Trace element content comparison for high-loss and low-loss sapphire*

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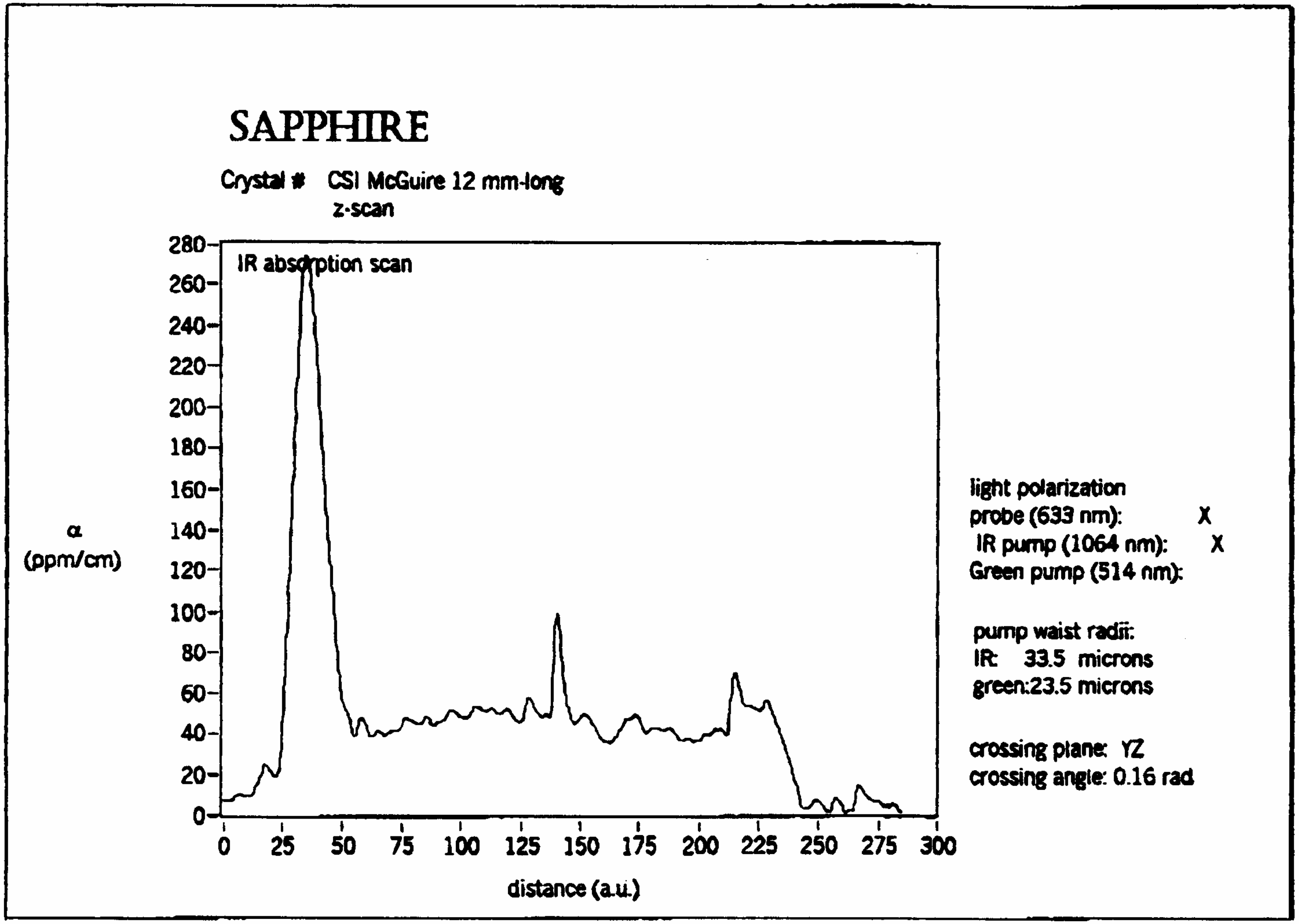
TALK OUTLINE

- Motivation
- Methods & Materials
- Results
- Summary & Future Work

1064 nm Absorption



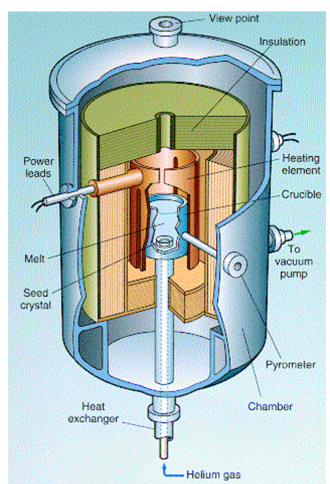
Trace element measurements in Al_2O_3

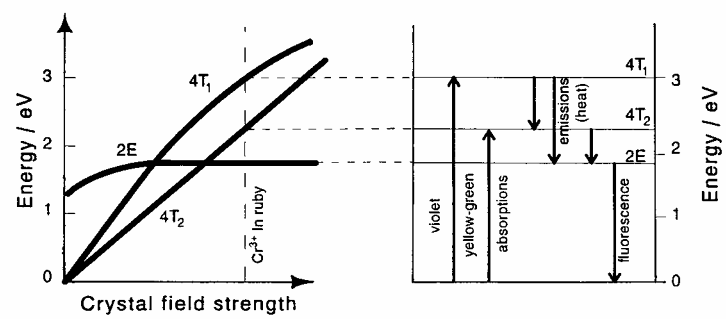
Objective:

Obtain physical correlations between chemical impurities (Ti, Cr, Fe, Co, etc.) and optical absorption characteristics of materials under consideration for use as test masses and optical coatings in advanced LIGO.

HEM™ Process

Crystal Systems, Inc.





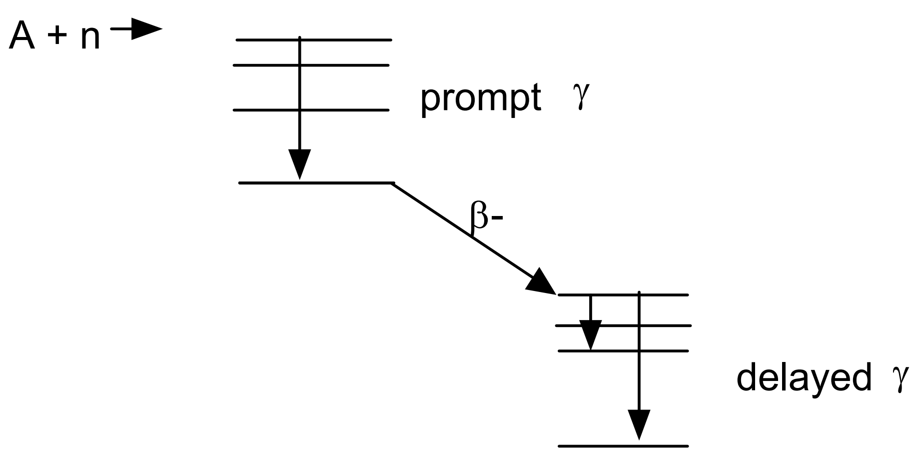
From K. Nassau. Scientific American 1980, 134.

Measurements Program

X-ray Fluorescence (XRF)	CAMD, SSRL, ALS
Extended X-ray absorption fine structure (EXAFS)	CAMD
X-ray absorption near edge spectroscopy (XANES)	CAMD, SSRL
Neutron Activation Analysis (INAA)	NIST
Prompt Gamma Neutron Activation Analysis (PGNAA)	NIST
Neutron Depth Profiling (NDP)	NIST
Electron Spin Resonance (ESR)	NIST

Neutron Activation Analysis (PGAA&INAA)

- Principle: when exposed to a neutron beam, nuclei absorb neutrons and form compound nuclei which de-excite by emission of prompt γ-rays. The often-produced radioactive product nuclei emit delayed γ-rays . The γ-ray energy is used to identify the isotope and the amount of radiation is directly proportional to the amount of element.



Neutron Activation Theory

- Prompt gamma activation

$$N_\gamma = N_{atoms} \cdot f \cdot \sigma_{cap} \cdot \Phi \cdot p_\gamma \cdot \varepsilon_\gamma \cdot \Delta T_{count}$$

- **Delayed gamma activation**

$$N_\gamma = N_{atoms} \cdot (\lambda^{-1}) \cdot f \cdot \sigma_{cap} \cdot \Phi \cdot I_\gamma \cdot \varepsilon_\gamma \cdot (TF)$$

where,

$TF = (1-\exp(-\lambda t_1))\exp(-\lambda t_2)(1-\exp(-\lambda t_3))$

t_1 = irradiation time

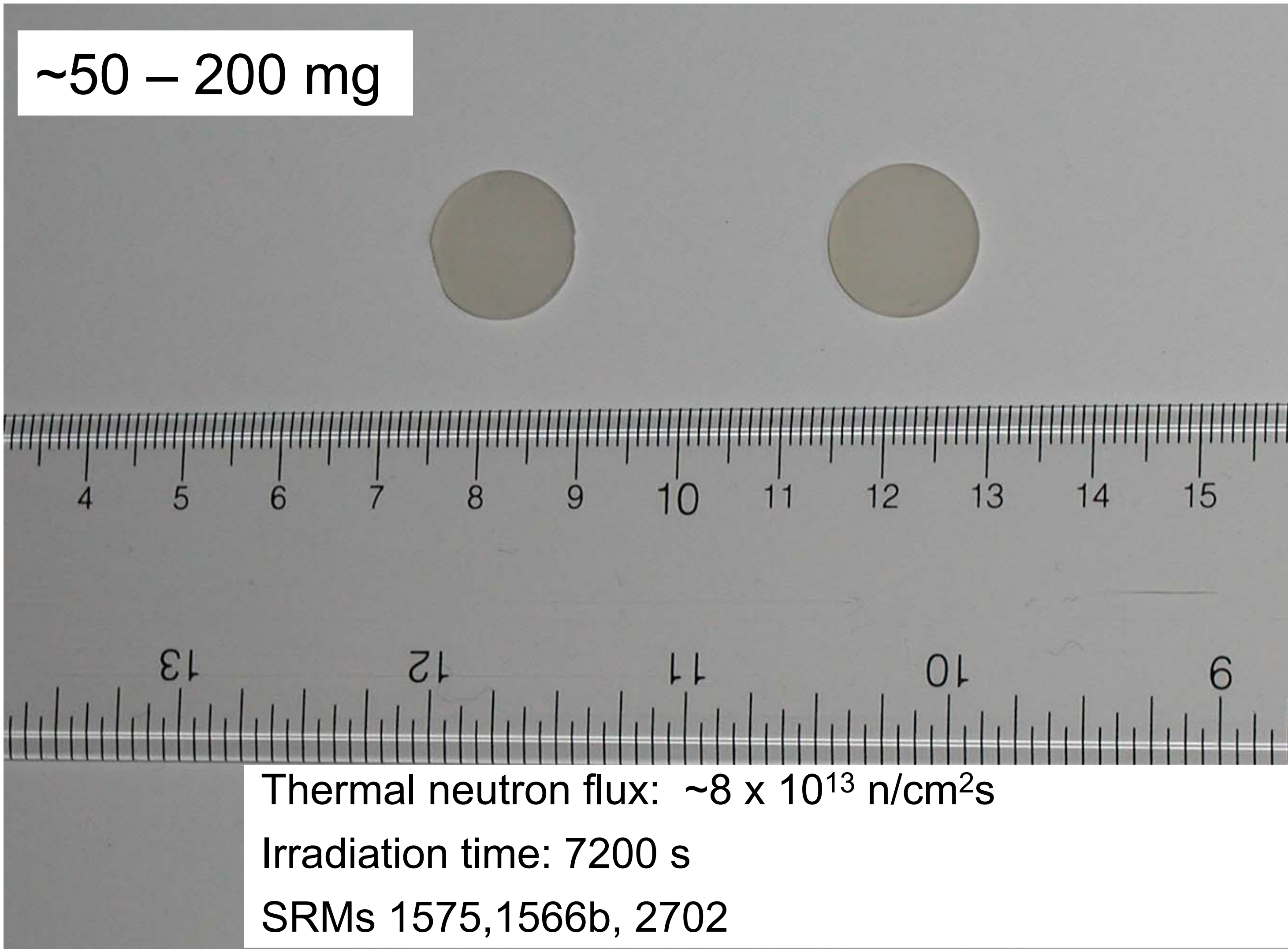
t_2 = decay time

t_3 = counting time

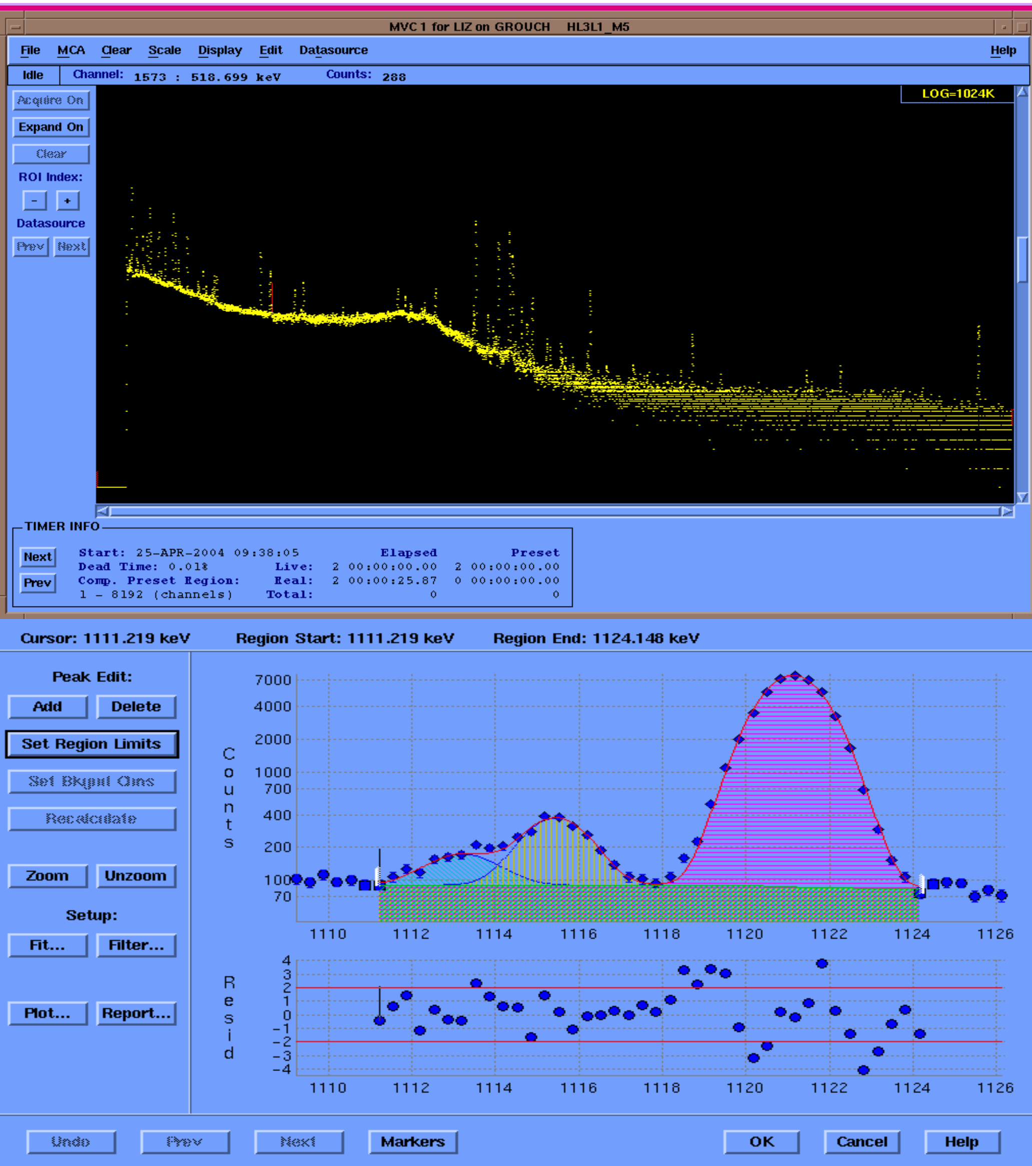
LIGO

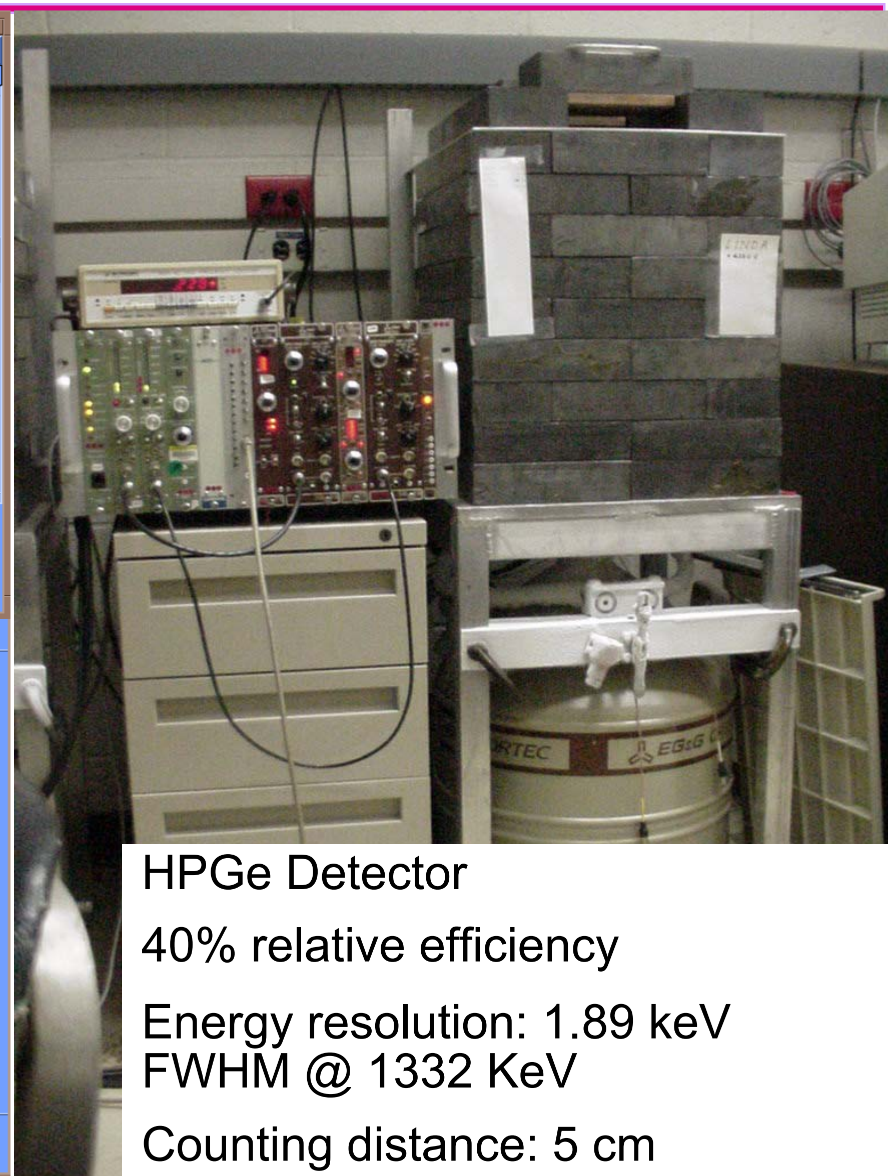
Sapphire samples

SOUTHERN UNIVERSITY And Agricultural & Mechanical College



γ-ray Spectroscopy





HPGe Detector

40% relative efficiency

Energy resolution: 1.89 keV FWHM @ 1332 KeV

Counting distance: 5 cm

NIST INAA Measurements

Mass fraction estimates based on comparison with SRM 2709 San Joaquim Soil.*

Element	Low Loss sample	High Loss sample	SRM 1575a	Certified Value
Sc	0.06 ± 0.02 ppb	0.20 ± 0.04 ppb	10.8 ± 0.8 ppb	10.1 ± 0.3 ppb
Cr	9 ± 2 ppb	8 ± 1 ppb	0.36 ±0.03 ppm	0.3 - 0.5 ppm range
Fe	≤ 1 ppm	≤ 1 ppm	45 ± 2 ppm	46 ± 2 ppm
Co	≤ 1 ppb	1.2 ± 0.4 ppb	68 ± 3 ppb	61 ± 2 ppb
Zn	30 ± 3 ppb	40 ± 4 ppb	39 ± 2 ppm	38 ± 2 ppm
Sb	≤ 2 ppb	≤ 2 ppb	10 ± 3 ppb	not certified
La	7 ± 0.4 ppb	4 ± 0.4 ppb	53 ± 7 ppb	not certified

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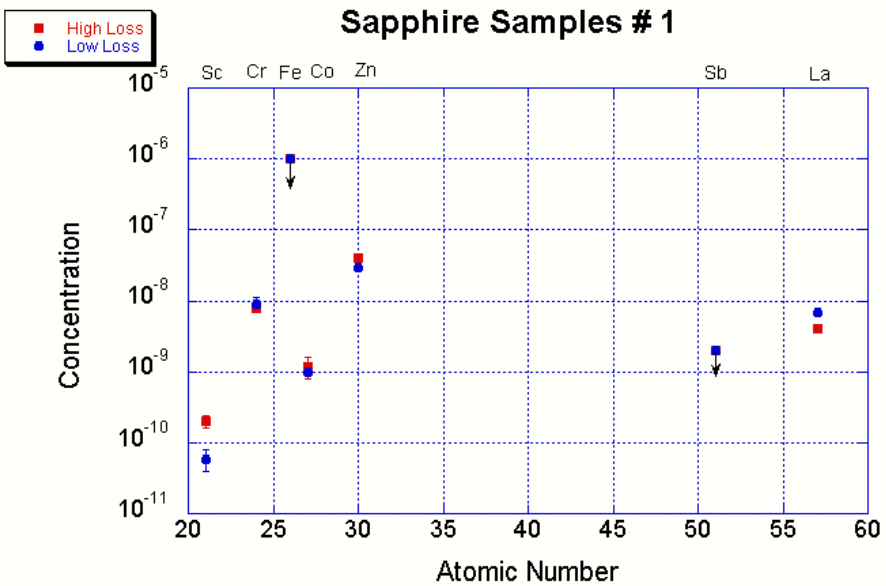
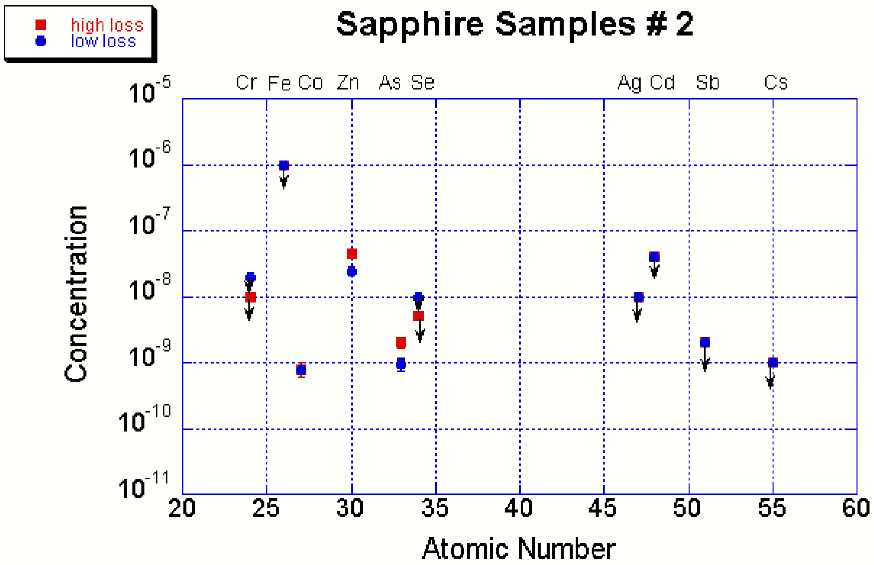
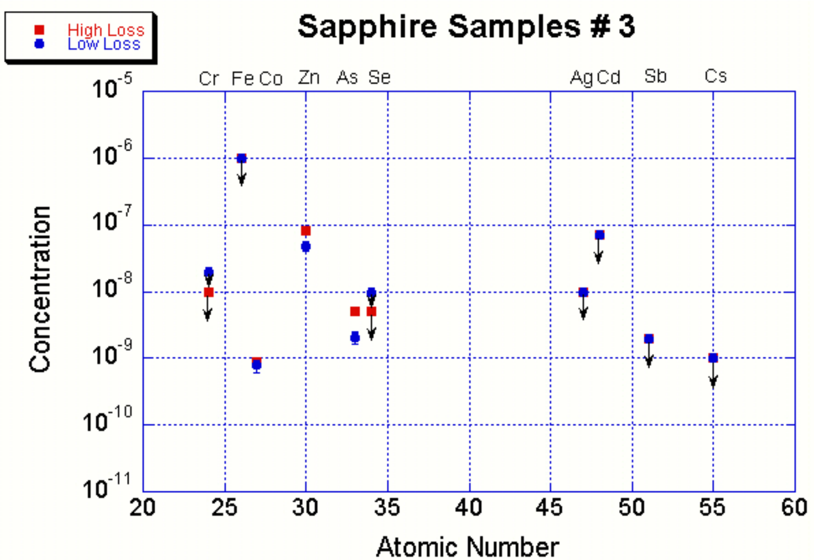
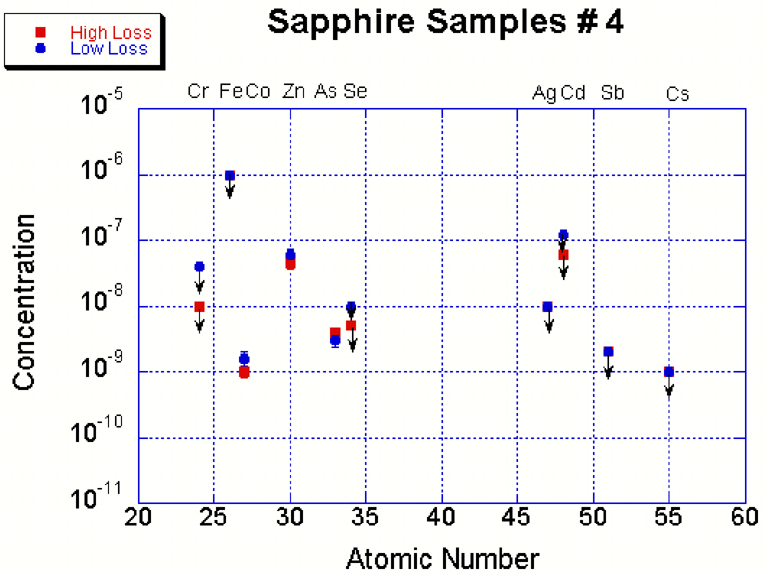
Trace Element Comparison









LIGO Summary & Future Work

- Synthetic sapphire measurements show typical broad range of elements at sub-ppm levels.
- Excellent sensitivity for the elements of primary interest.
- First-time measurements of transition metal and higher-Z elements at sub-ppm levels in synthetic sapphire.
- Correlations between absorption and trace element content not evident.
- Successful implementation of a program of research-based trace element measurements for advanced LIGO optics.
- Fused silica substrate down select in March 2005
- Application of work to losses in coatings on fused silica in progress.
- Development of local support facilities is well underway at Southern University and at the LIGO Livingston Observatory.

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