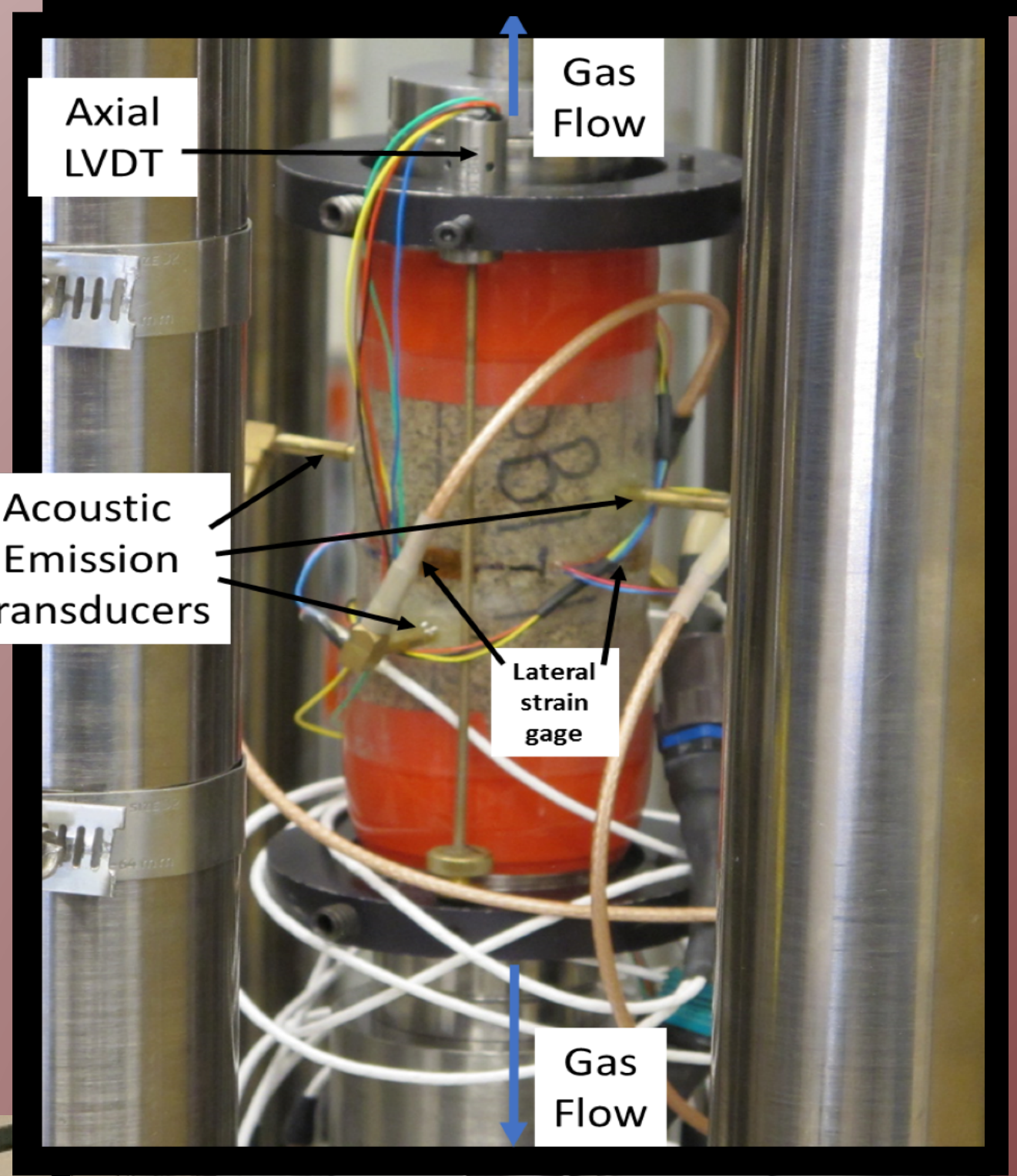
T43A-3014

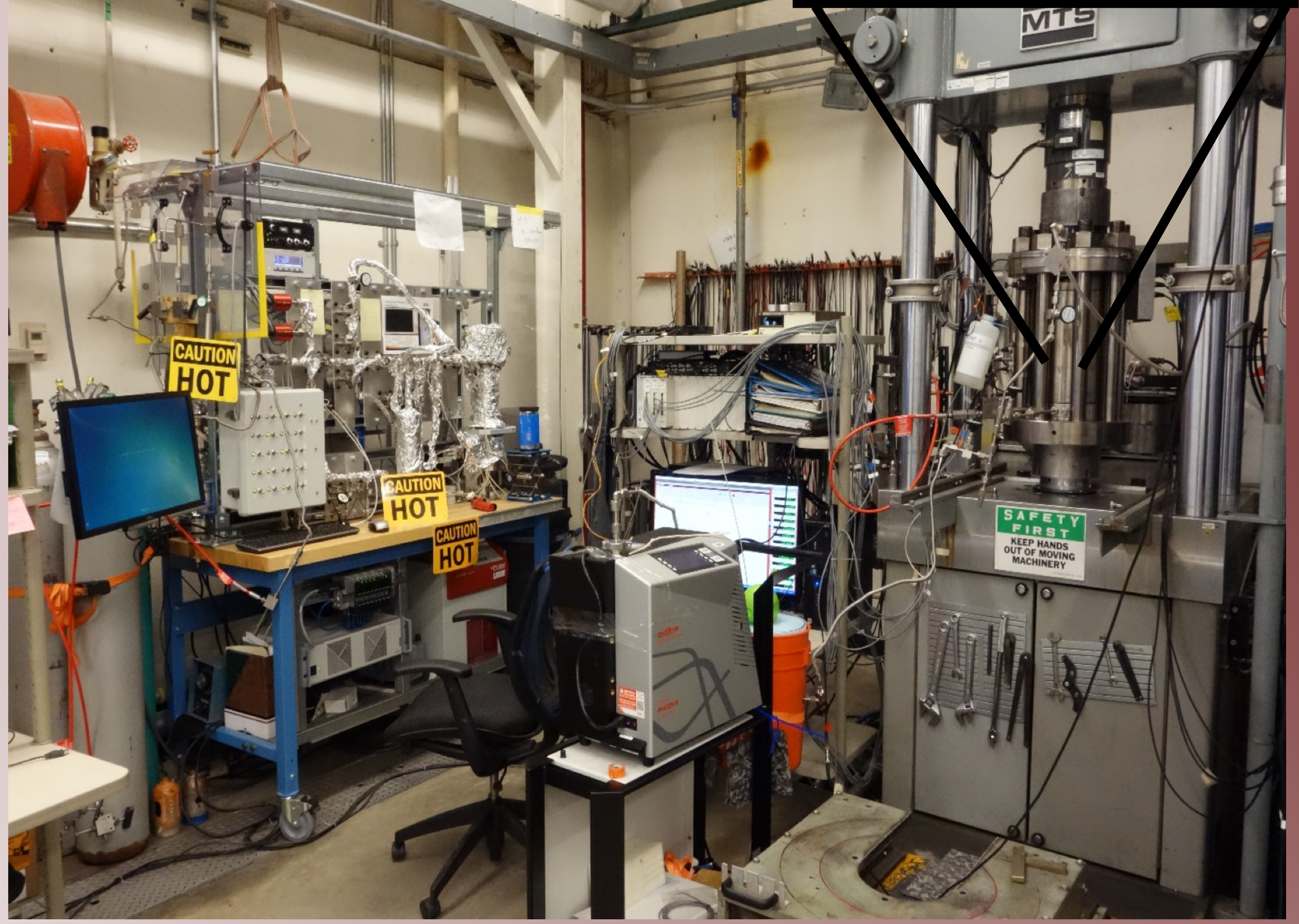
Using Helium as a Tracer of Dynamic Rock Deformation

W. Payton Gardner, University of Montana - Department of Geosciences
Steven J. Bauer, Sandia National Laboratories - Geomechanics Department

I. Abstract

Here we present models of noble gas release from rocks undergoing triaxial deformation and eventual macroscopic failure. Using a newly developed analytical capability, we have shown that accumulated helium in immobile porosity and mineral grains is released during deformation. We observe increases in gas release before macroscopic failure of the specimen, with a sharp increase in gas release during macroscopic failure. In this study, we develop dynamic dual permeability numerical models which simulate time dependent permeability and fracture-matrix surface area creation during deformation. These models are then used to interpret our new signal, and explore the sensitivity of the signal to rock deformation characteristics. The gas release signal is a combination of dynamic permeability creation and an increase in surface area for matrix diffusion as new microcracks intersect gas laden intra and inter crystalline pores. Gas release during dilation and rock failure is controlled by permeability increases. The sharp increase in gas release during failure is the result of permeability creation during fracturing. Increased in matrix porosity and permeability are required for higher helium release rates after fracturing and controls the long term helium release signal, due to matrix damage during fracture. Our results indicate that radiogenic noble release can be used to monitor and trace mechanical deformation of rocks. This new signal can be used to provide information on the characteristics of deformation, including fracture and matrix permeability and porosity.





II. Introduction

We developed an analytical system to analyze noble gases evolved from rocks undergoing mechanical deformation. Our system utilizes a quadrupole mass spectrometer which plumbed direction to the pore space of rocks in a mechanical triaxial cell. Using this system we have analyzed gases from several rock types during deformation.

The basic deformation signal we observe is:

- Decrease in gas during initial elastic deformation.
- An increase in gas release after roughly 1/3 of the final yield strength is reached.
- A sharp increase during macroscopic failure.
- Subsequent decrease is gas release after failure.

III. Methods

- Here we develop a dynamic dual permeability model, which allows us to model gas release from the core with time evolving fracture and matrix permeabilities.
- We then use this model and the observed gas release from a shale undergoing deformation to infer deformation processes and the effect of deformation on the rock transport properties.
- First we estimate the initial matrix transport properties by fitting the gas release from the core before deformation with a single permeability model.
- Then we explore the effect of change matrix and fracture permeability and porosity on the signal.
- Comparison of the modeled and observed data allows us to distinguish what processes are controlling gas release from the core.

IV. Theory

Darcy's law for a compressible, real gas can be written as:

$$q_{g_x} = -\frac{k_g}{\mu_g}\frac{\bar{p}}{zRT}\frac{\partial P}{\partial x}, \tag{1}$$

Flow in the fracture domain is given by:

$$n_f \frac{\partial}{\partial t}\left(\frac{p_f}{z_p}\right) = \frac{\partial}{\partial x}\left(\frac{k_f}{\mu_g}\frac{p_f}{z(p_f)}\frac{\partial p_f}{\partial x}\right) + R_m, \tag{2}$$

Gas flow through the matrix is:

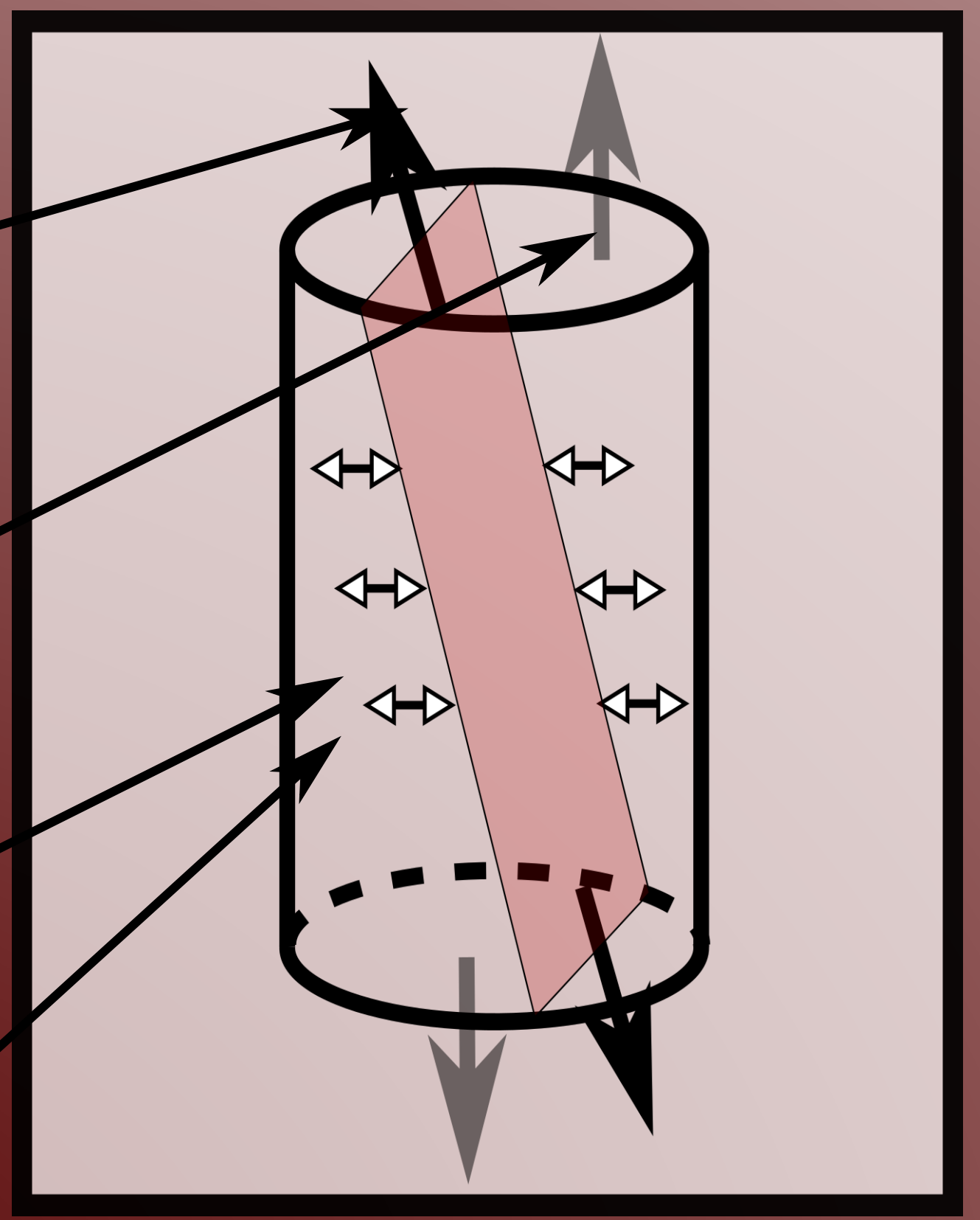
$$n_m \frac{\partial}{\partial t}\left(\frac{p_m}{z_p}\right) = \frac{\partial}{\partial x}\left(\frac{k_m}{\mu_g}\frac{p_m}{z(p_m)}\frac{\partial p_m}{\partial x}\right) + R_f, \tag{3}$$

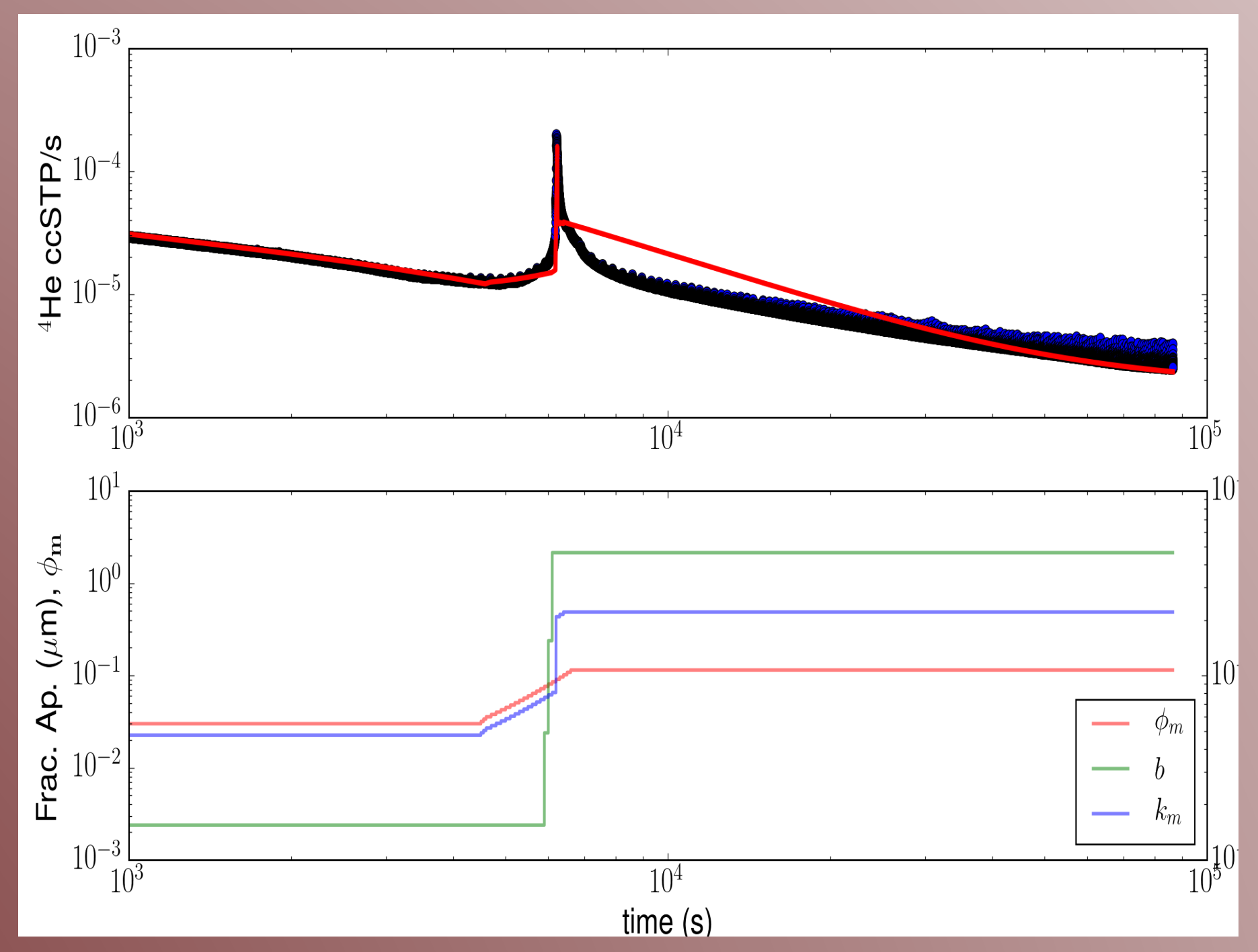
Exchange between fracture and matrix:

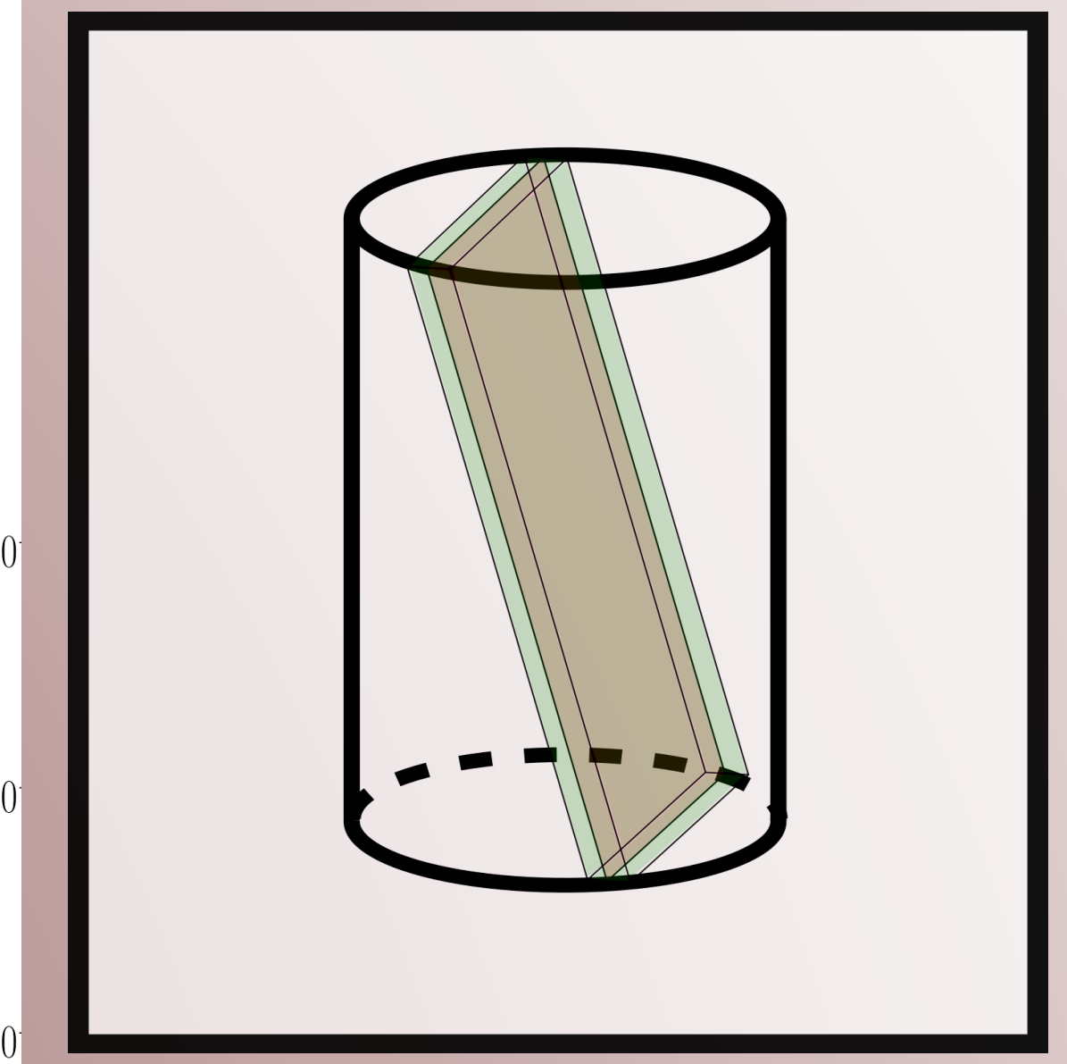
$$R_m = -2 * \frac{k_m}{\mu_g}\frac{p_m}{z(p_m)b}\frac{(p_f - p_m)}{l_c}. \tag{4}$$

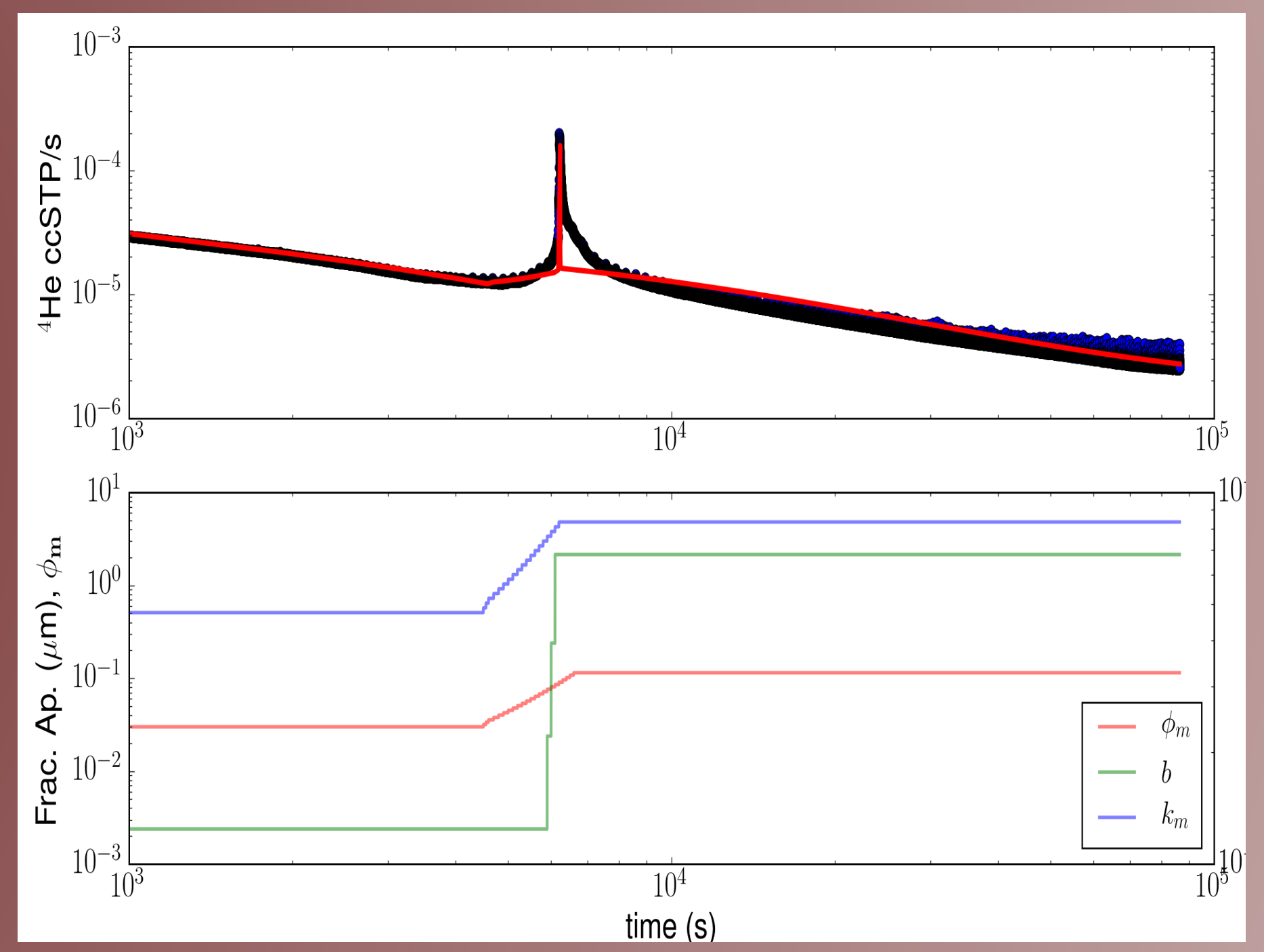
where R_f is the fracture source-sink and is approximated with the same linearization for a characteristic matrix-fracture interaction length:

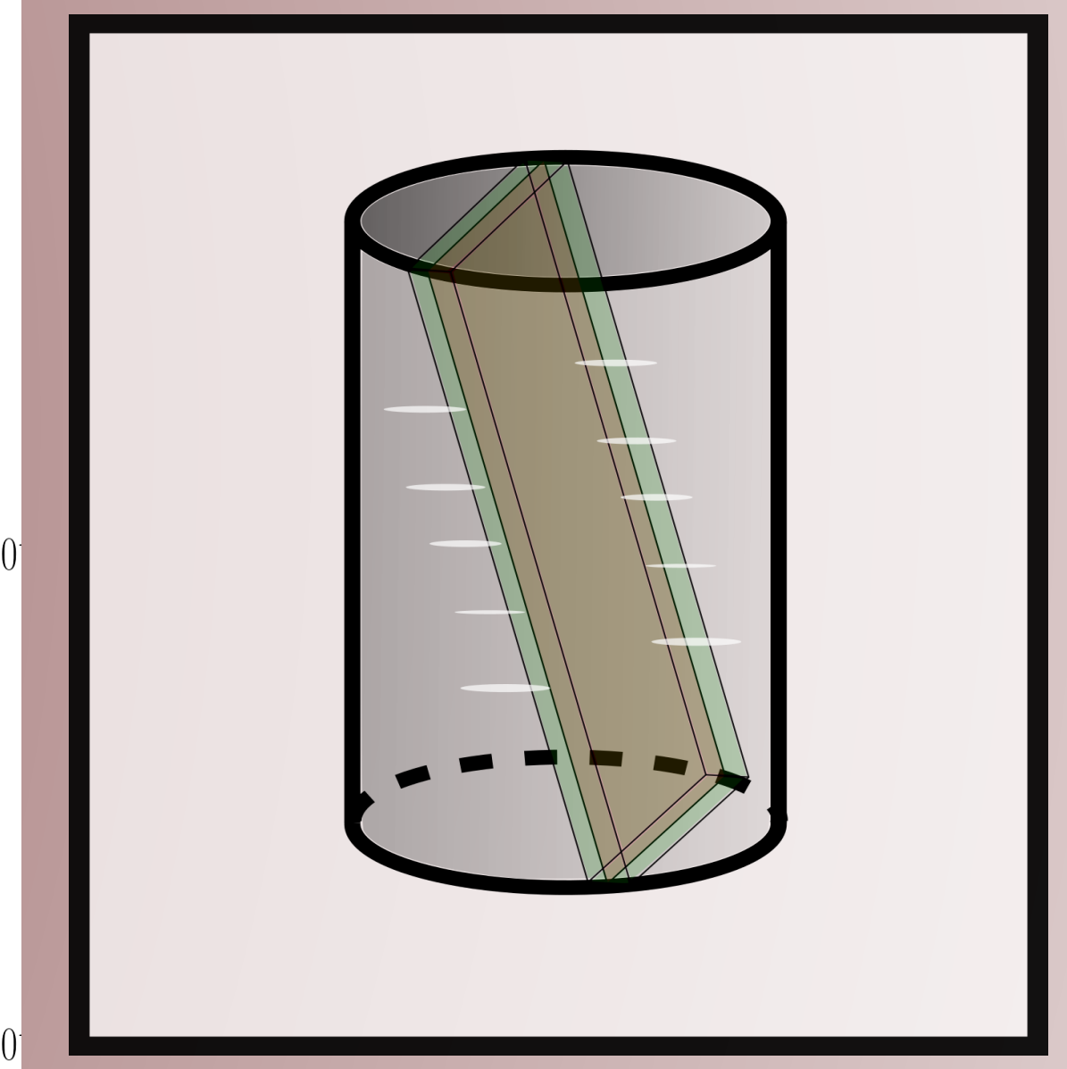
$$R_f = -\frac{k_m}{\mu_g}\frac{p_m}{z(p_m)l_c}\frac{(p_m - p_f)}{l_c}. \tag{5}$$

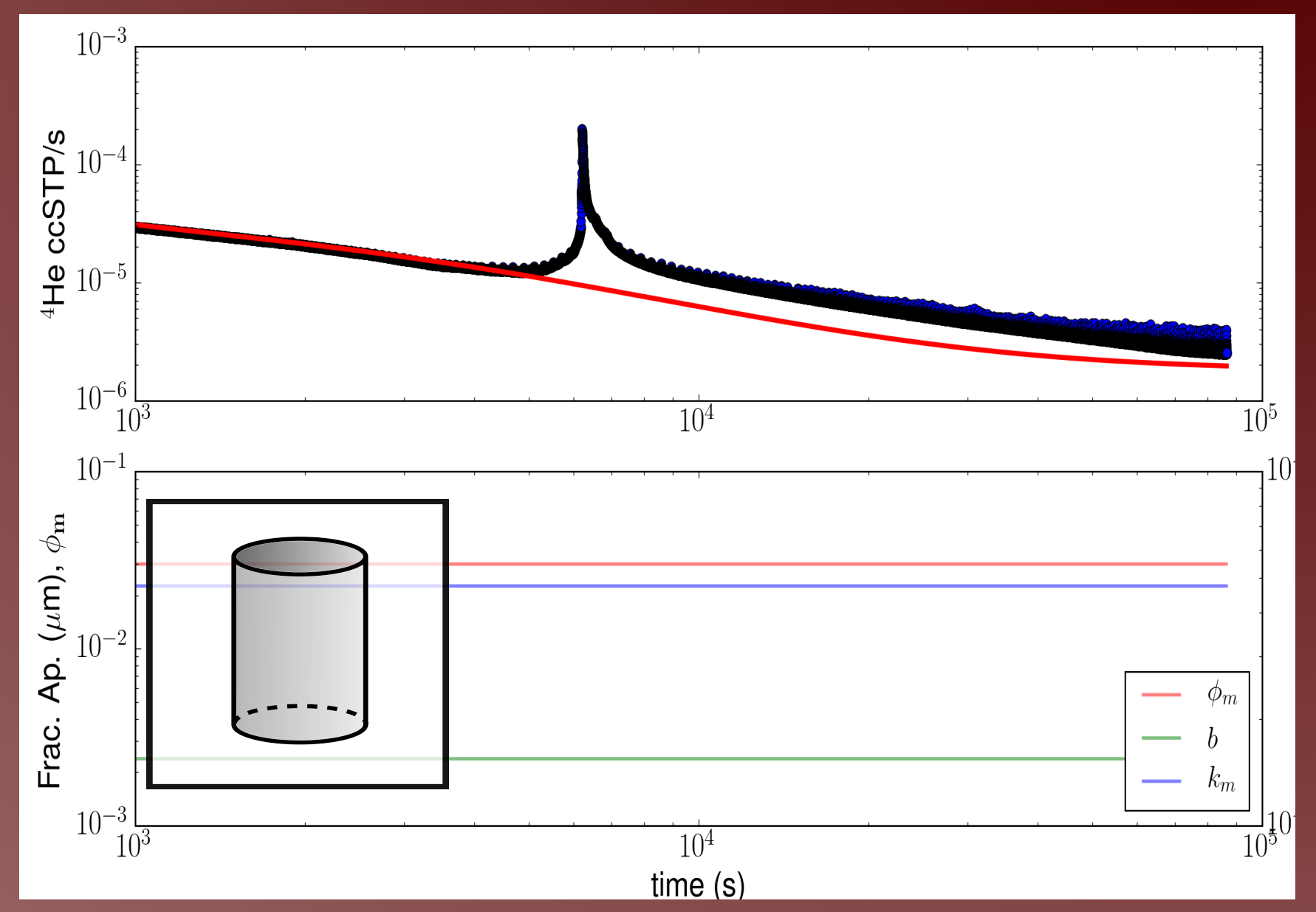


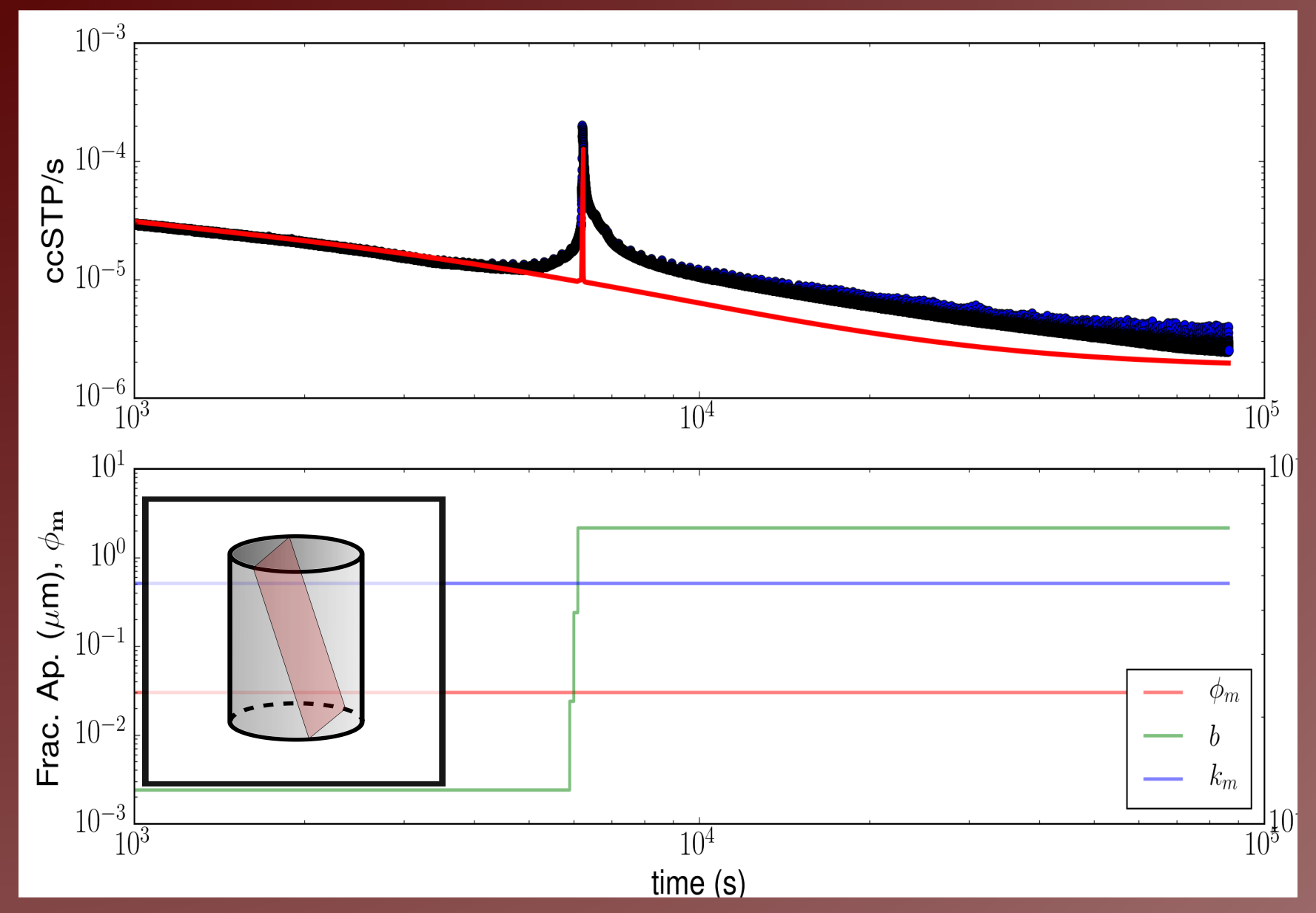


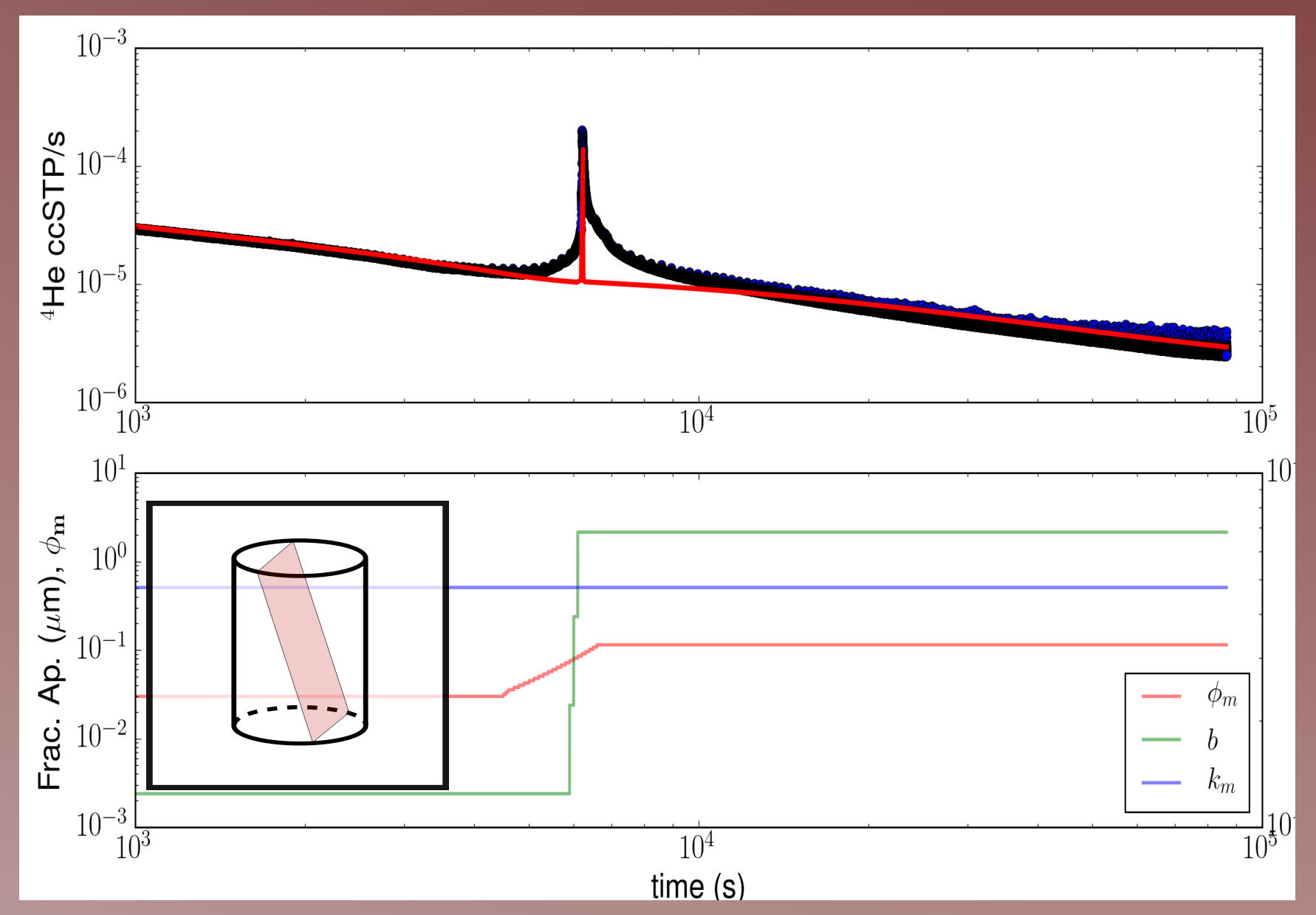


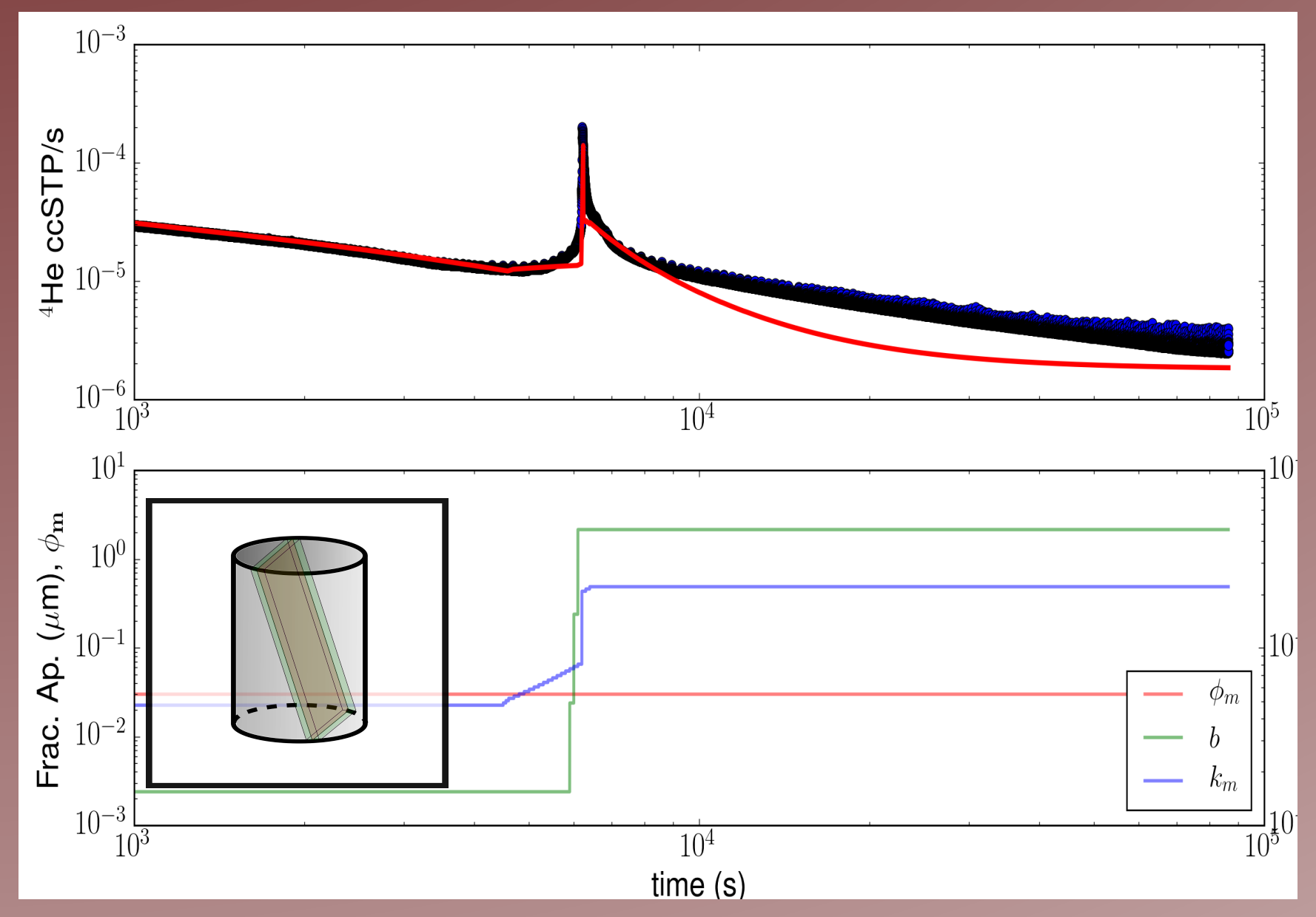












IV. Results

- Flow decrease during the elastic portion of deformation is well modeled by drainage of undisturbed matrix.
- Fracture creation *rapidly* increases the gas release, but the fracture domain drains rapidly.
- In order to reproduce the early time, long-wavelength flow increases an increase in matrix permeability is required.
- To reproduce the late time gas flow, an increase in effective porosity is required.
- The combination of matrix permeability needed for early time and matrix porosity needed late time produced too high a gas flow after rupture.
- The best fit model includes a slight increase in matrix permeability and effective matrix porosity.

IV. Conclusions

- We developed a dynamic dual permeability model to explore gas transport from rock cores undergoing triaxial deformation. Our model includes two permeability zones, both of which can undergo dynamic changes to the parameters controlling gas release and transport. These domains are linked via a linear Darcy flux term which relies on the pressure distribution in both domains at a given time, thus coupling the fracture and matrix domains.
- We use the FiPy, integral finite volume solver to approximate the solution to our system of non-linear partial differential equations.
- The model is then used to try to reproduce gas released from an experiment where tight shale was triaxially deformed through macroscopic failure.
- The effect of changing controlling parameters is explored, allowing us to investigate the effect of deformation on gas transport parameters in a quantitative sense.
- We find that, fracture creation alone does not explain the gas release, and that dilation and damage in the matrix is an important process.
- At early times post failure, the gas release best modeled by a high permeability matrix; and at late time gas release is controlled by dilation increasing the effective matrix porosity.
- Our best fit model includes fracture formation, and a limited increase in matrix permeability and porosity. This model, which reproduces the general features of gas release over the length of deformation indicates that some amount of pervasive dilation and damage occurs throughout the core.
- However, a dual permeability model can not completely reproduce the early time post-deformation gas release. A third, limited volume, high permeability damage zone which controls the initial post damage response and larger volume modified by a lower extent of pervasive dilation and damage is likely required to reproduce the long term post failure gas release.

Acknowledgements: Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

SAND2016-12462C