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Elastic Properties of Natural Biotite Crystals by Brillouin Spectroscopy

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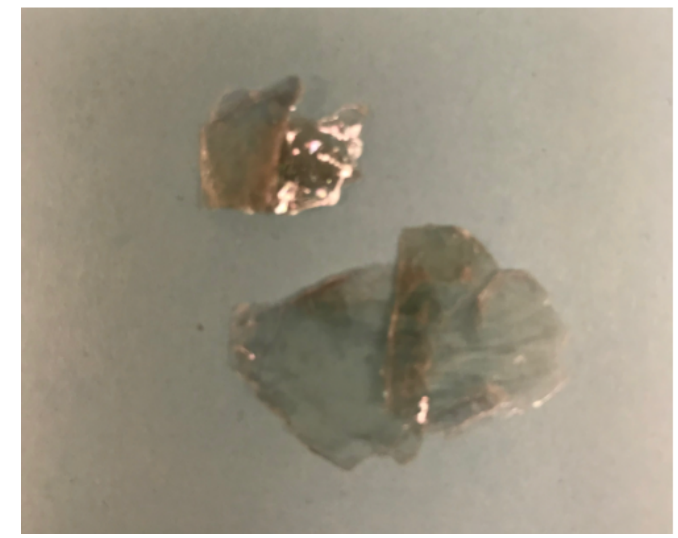
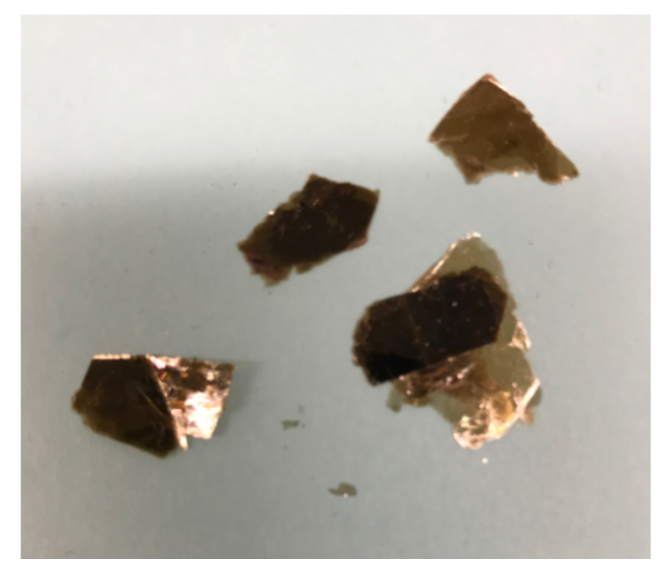
Outline

- Introduction / Motivation
- Theory
- Experimental Setup
- Results
- Conclusion





Motivation

- Study how natural chemical impurities influence the elastic properties of biotite and micas in general.
- Study acoustic phonon behaviour of two-dimensional crystals.
- Complement previous work on elastic properties on mica, specifically muscovite.

Introduction

- Mica is a naturally growing crystal with a number of different species.
- Monoclinic structure : $a \neq b \neq c; \alpha = \gamma = \pi/2 \neq \beta$
- Perfect cleavage along {001}

Biotite

$K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$

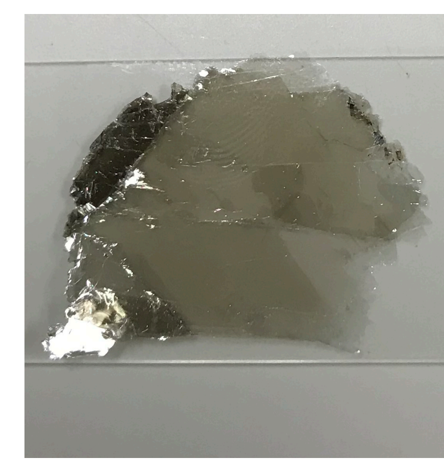
Phlogopite	$KMg_3(AlSi_3O_{10})OH_2$
Eastonite	$KMg_2Al(AlSi_3O_{10})OH_2$
Siderophyllite	$KFe^{2+}{}_2Al(AlSi_3O_{10})OH_2$
Annite	$KFe^{2+}{}_3(AlSi_3O_{10})OH_2$

Fe%

Density and Refractive Increase

Muscovite

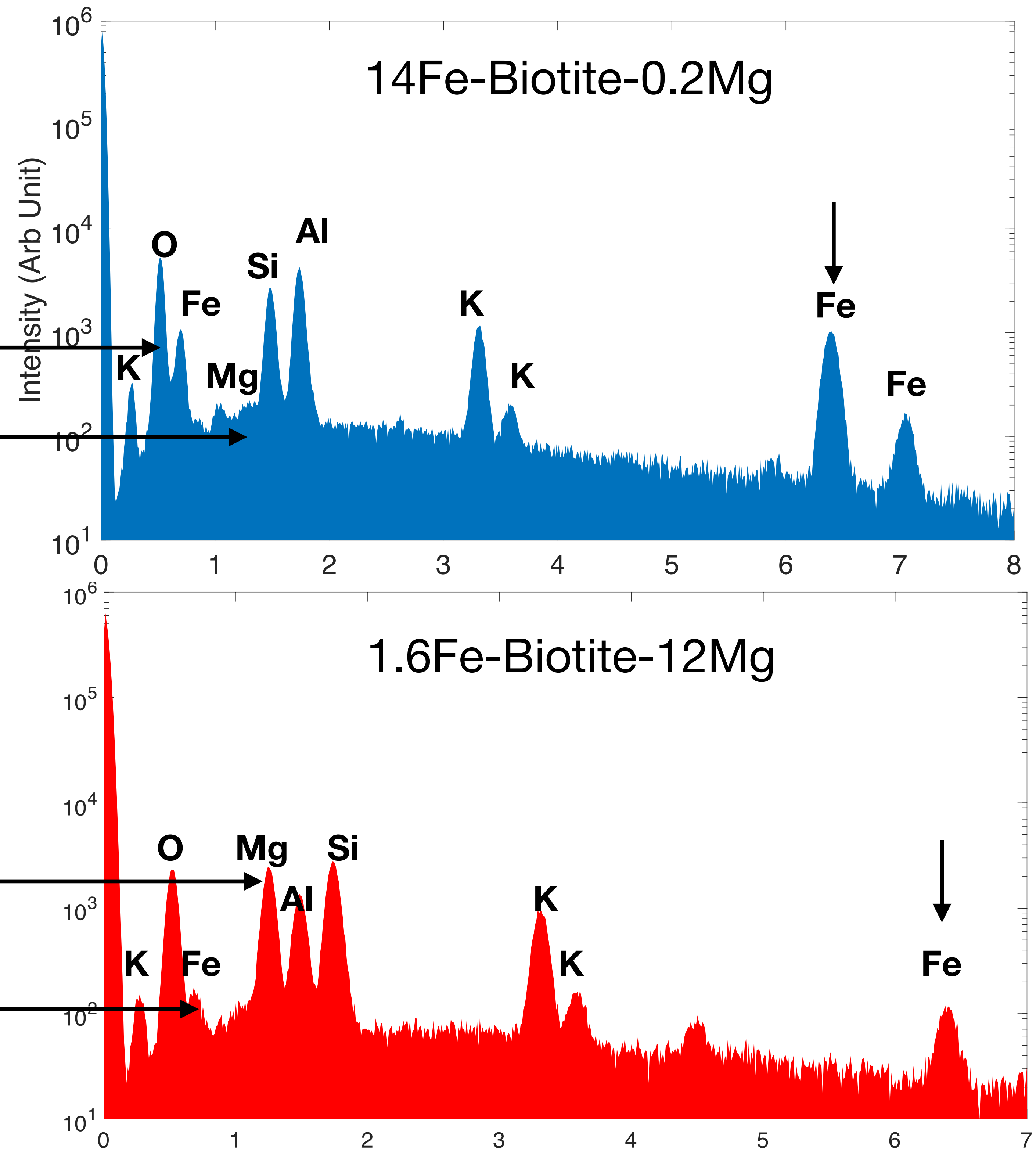
$KAl_2(AlSi_3O_{10})(F,OH)_2$



Sample Characterization

Strong peaks due to Fe and weak peaks due to Mg

Strong peaks due to Mg, weaker peaks due to Fe



Sample Characterization

- Electron microprobe analyzer (EMPA) data was collected in order to obtain a detailed analysis of the chemical compositions of all samples.
- Greatest differences are shown between Fe and Mg, and to some extent Al

Sample	Fe	Mg	Al	K	O	Si
14Fe-Biotite-0.2Mg	13.96	0.16	8.97	4.68	56.16	15.02
9.7Fe-Biotite-4.6Mg	9.66	4.61	7.07	5.22	56.64	15.69
2.3Fe-Biotite-0.4Mg	2.25	0.42	12.72	5.47	60.95	17.86
1.6Fe-Biotite-12Mg	1.57	11.95	4.08	5.27	57.26	15.34
0.7Fe-Biotite-0.3Mg	0.68	0.28	15.17	5.23	60.06	17.96

Brillouin Light Scattering

Brillouin scattering is the scattering of light by thermally excited phonons (acoustic waves).

Energy $\hbar\omega_s = \hbar\omega_i \pm \hbar\Omega$

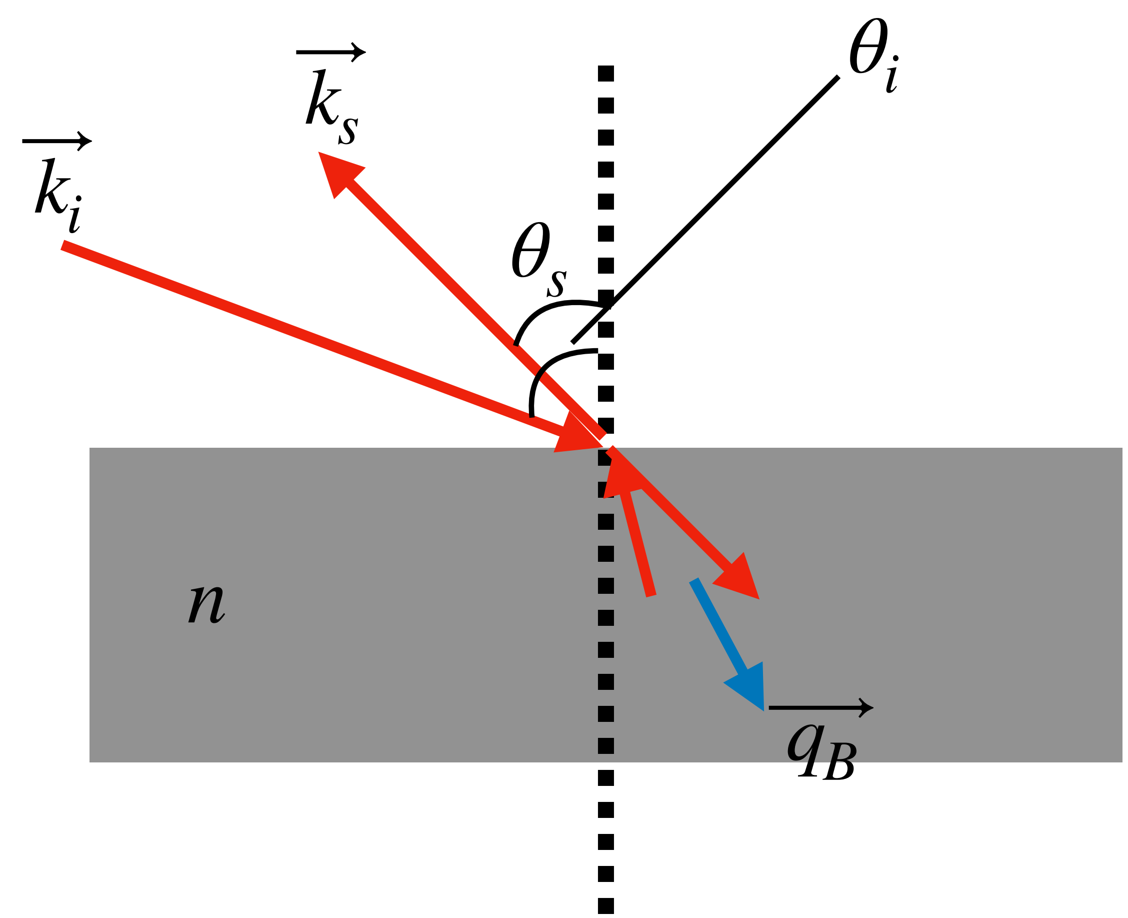
Momentum $\hbar\overrightarrow{k}_s = \hbar\overrightarrow{k}_i \pm \hbar\overrightarrow{q_B}$

Wave vector of incident (scattered) $\overrightarrow{k_i}\ (\overrightarrow{k_s})$

Angle of incidence (scattered) light $\theta_i\ (\theta_s)$

Wave vector of phonon (bulk) $\overrightarrow{q_B}$

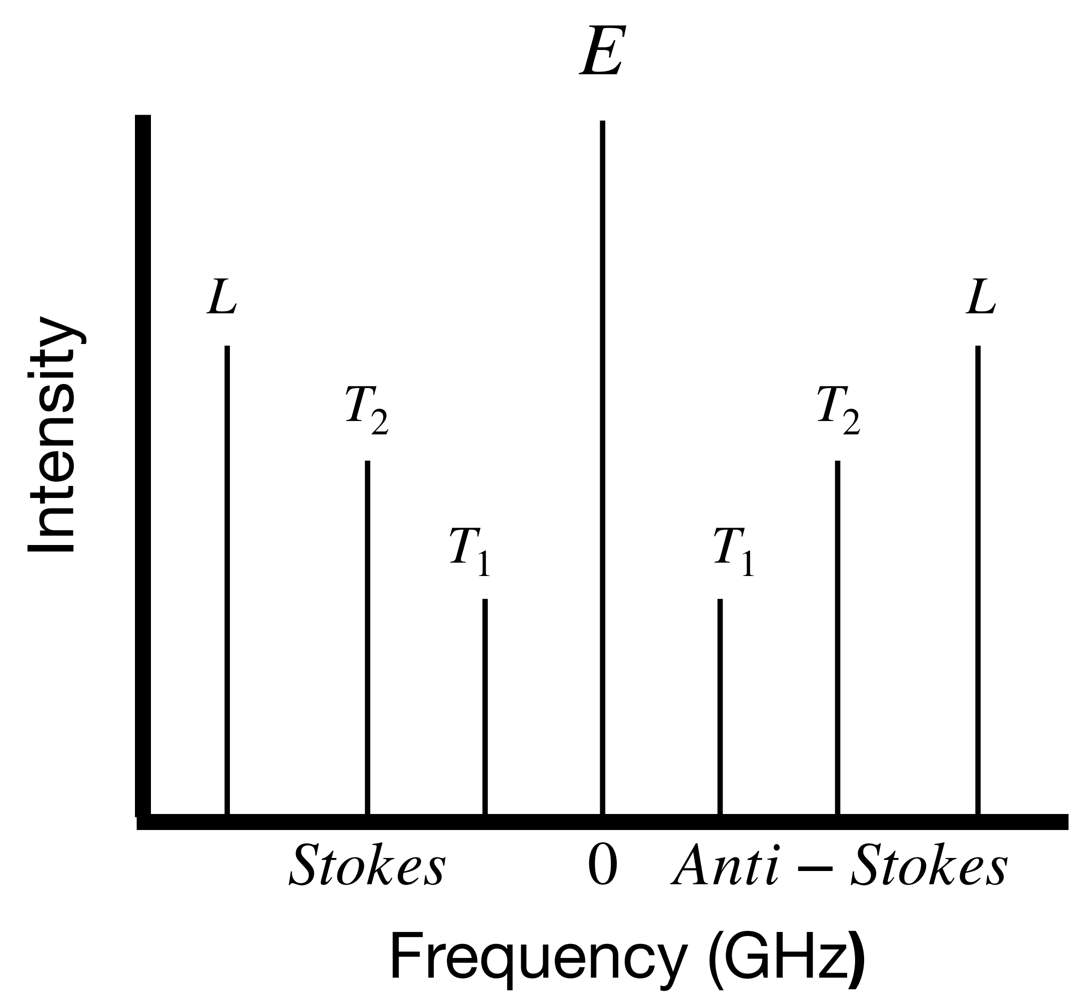
Refractive index of material n



Brillouin Light Scattering

There are two types of bulk phonon modes:
(i) Longitudinal and (ii) Transverse

$$v_{L,T} = \frac{f_{L,T}\lambda}{2n}$$

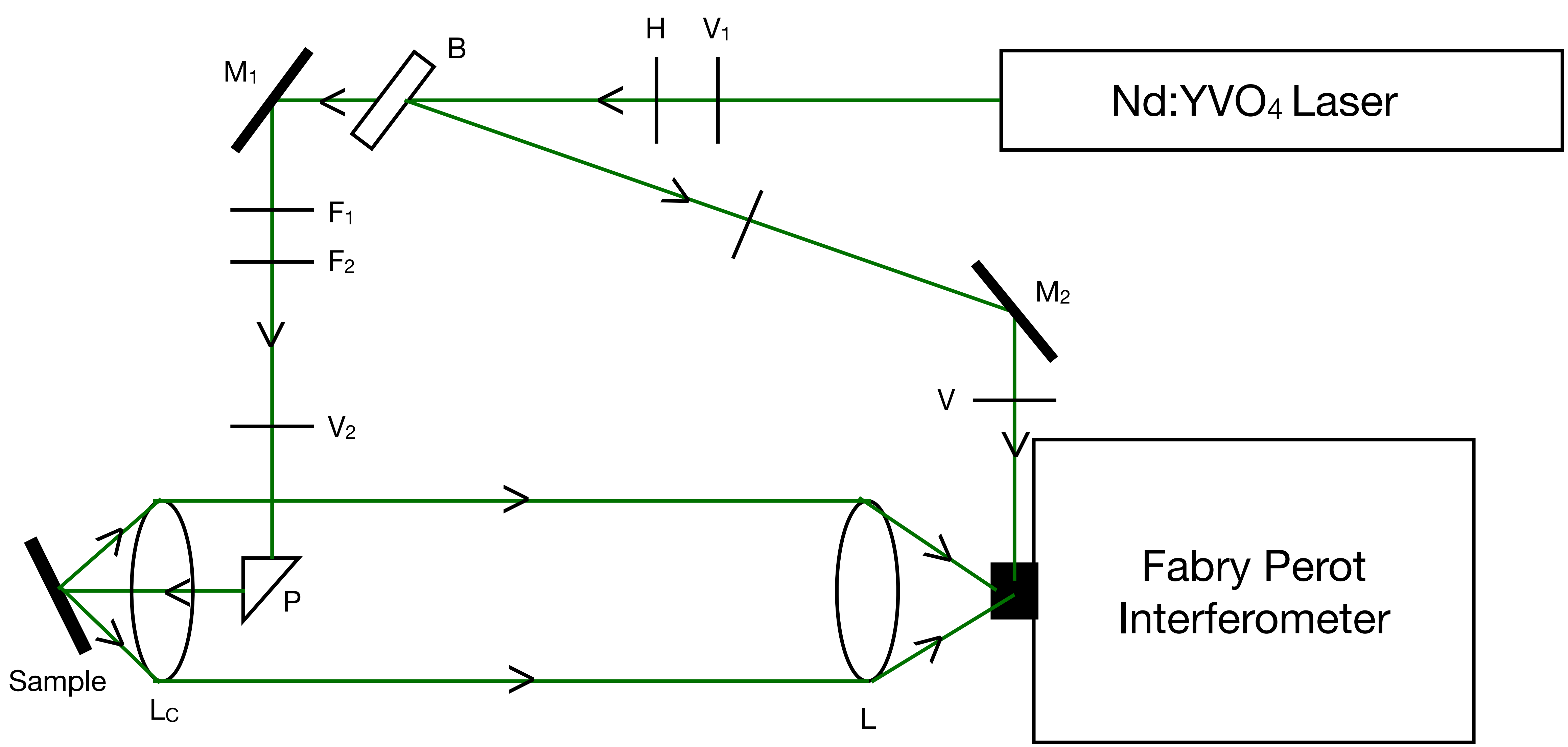


$f_{L,T}$ = frequency shift of longitudinal or transverse phonons
$v_{L,T}$ = velocity of longitudinal or transverse phonons
λ = wavelength of light (532 nm)
n = refractive index of biotite

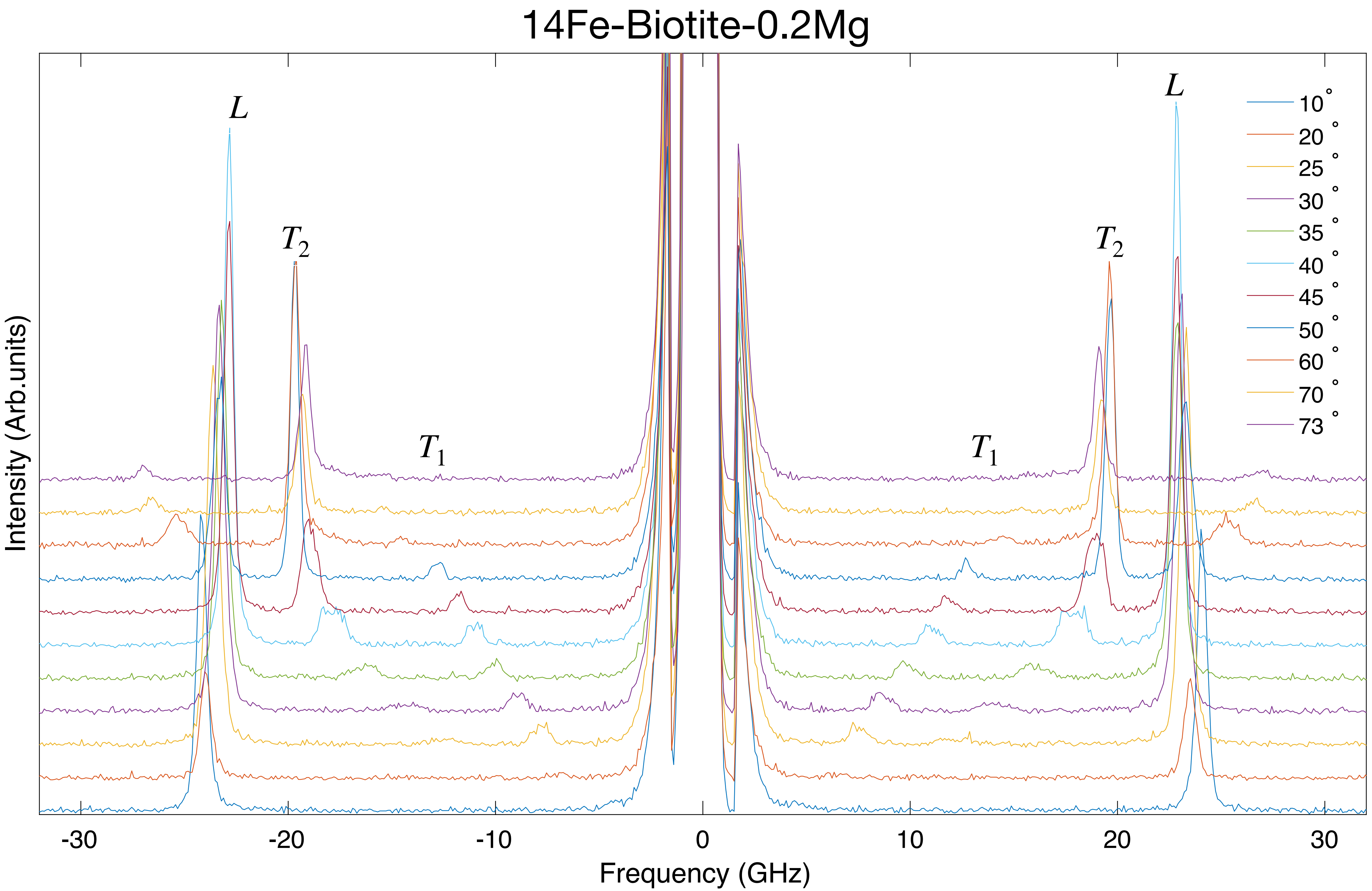
Experimental Setup

- $Nd : YVO_4$ laser
- Wavelength of 532 nm and beam power of 50 mW

- 180° backscattering geometry
- Scattered light analyzed by a six pass tandem Fabry Perot interferometer



Brillouin Spectra



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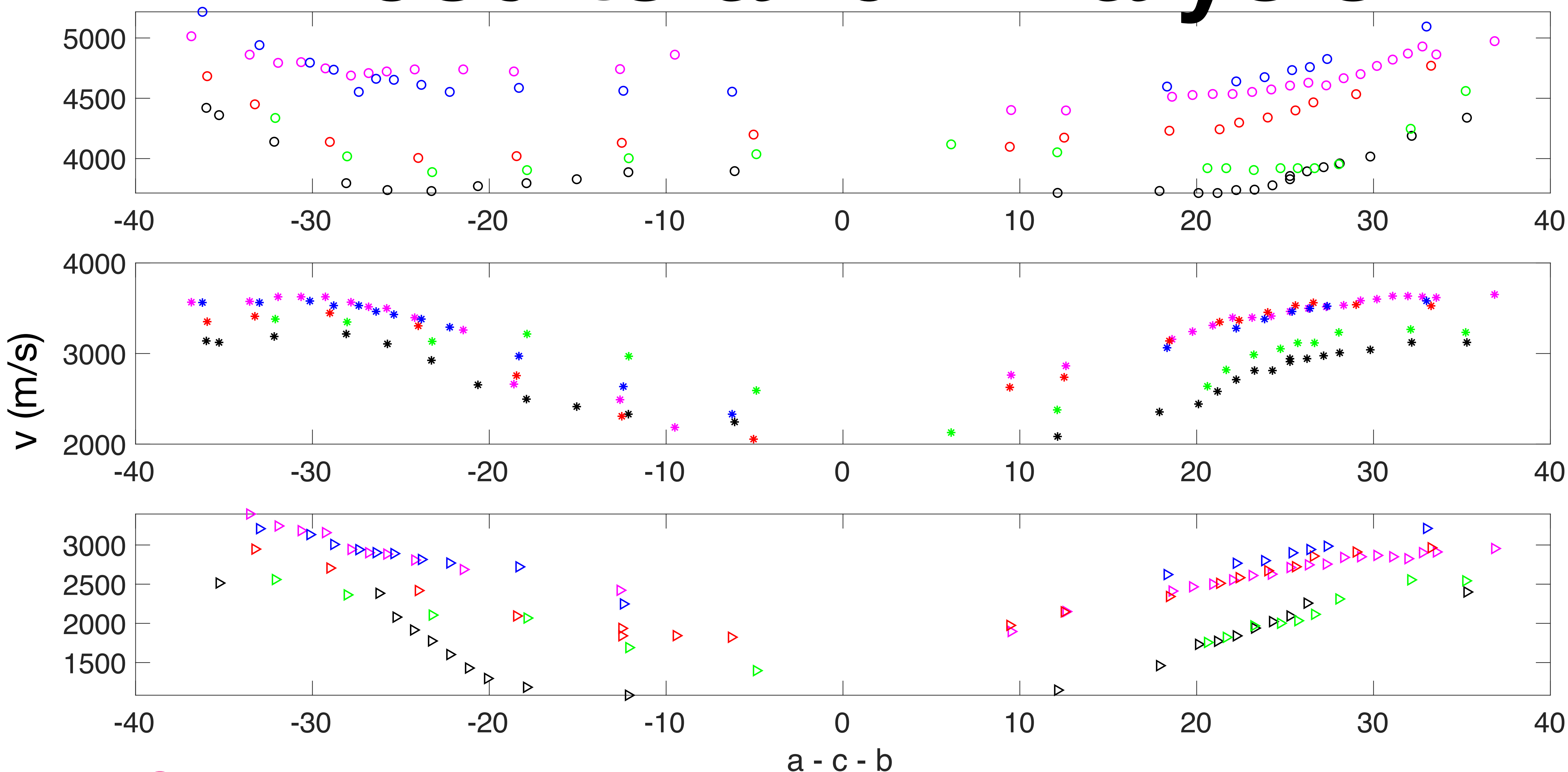
Results and Analysis



- 0.7Fe-Biotite-0.3Mg
- 1.6Fe-Biotite-12Mg
- 2.3Fe-Biotite-0.4Mg
- 9.7Fe-Biotite-4.6Mg
- 14Fe-Biotite-0.2Mg

In general phonon velocities decrease with increasing Fe concentration.

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Results and Analysis

$$C_{eff} = \rho v^2$$

$$C_{eff} = C_{66}\sin^2\theta + C_{44}\cos^2\theta + 2C_{46}\sin\theta\cos\theta$$

$$C_{eff}^{\pm} = \frac{1}{2}(-b \pm \sqrt{b^2 - 4c})$$

$$b = -\left[\sin^2\theta(C_{11} + C_{55}) + 2\sin\theta\cos\theta(C_{15} + C_{35}) + \cos^2\theta(C_{33} + C_{55})\right]$$

$$\begin{aligned} c = {} & \sin^4\theta(C_{11}C_{55} - C_{15}^2) + 2\sin^3\theta\cos\theta(C_{11}C_{35} - C_{13}C_{15}) + \\ & \sin^2\theta\cos^2\theta(C_{11}C_{33} - C_{13}^2 + 2C_{15}C_{35} - 2C_{13}C_{55}) \\ & + 2\sin\theta\cos^3\theta(C_{33}C_{15} - C_{13}C_{35}) + \cos^4\theta(C_{33}C_{55} - C_{35}^2) \end{aligned}$$

$$C_{eff}^3 + \alpha C_{eff}^2 + \beta C_{eff} + \gamma = 0$$

$$\alpha = -\left[(C_{66} + C_{22})\cos^2\theta + (C_{55} + C_{33})\sin^2\theta + C_{44}\right]$$

$$\begin{aligned} \beta = {} & \cos^4\theta(C_{44}C_{66} + C_{22}C_{44} + C_{22}C_{66} - C_{46}^2) \\ & + \sin^2\theta\cos^2\theta(C_{44}C_{66} - C_{23}^2 - C_{25}^2 - 2C_{23}C_{44} - 2(C_{25}C_{35})C_{46} \\ & + C_{44}C_{55} + C_{33}C_{66} + C_{22}(C_{33} + C_{55}) - C_{46}^2) \\ & + \sin^4\theta(C_{33}C_{44} - C_{35}^2 + C_{33}C_{55} + C_{44}C_{55}) \end{aligned}$$

$$\begin{aligned} \gamma = {} & -[\cos^6\theta(C_{22}C_{44}C_{66} - C_{22}C_{46}^2) + \cos^4\theta\sin^2\theta(2C_{22}C_{35}C_{46} + C_{22}C_{44}C_{55} \\ & + C_{22}C_{33}C_{66} - C_{25}^2C_{44} - C_{23}^2C_{66} + 2C_{25}C_{23}C_{46} + \\ & 2C_{23}C_{46}^2 - 2C_{44}C_{23}C_{66}) + \sin^4\theta\cos^2\theta(C_{33}C_{55}C_{22} - C_{35}^2C_{22} - C_{33}C_{46} \\ & + C_{33}C_{44}C_{66} - C_{25}^2C_{33} - C_{23}^2C_{55} + 2C_{25}C_{35}C_{44} - 2C_{25}C_{33}C_{46} \\ & + 2C_{25}C_{23}C_{35} + 2C_{23}C_{35}C_{46} - 2C_{23}C_{44}C_{55}) + \sin^6\theta(C_{44}C_{55}C_{33} - C_{35^2}C_{44}]) . \end{aligned}$$

$$\chi^2 = \sum \frac{(C_{eff} - y_i)^2}{\sigma_i^2}$$

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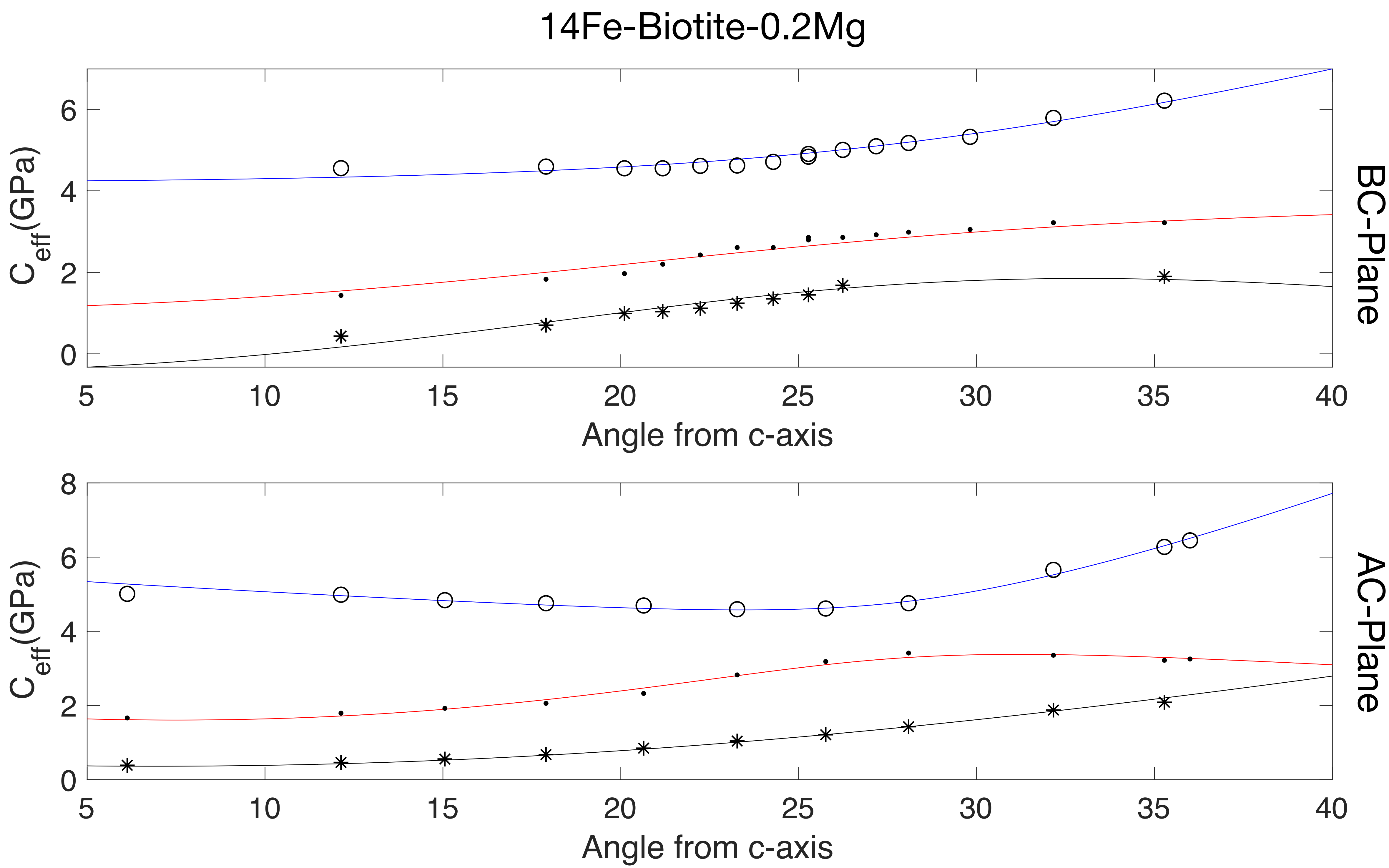

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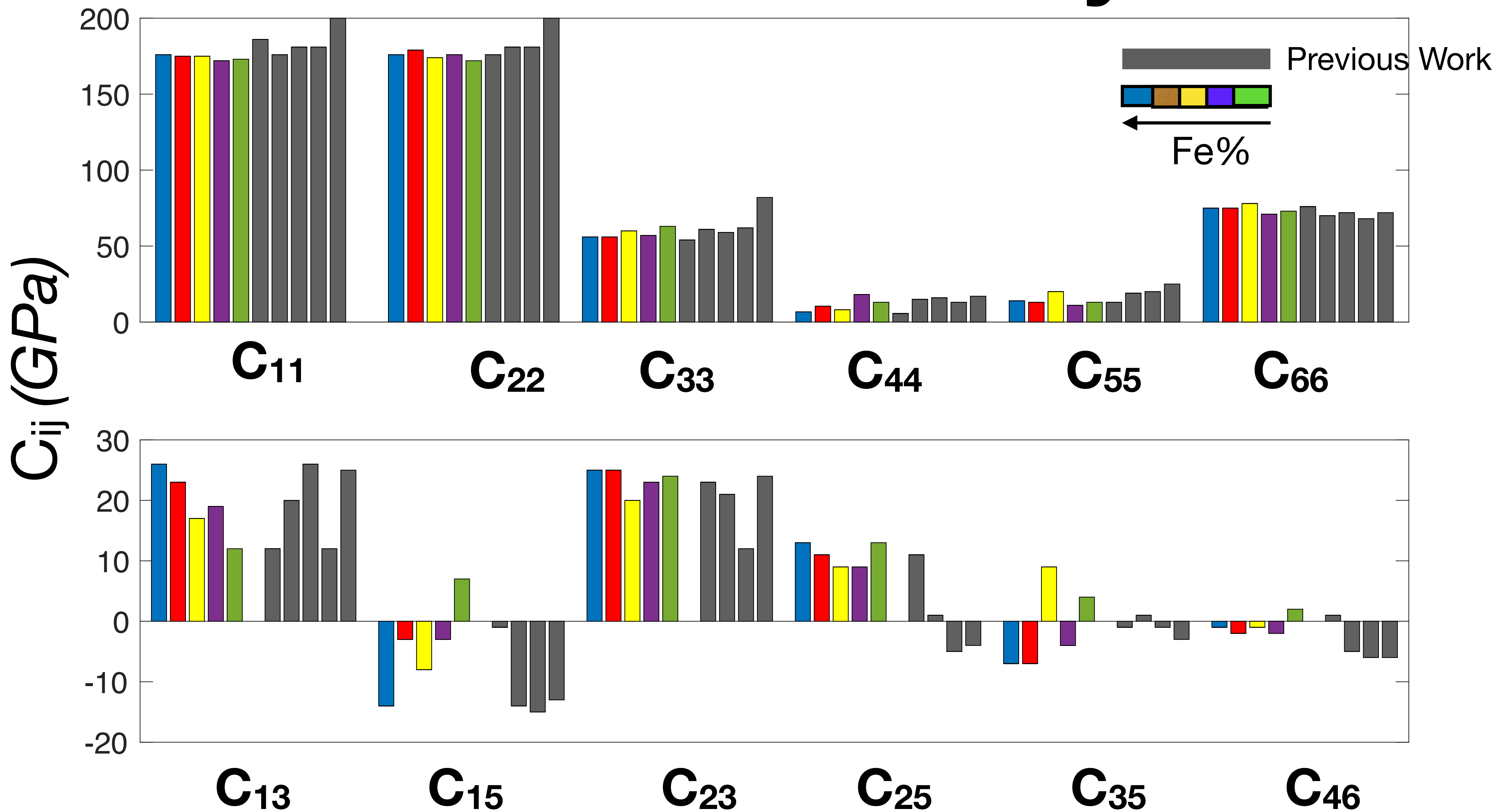

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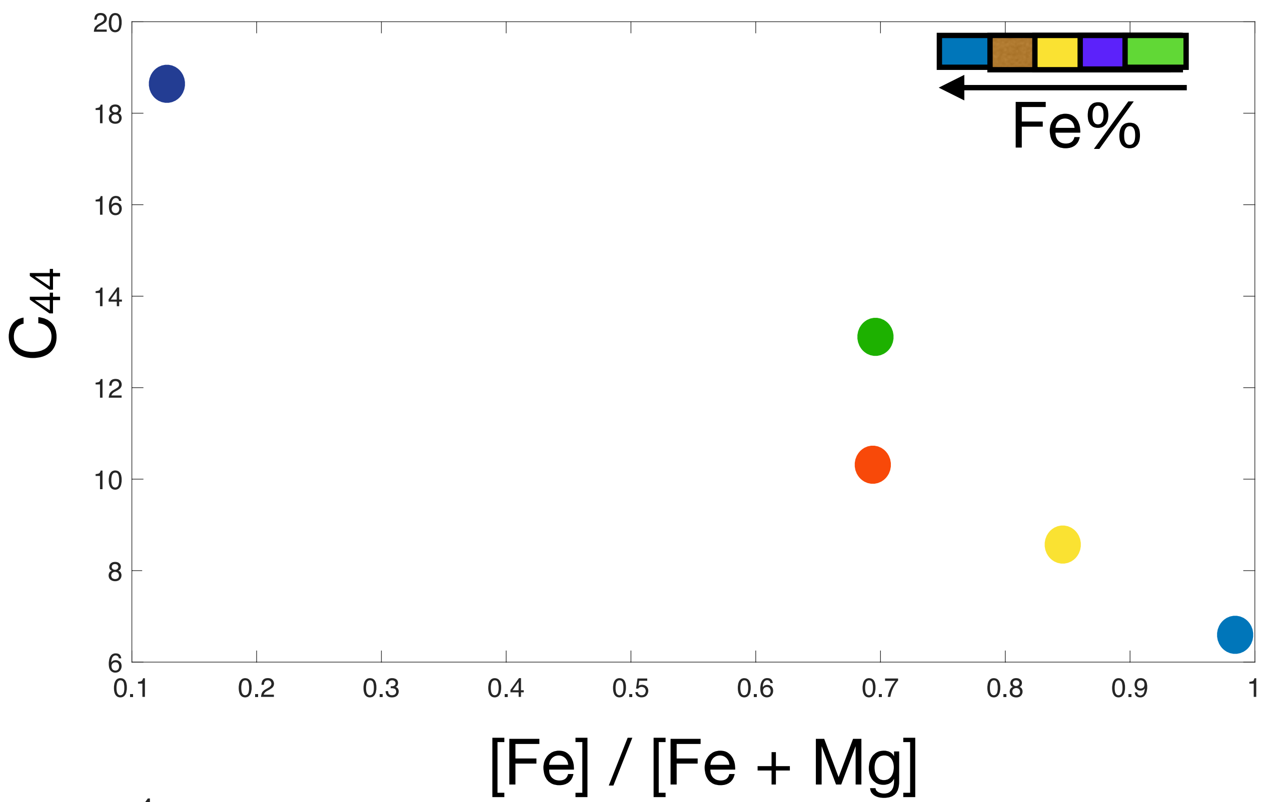
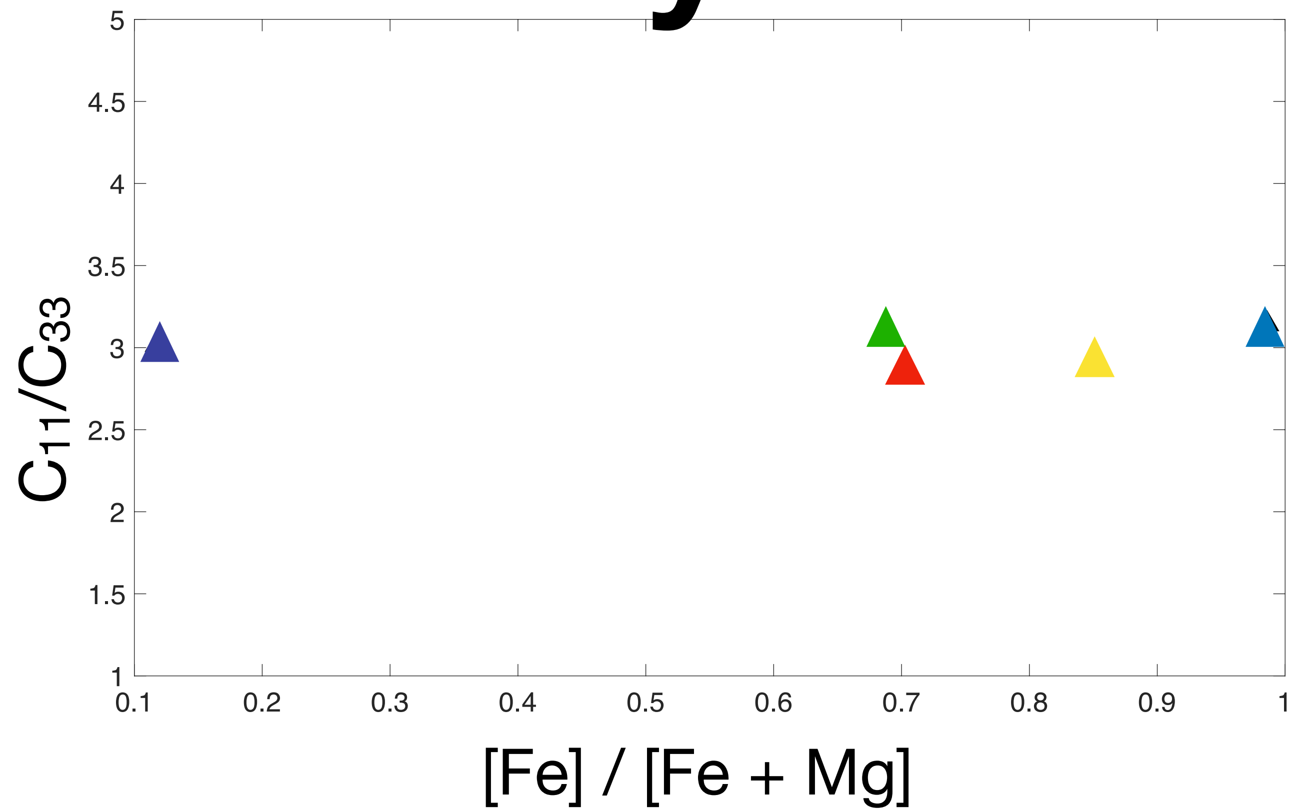
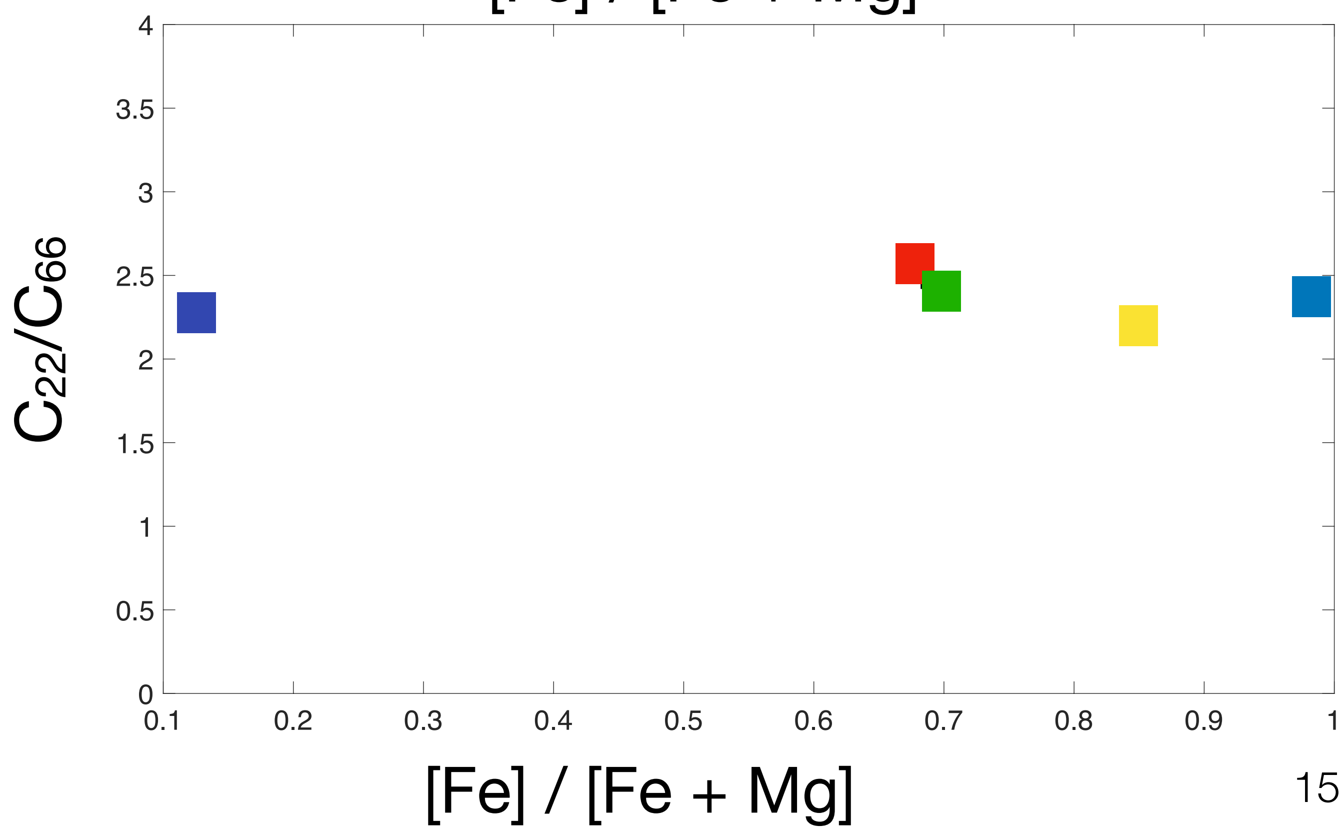
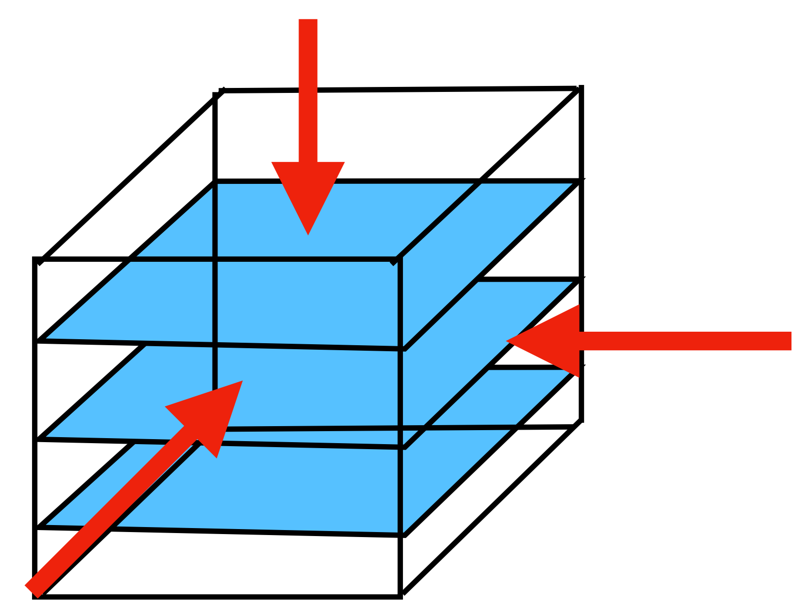
Results and Analysis









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Conclusion

1. Brillouin light scattering was done on samples of biotite with differing concentrations of primary impurities Fe and Mg.
2. 12 of the 13 Elastic constants were obtained via non-linear least squares fitting.
3. Elastic constants throughout this study showed that constants such as C_{11}, C_{22}, C_{33}, C_{55} and C_{66} remain in general fairly constant as impurities (Fe and Mg) change. However constants such as C_{44}, C_{15}, C_{35} and C_{46} show a relatively big change with differing impurities
4. As well when comparing with muscovite, it should be noted that muscovite lacks both Fe and Mg and is much higher in Al which could be an indication why some of our constants are so different then previous work.

In general it was seen that chemical impurities do influence the mechanical properties and elastic properties. This is best shown from the velocity vs direction plot.

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