Silicon drift detector response function to hard x-rays (with an introduction on quantitative MicroXRF And the Planetary Instrument for X-ray Lithochemistry)

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with special thanks to Tim Elam for project guidance

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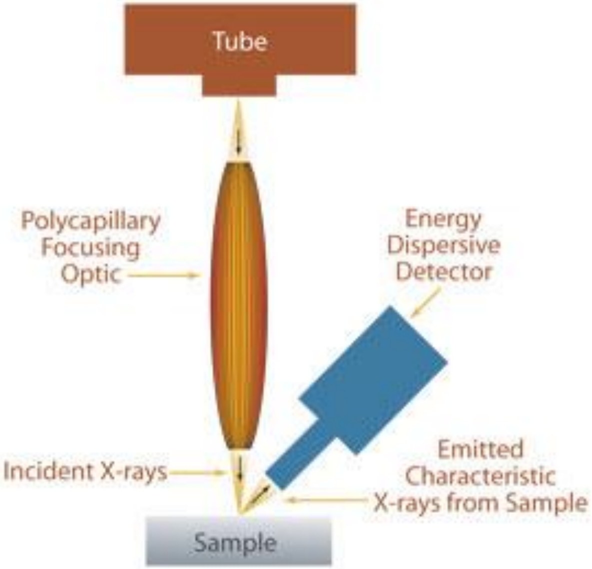
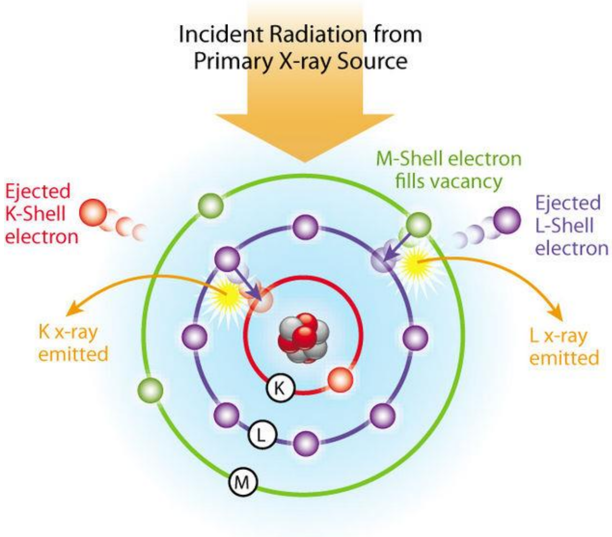
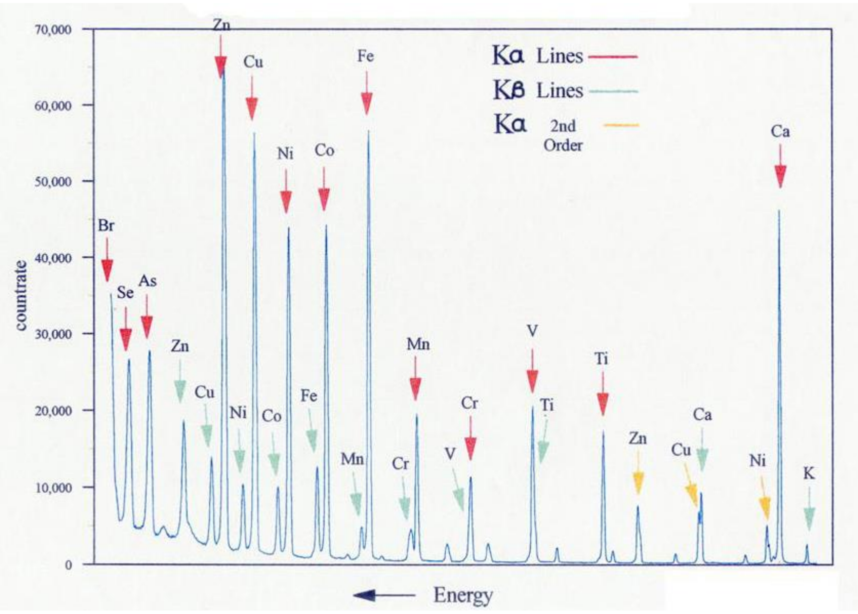
X-ray Fluorescence and µXRF



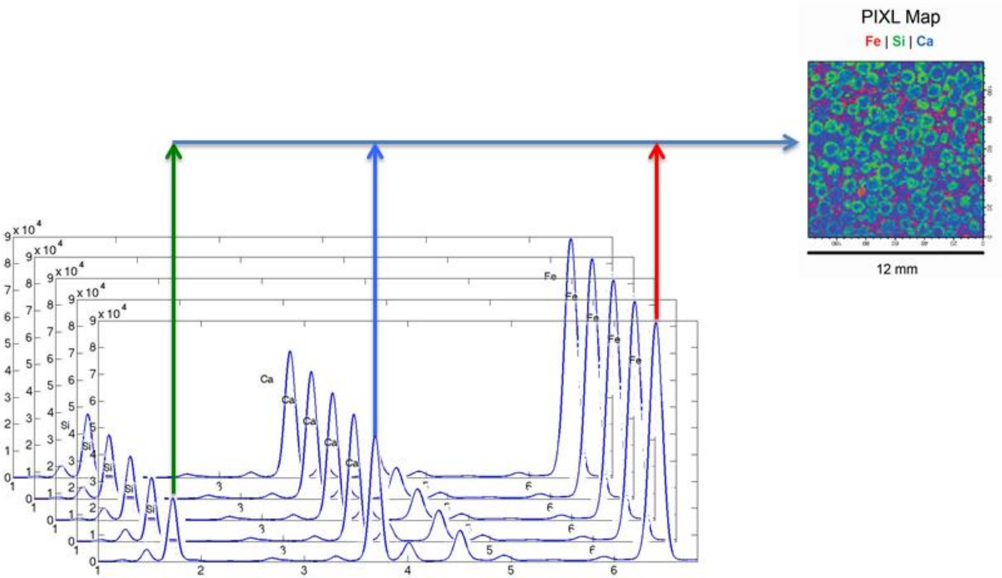
https://xos.com/technologies/xrf/



http://in.niton.com/en/

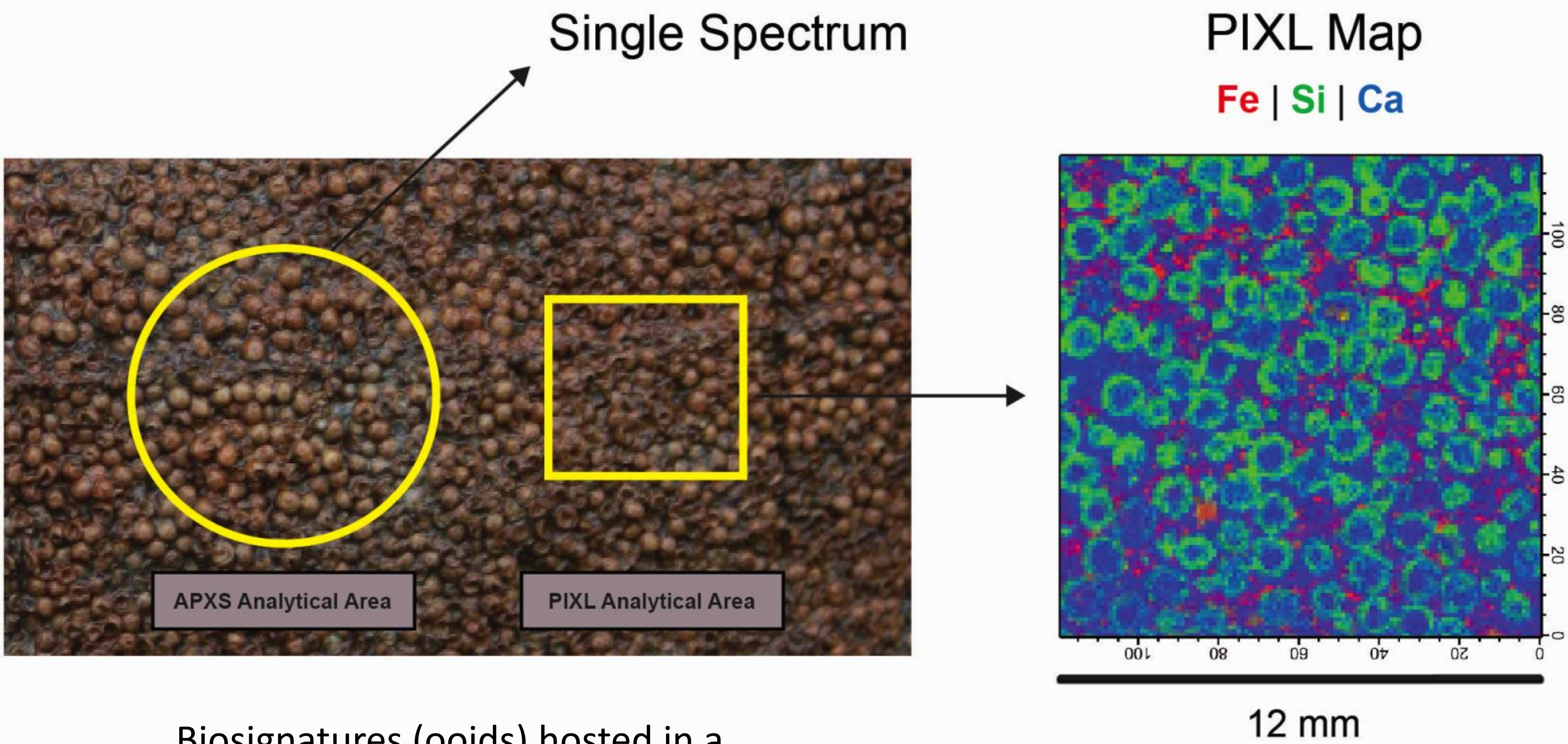


https://en.wikipedia.org/wiki/X-ray_fluorescence#/media/File:XRFScan.jpg



Elam, PIXL Seminar, Nov 2015

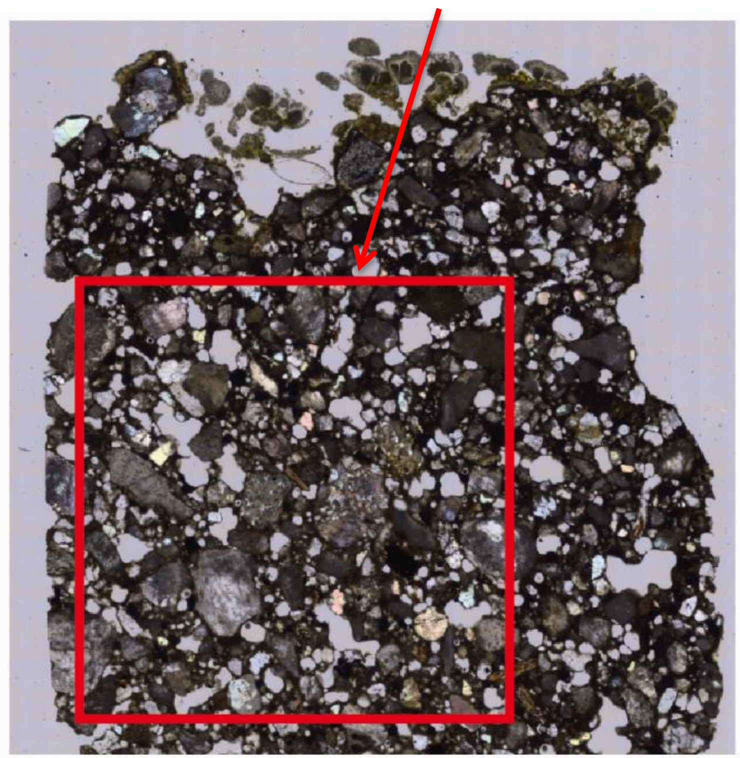
Why Micro XRF?



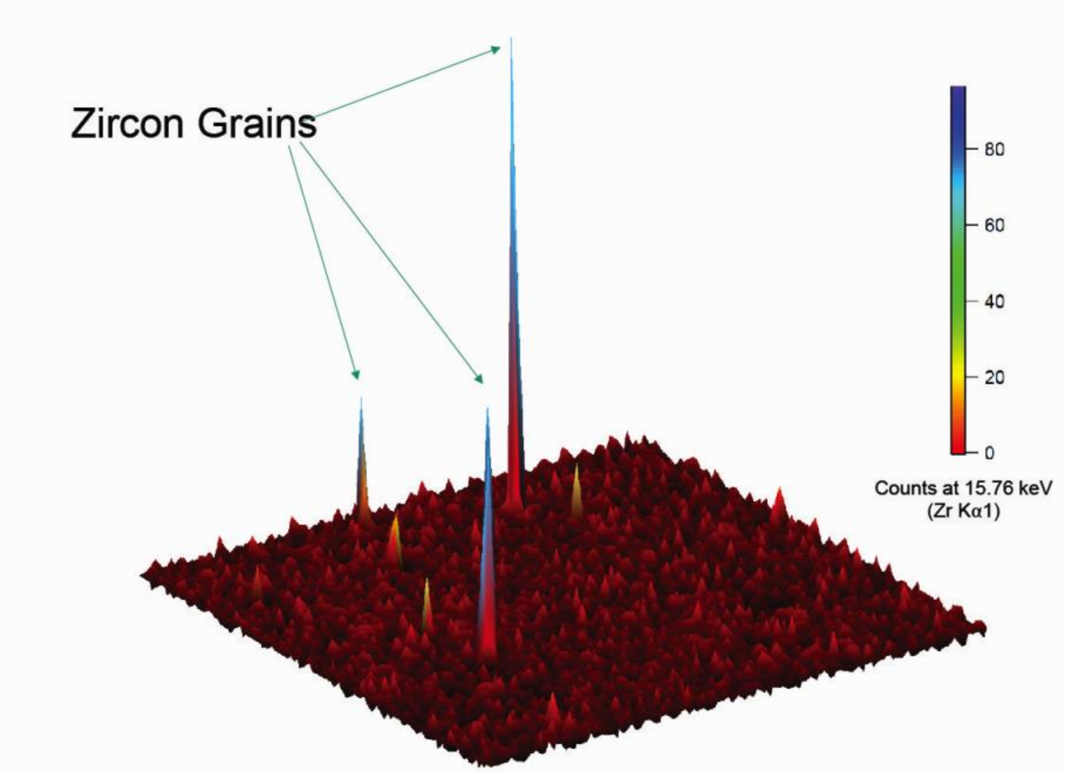
Biosignatures (ooids) hosted in a
2.7 billion-year-old carbonate rock

Some pixels can be very different

Area of element maps



Visible light image

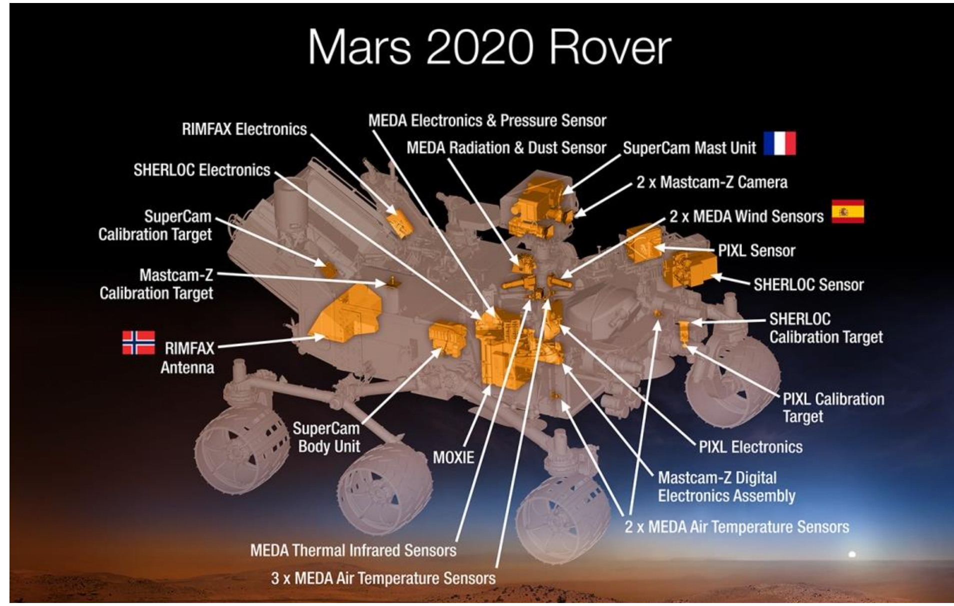


Recent microbialite from the Death Valley Area

Elam, PIXL Seminar, Nov 2015

Mars 2020 Mission

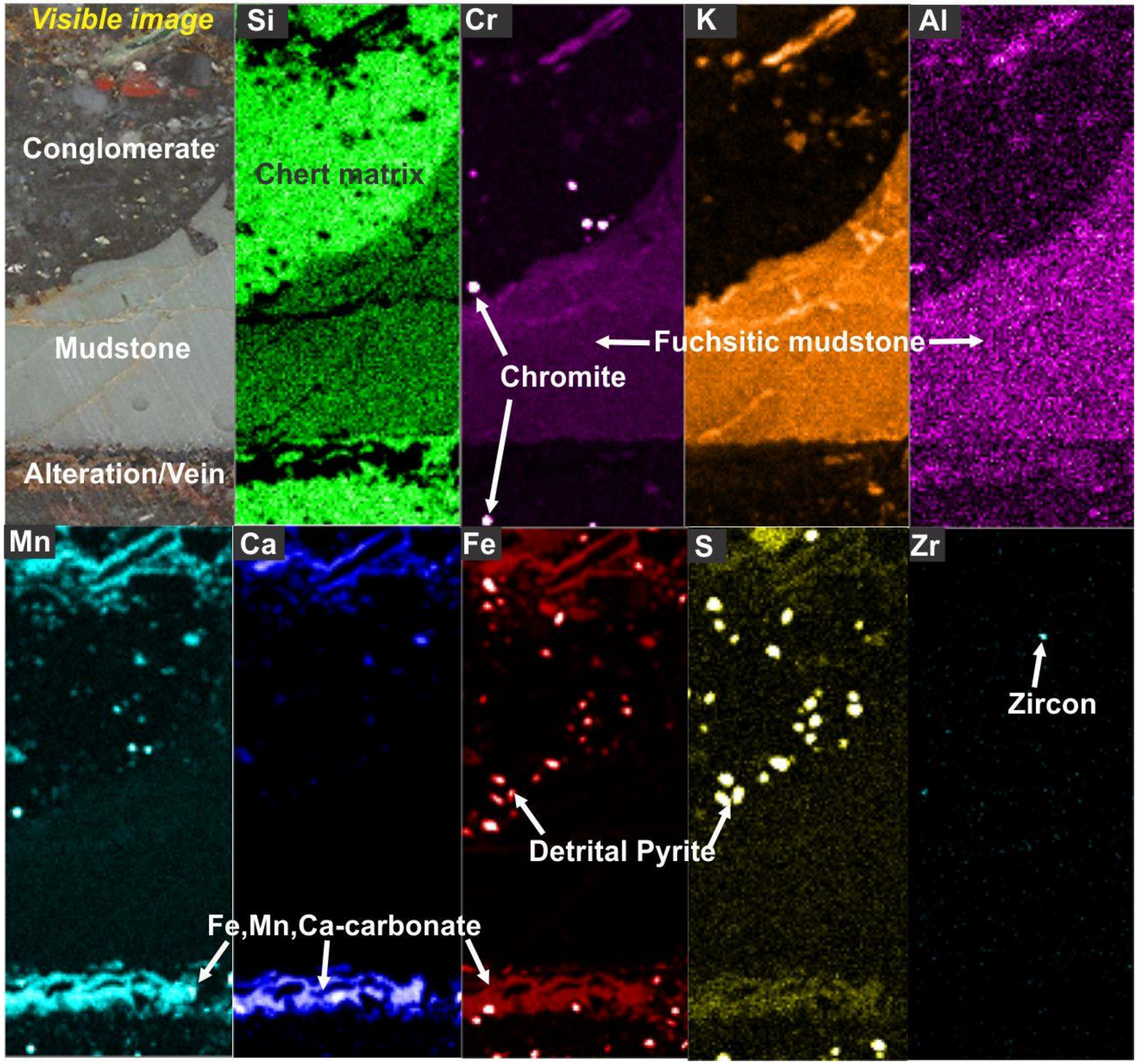
- M2020 Science Objectives
  - **Habitability:** Characterize the geologic record for astrobiologically relevant environments and geologic diversity
  - **Biosignatures:** Search for materials with high biosignature preservation potential
  - **Sample Caching:** Obtain a pristine set of geologically diverse samples and cache for future return to Earth
  - **Prepare for Humans:** Demonstrate *in situ* resource utilization technologies and characterize dust size and morphology



- Mission life: 1.5 Mars years/1005 Martian days
- Flight Instruments delivered by Fall 2018, Launch July 2020, Land February 2021
- Instrument Complement:
  - Mastcam-Z and Supercam for panoramic/stereo imaging and chemical analysis
  - MEDA for weather
  - RIMFAX ground penetrating radar
  - MOXIE technology experiment to produce Oxygen from CO_2
  - SHERLOC and WATSON for UV Raman and high resolution imaging
  - PIXL: Topic of today's talk and the coolest instrument on the Mars 2020 Mission!

http://mars.nasa.gov/mars2020/mission/instruments/

Assessing Past Environments

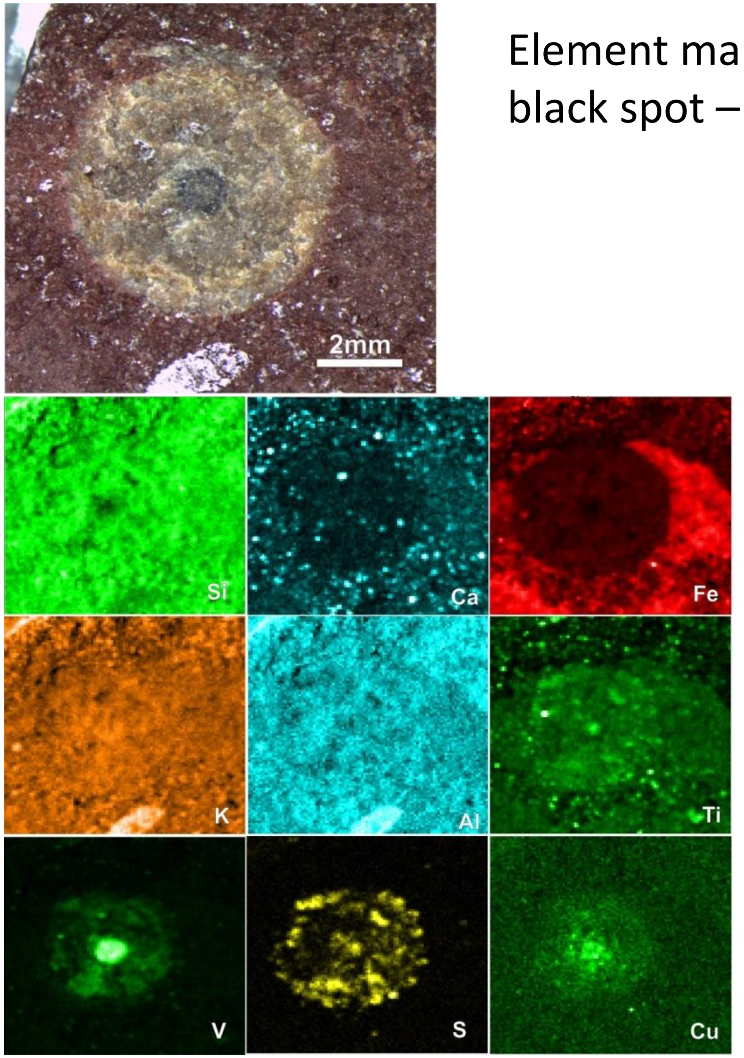


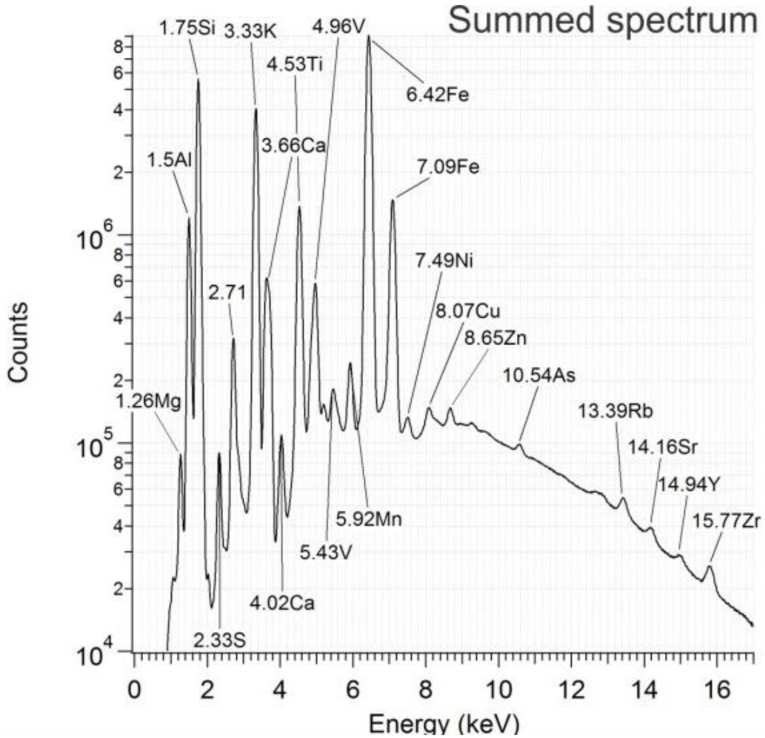
3.45 billion yr old conglomerate deposited on an ancient paleosol

Map size = 2 x 1 cm
Step size = 150μm

Detection of Potential Chemical Biosignatures

Element maps reveal concentrated vanadium and copper in the black spot – a potential biosignature in sandstone



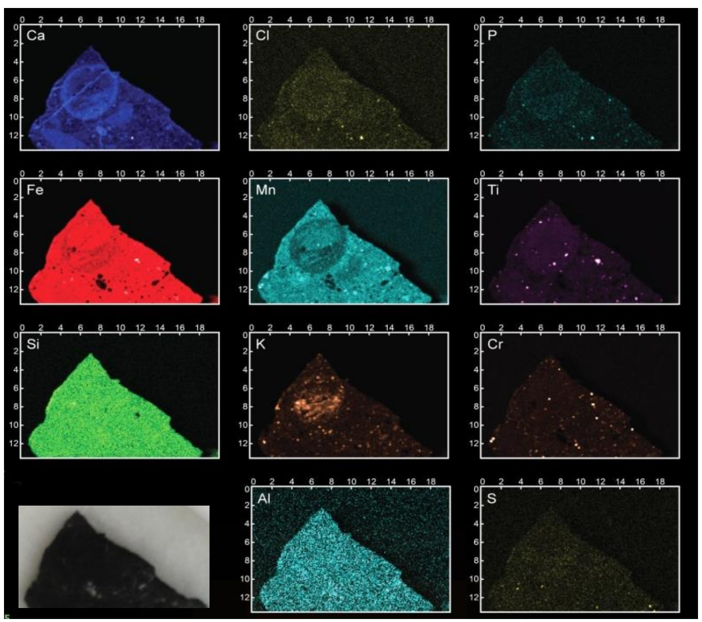


Sample from Spinks et al. *International Journal of Astrobiology,* 2010

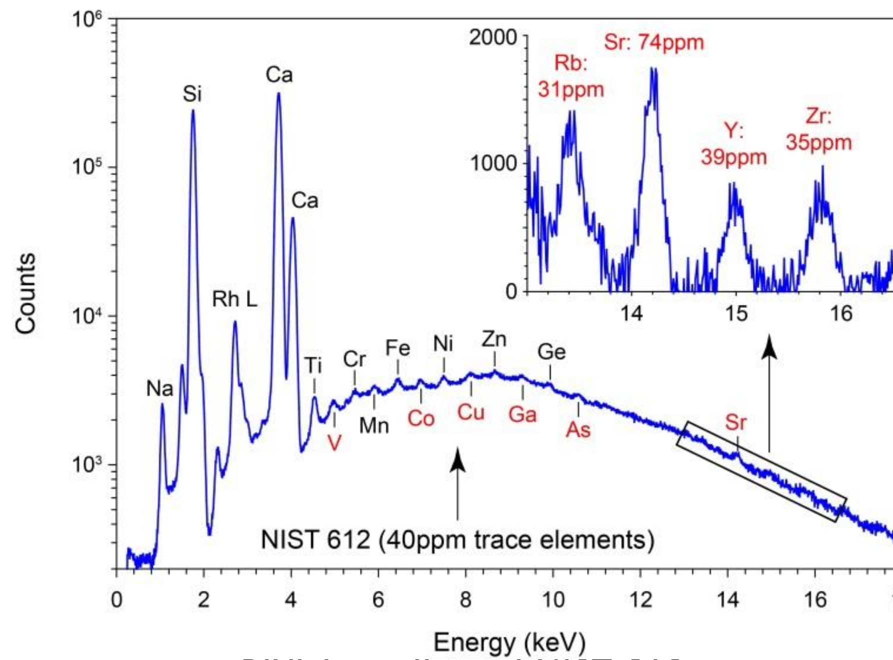
PIXL Science, Data Analysis, and Hardware Team (partial)

- Abigail Allwood — PI
- Joel Horowitz — DPI
- Benton Clark — Co-I
- Tim Elam — Co-I
- John Grotzinger — Co-I
- Robert Hodyss — Co-I
- John Jorgensen — Co-I
- Scott McLennan — Co-I
- Michael Tice — Co-I
- Allan Treiman — Co-I
- David Flannery — Co-I
- Yang Liu — PS

- Marc Foote — IPM
- Larry Wade — ISE
- Douglas Dawson — XRS Cog-E
- Moxtek — X-ray tube
- XOS — Polycapillary X-ray Optics
- Amptek — Detectors
- Steve Battel — HVPS
- Eric Hertzberg — HVPS
- University of Michigan — HVPS
- Danish Technical University — Camera System



Element maps of Martian meteorite NWA 7034

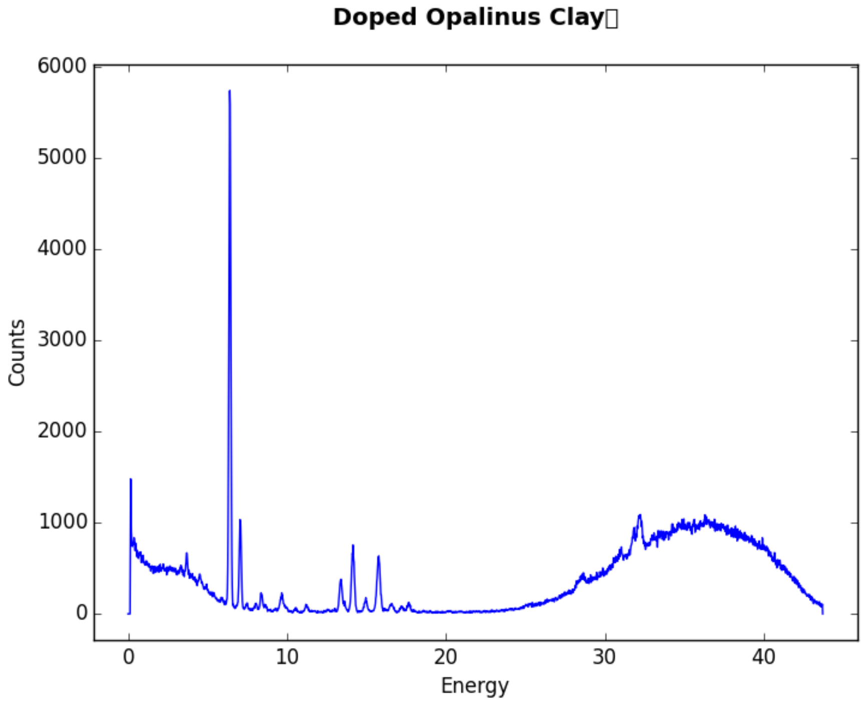


PIXL breadboard NIST 612 spectrum

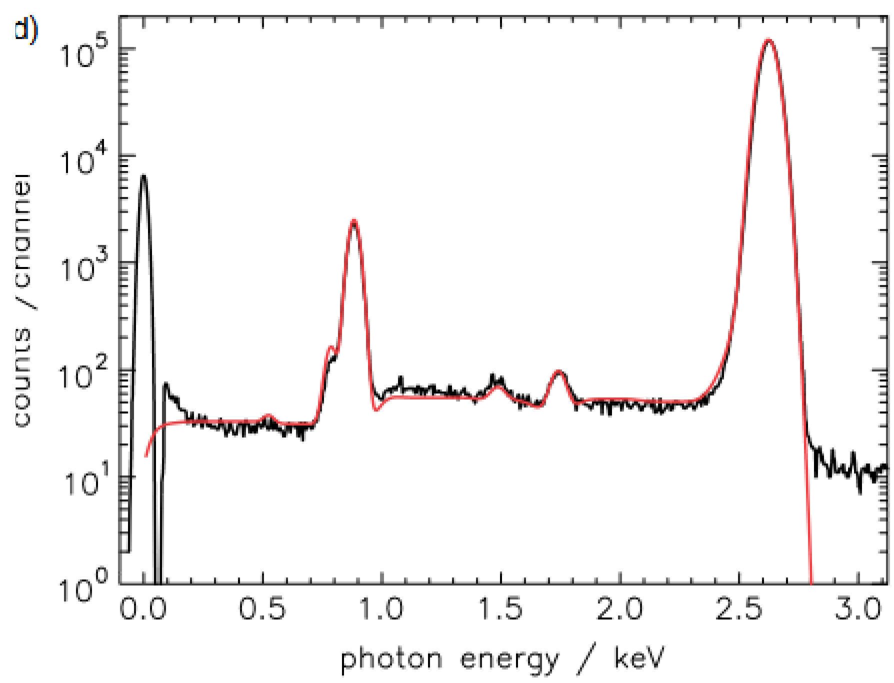
Elam, PIXL Seminar, Nov 2015

The Problem

- Significant low energy counts when using high energy sources is not understood
- Differences observed in soft and hard x-ray output functions using the same detectors
- SDD response functions well researched and modeled for low energy x-rays
- Not so for high energy x-rays



W. T. Elam, unpublished raw data, 2015



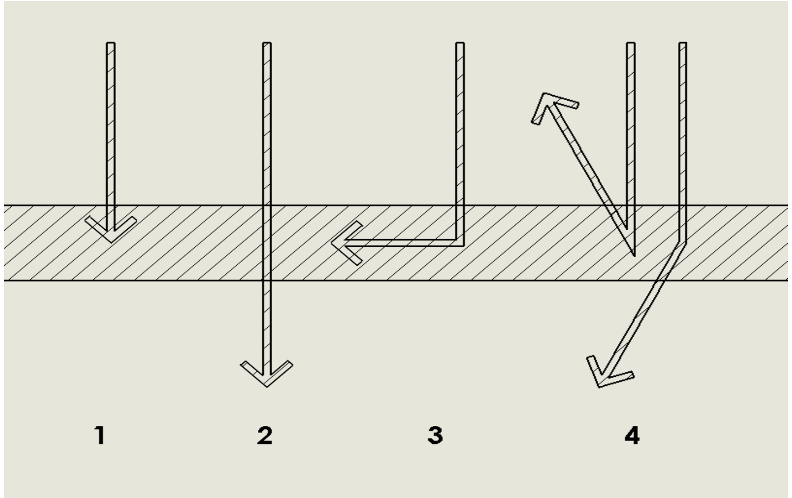
F. Scholze, M. Procop, X-Ray Spectrometry. 2009, 38, 312-321

Hypothesis

Any photon incident to the detector will have one of four fates:

1. Photon is fully absorbed, its full energy is captured by the detector
2. Photon passes through the detector with no interaction, no energy is captured by the detector
3. Photon scatters inelastically in the detector, the scattered photon is then absorbed without escaping the detector. All of the incident photon energy is captured by the detector and measured as one count.
4. Photon scatters inelastically in the detector; the scattered photon then escapes the detector with no subsequent interactions. Only the energy transferred to an electron during the scattering event is captured and measured by the detector.

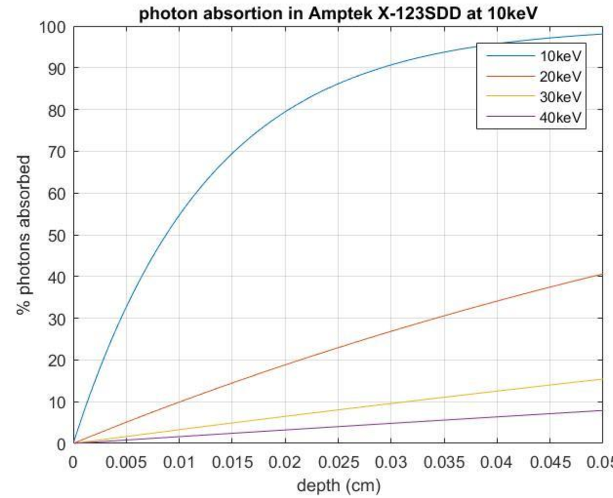
We think case #4 is the cause of low energy counts being registered when there are no low energy photons present.



The physics of the four processes

Input photon beam absorption

$$N_{absorbed} = N_0\left(1 - e^{(-\sigma\rho L)}\right)$$



Photon Compton scattering

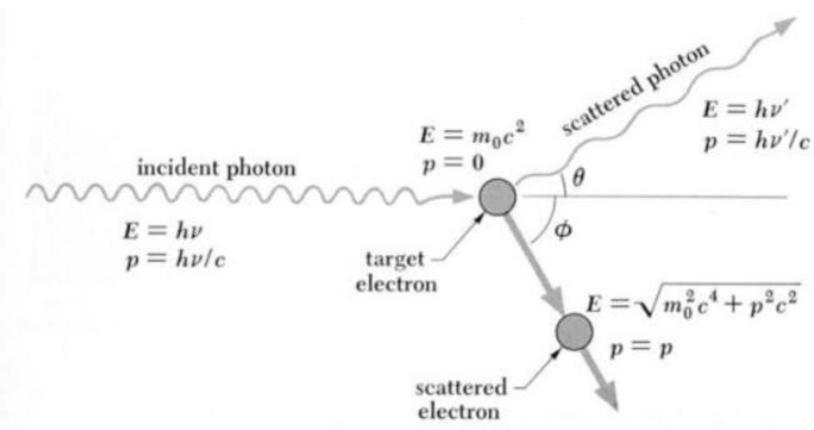
$$\frac{d\sigma_c^Z}{d\phi} = \pi r_e^2 S(x,Z)\sin\phi\left[\left(1+\alpha(1-\cos\phi)\right)^{-2}\left[1+\cos^2\phi + \frac{\alpha^2(1-\cos\phi)^2}{1+\alpha(1-\cos\phi)}\right]\right]$$

$$\frac{dN}{d\phi} = N\left(1 - e^{-\frac{d\sigma_c^Z}{d\phi}d\phi\rho_{atomic}L}\right)$$

Scattered photon and electron energy

$$E_{scattered} = E_0\frac{1}{1+\alpha(1-\cos\phi)}$$

$$E_{electron} = E_0\frac{\alpha(1-\cos\phi)}{1+\alpha(1-\cos\phi)}$$



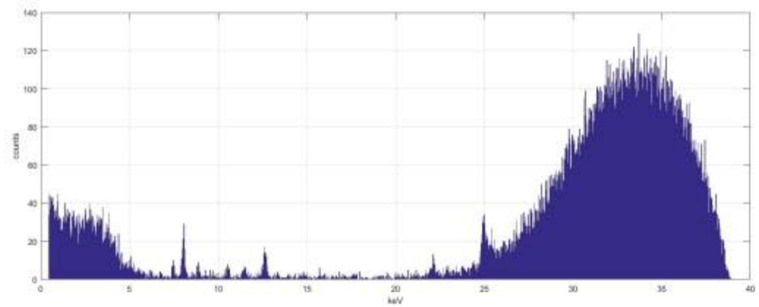
https://universe-review.ca/R15-12-QFT10.htm

Scattered photon escape

$$N_{escape} = N_{scattered}e^{(-\sigma_{escape\_photon}\rho EL)}$$

Numerical modeling of the problem

- We don’t have access to a monochromatic source
- Must work backwards from the experimental source peak to derive the incident x-ray beam

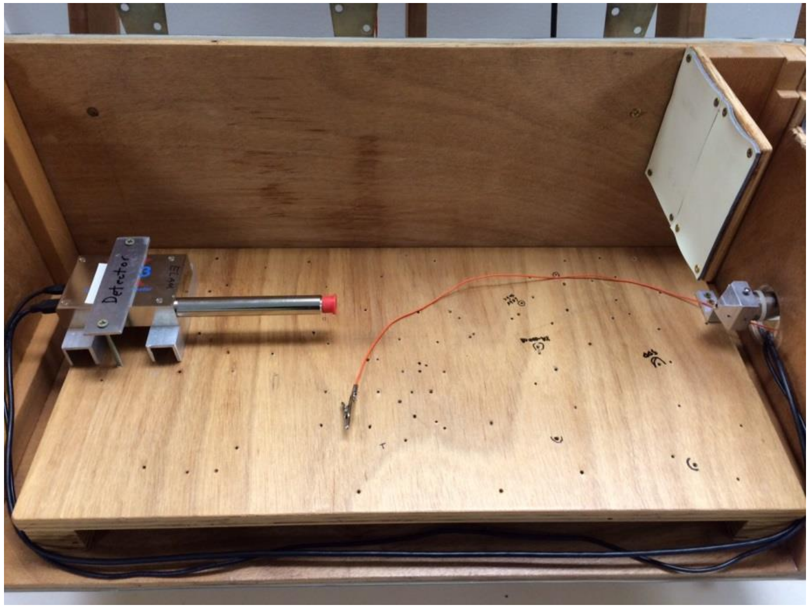


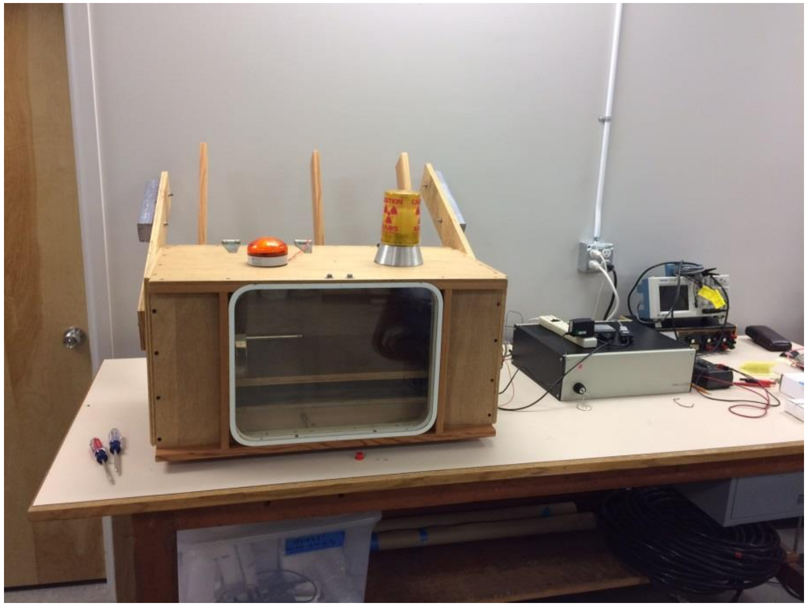
- Number of electrons contributing to the compton scattering response calculated numerically
- Energy of each electron is calculated
- Compton response and source peak response are summed as the total response function

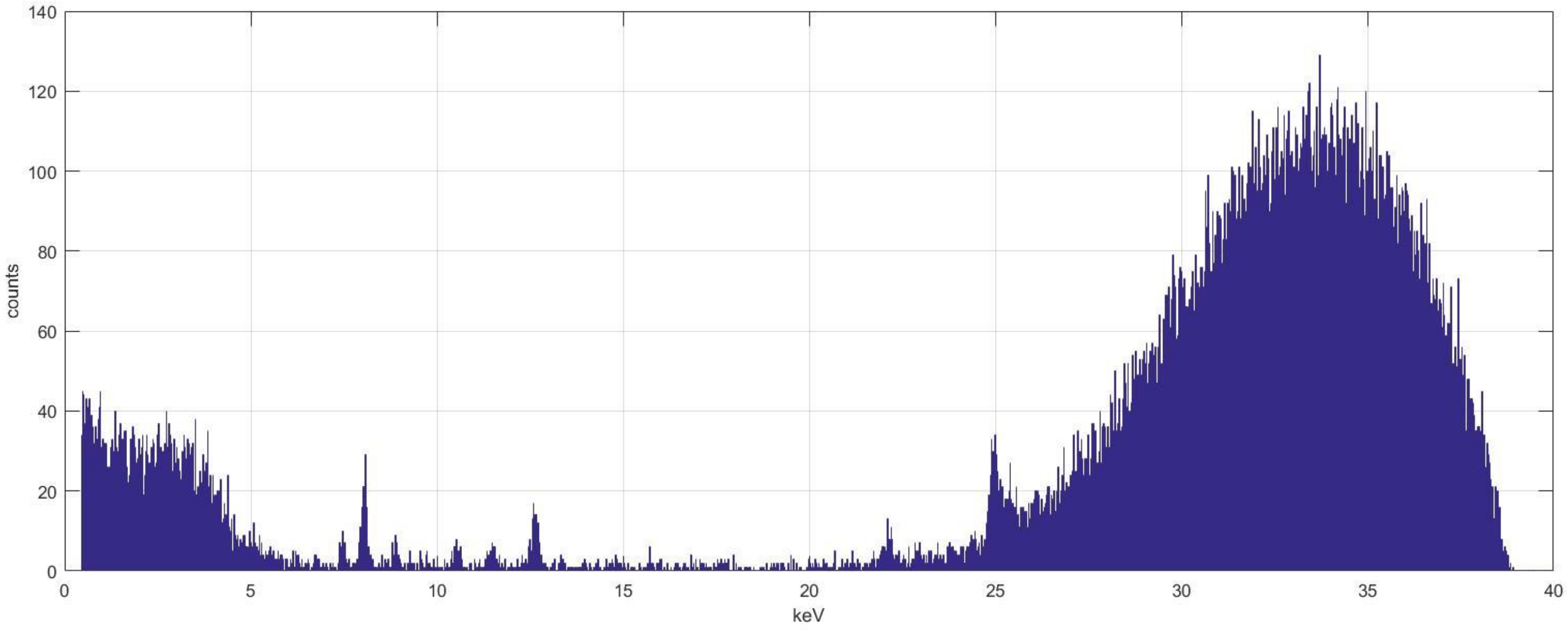
$$N_{scattered\_electrons} = \sum_{E=0}^{E=E_{\max}} \sum_{D=0}^{D=\det ector\_thickness} N_{0,E}\, e^{(-\sigma_{incident\_photon}\rho D)} \sum_{\phi=0}^{\phi=\pi} \left(1 - e^{(-\frac{d\sigma_C}{d\phi} d\phi \rho_{atomic} dD)}\right)\left(e^{(-\sigma_{escape\_photon}\rho EL}\right) d\phi dD dE$$

$$E_{electron} = E_0 \frac{\alpha(1-\cos\phi)}{1+\alpha(1-\cos\phi)}$$

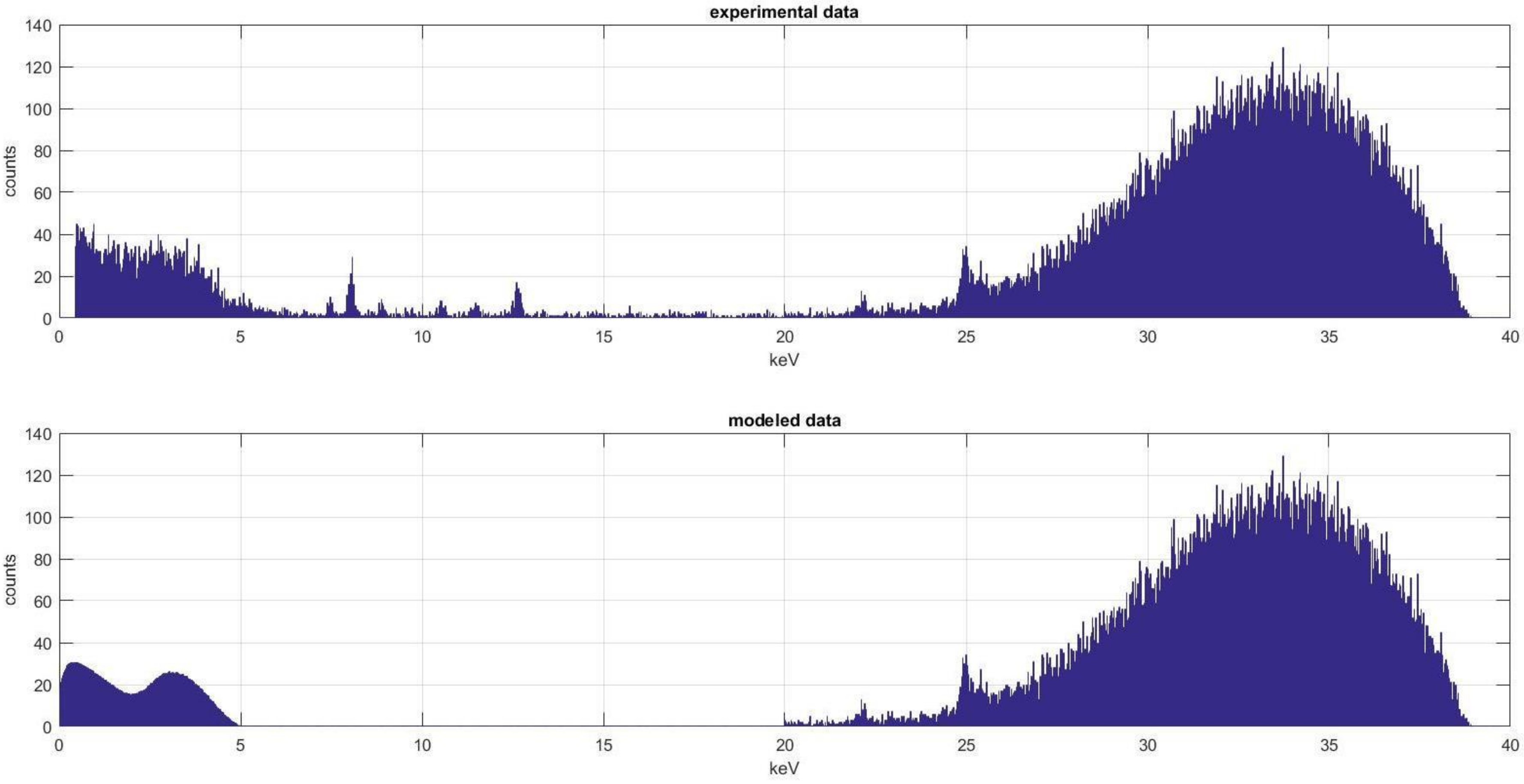
Experimental Data







Comparison of model and experiment



Looks pretty good!

What's next?

- Design and run a better experiment: higher counts, cleaner data
- Statistical comparison of model and experimental data to quantify the accuracy of the model
- Send this thing to Mars and check out some rocks

Thank you
&
any questions???