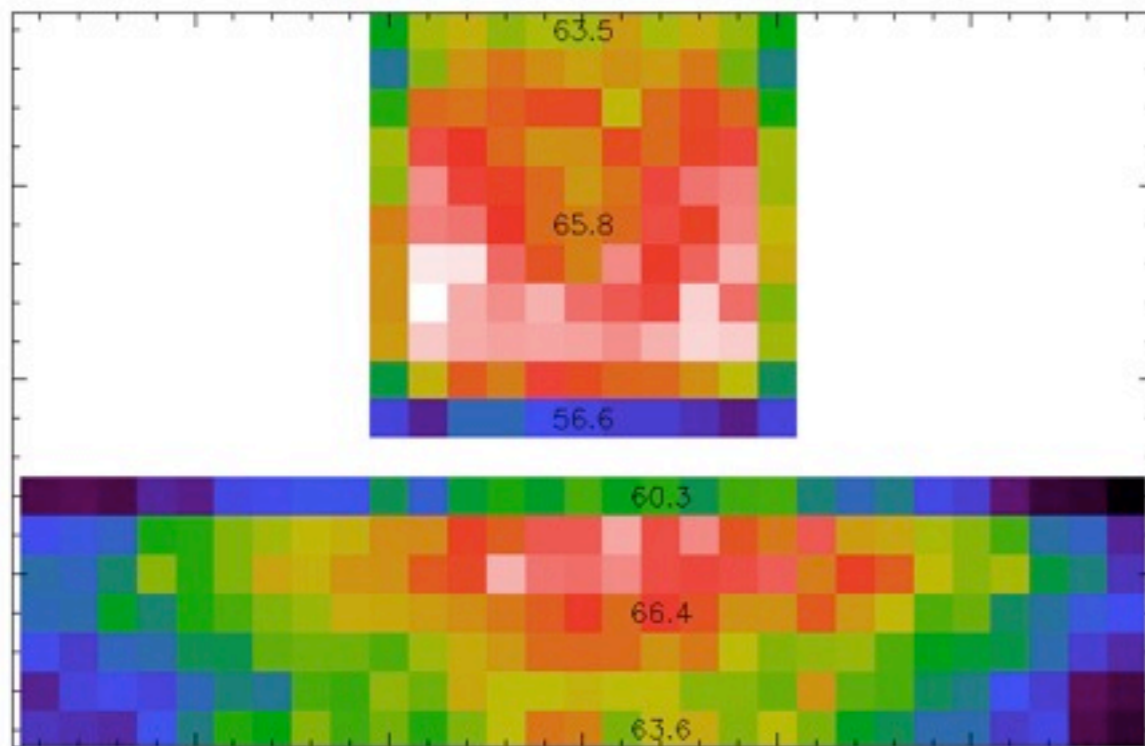
186x186p/node (I), 146x212p/node (S)

Geometry Model



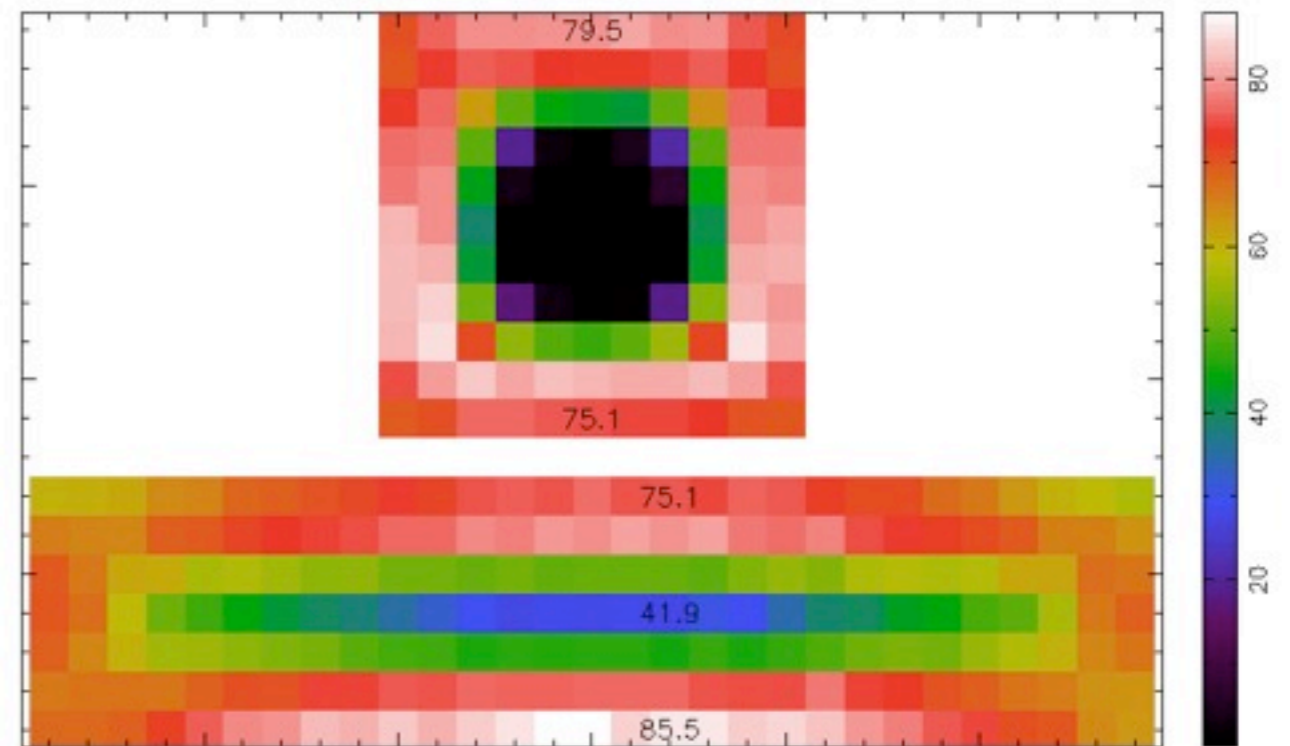
Chandra Contaminant Migration Model Results

Mass Column of Octadecane ($C_{18}H_{38}$) at $t=9$ years



low volatility (0.10)

“deposition” dominated: central regions have highest accumulation because center views more nearby cold surfaces, pattern is asymmetric



high volatility (2.50)

“thermal” (vaporization) dominated: warm central regions begin to clean, pattern follows local temperature distribution with more material near cold edges