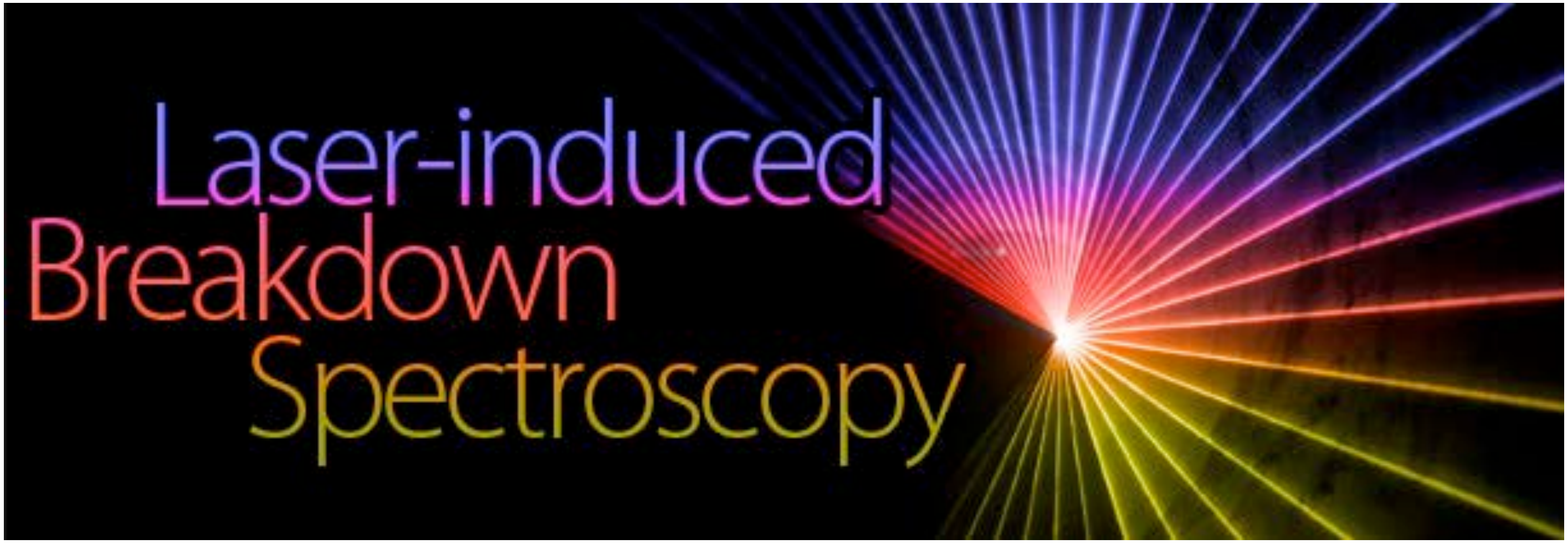
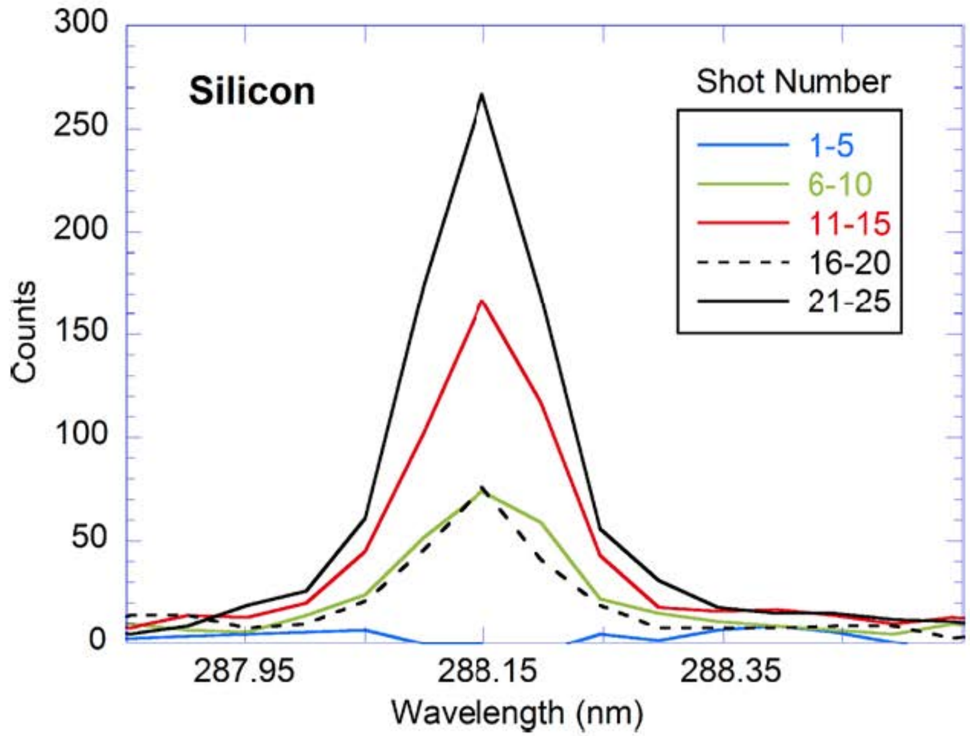


Active Remote Sensing of Elemental Chemistry

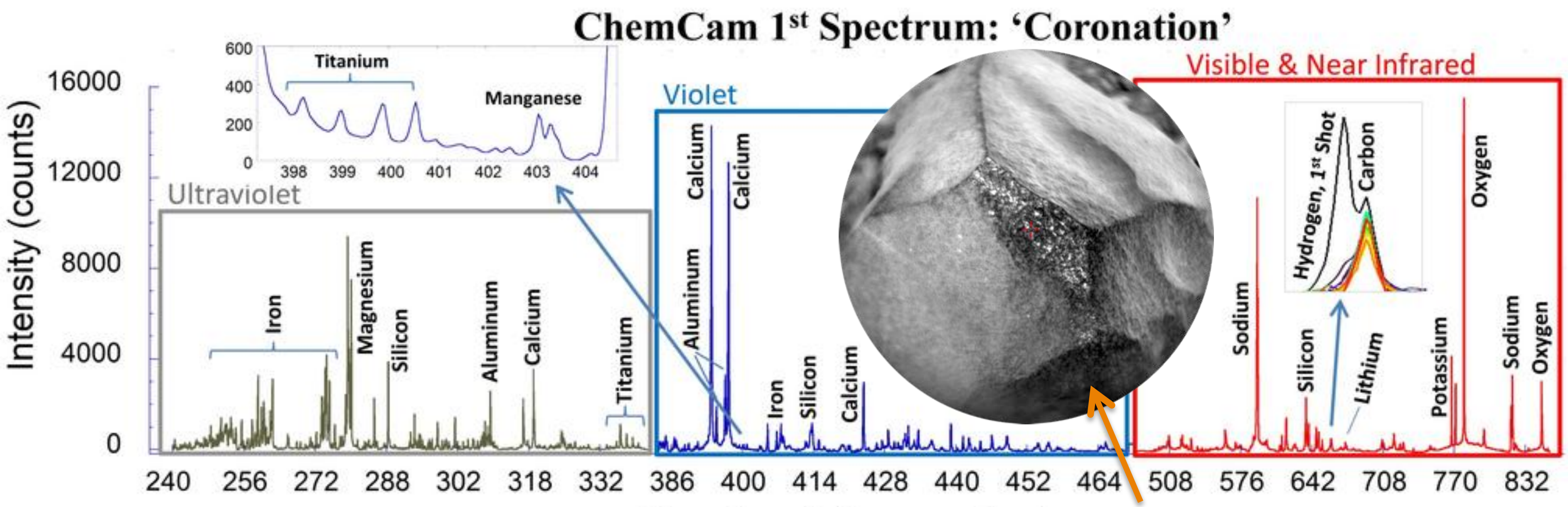
Fig. 26 Test of LIBS profile through thick dust. Loose dolomite dust was placed on a pressed basalt target, lying at an ∼45° angle. *Circle* indicates the pit created by the laser pulses

Rock	Distance	# Pulses	Maximum depth
Basalt	3 m	500	410 µm
Basalt	3 m	1000	300 µm
Basalt	7 m	500	240 µm
Basalt	7 m	1000	330 µm
Calcite	3 m	500	400 µm
Calcite	3 m	1000	>560 µm

Fig. 27 Successive five-spectrum averages showing the 288 nm Si emission line strength as the laser profiles through the Si-free dust to the Si-containing basalt at the analysis location shown in the previous figure. The low peak for laser shots 16–20 likely results from powder falling back into the hole



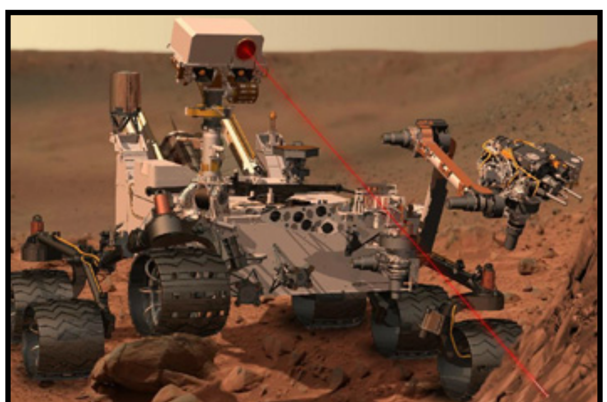
Wiens et al. (2012)

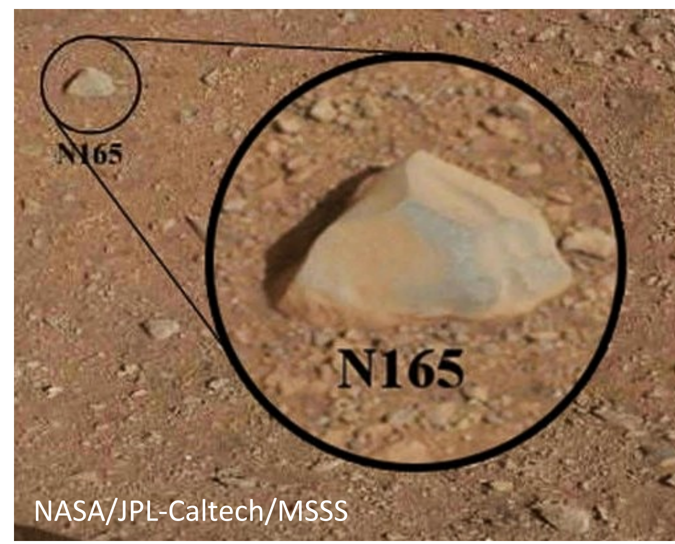


NASA/JPL-Caltech/LANL/CNES/IRAP/IAS/MSSS
NASA/JPL-Caltech/LANL/CNES/IRAP

ChemCam spectra of Coronation

Target: Coronation (N165)
Sol 13
Shots: 30



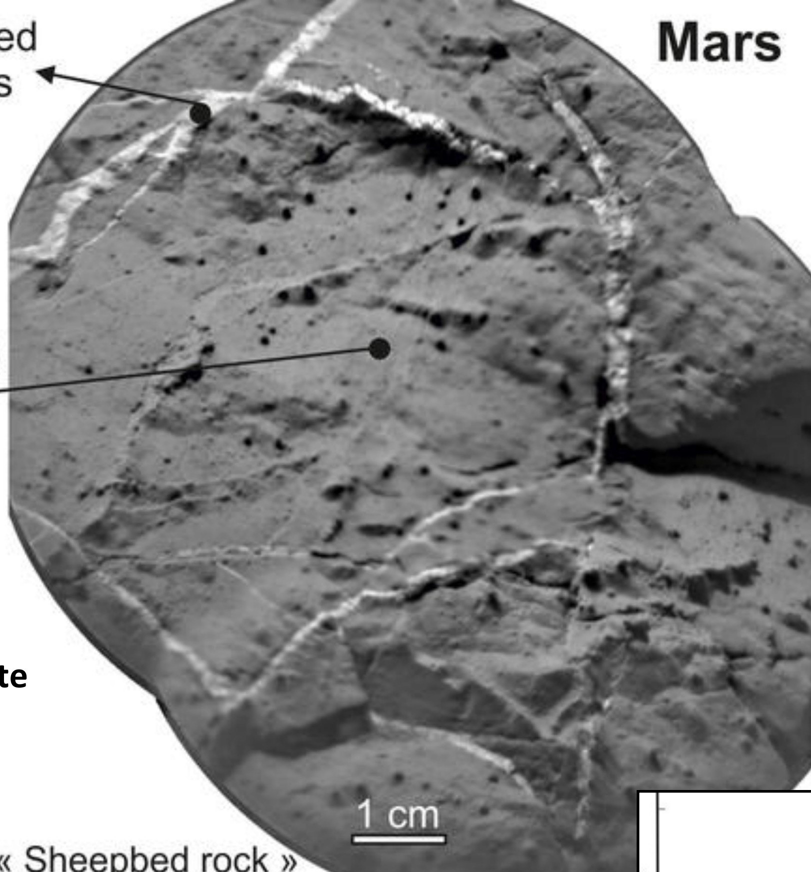


CURIOSITY

Mars Earth

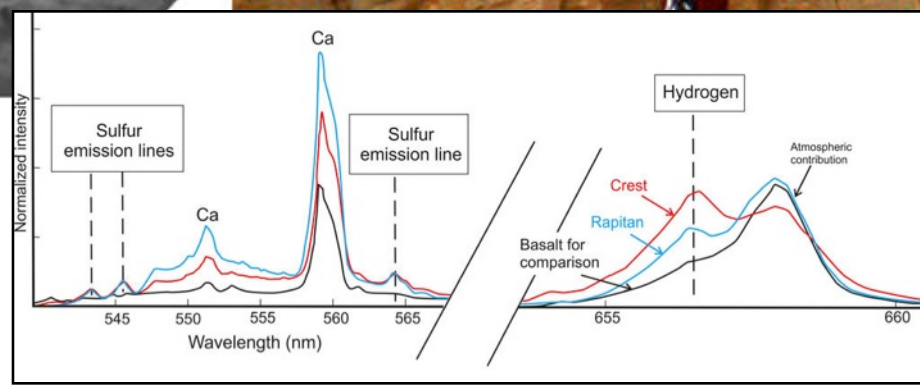
Veins of hydrated calcium sulfates

Sediments with basaltic composition



ChemCam Remote Micro-Imager

NASA/JPL-Caltech/LANL/CNES/IRAP/IAS/
LPGN/CNRS/LGLyon/Planet-Terre

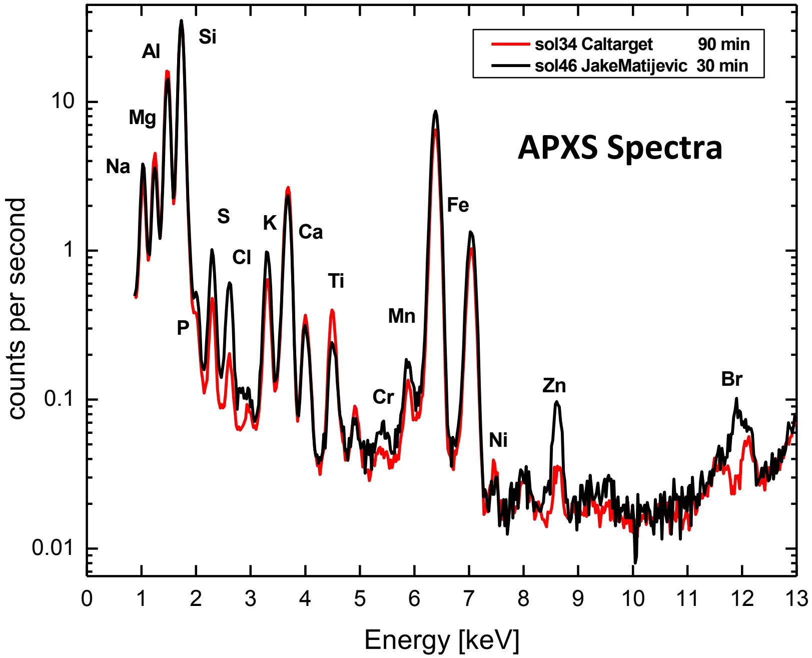


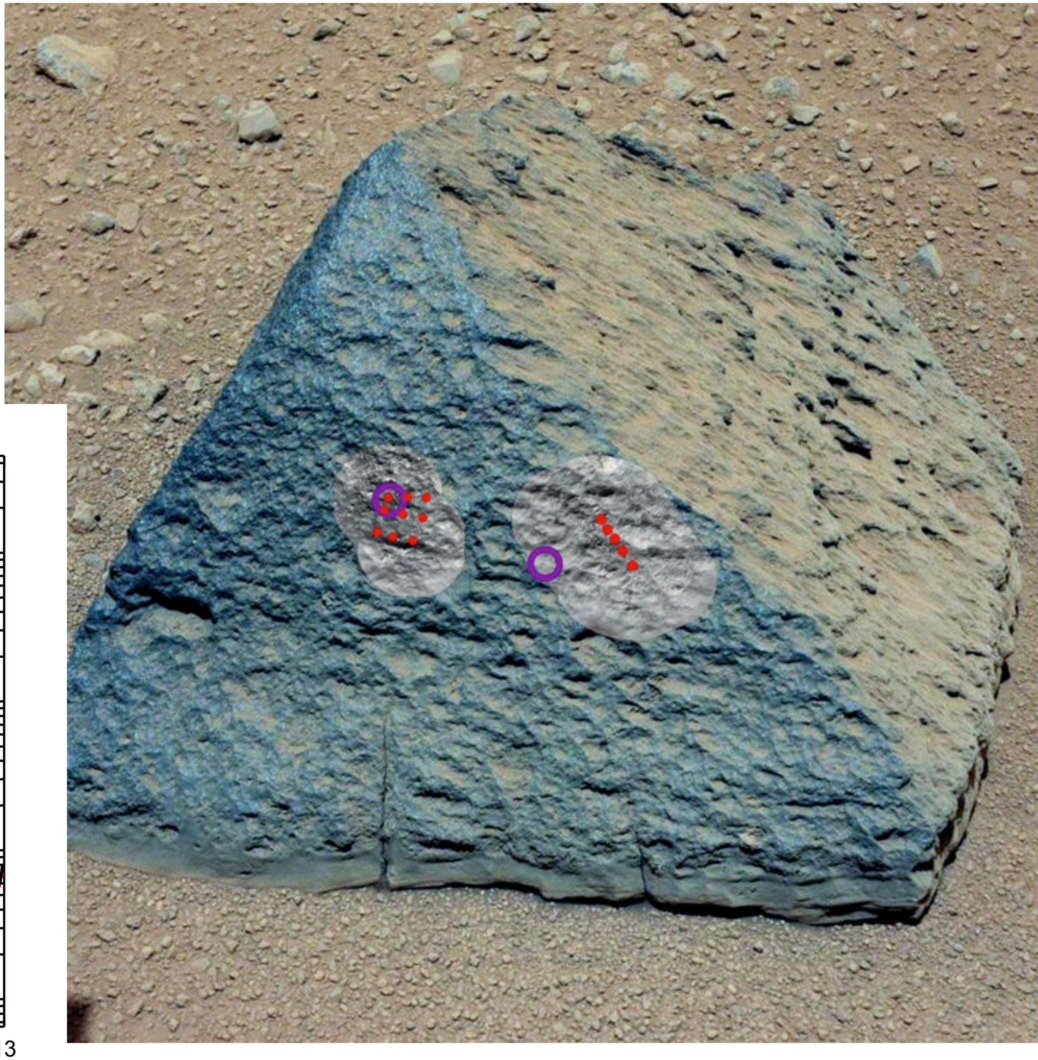
ChemCam spectra from sol 125 "Crest" and 135 "Rapitan"

"Sheepbed" rocks contain 1 to 5-mm fractures filled with calcium sulfate minerals that precipitated from fluids at low to moderate temperatures

Jake Matijevic studied by Mastcam (image), APXS, and ChemCam

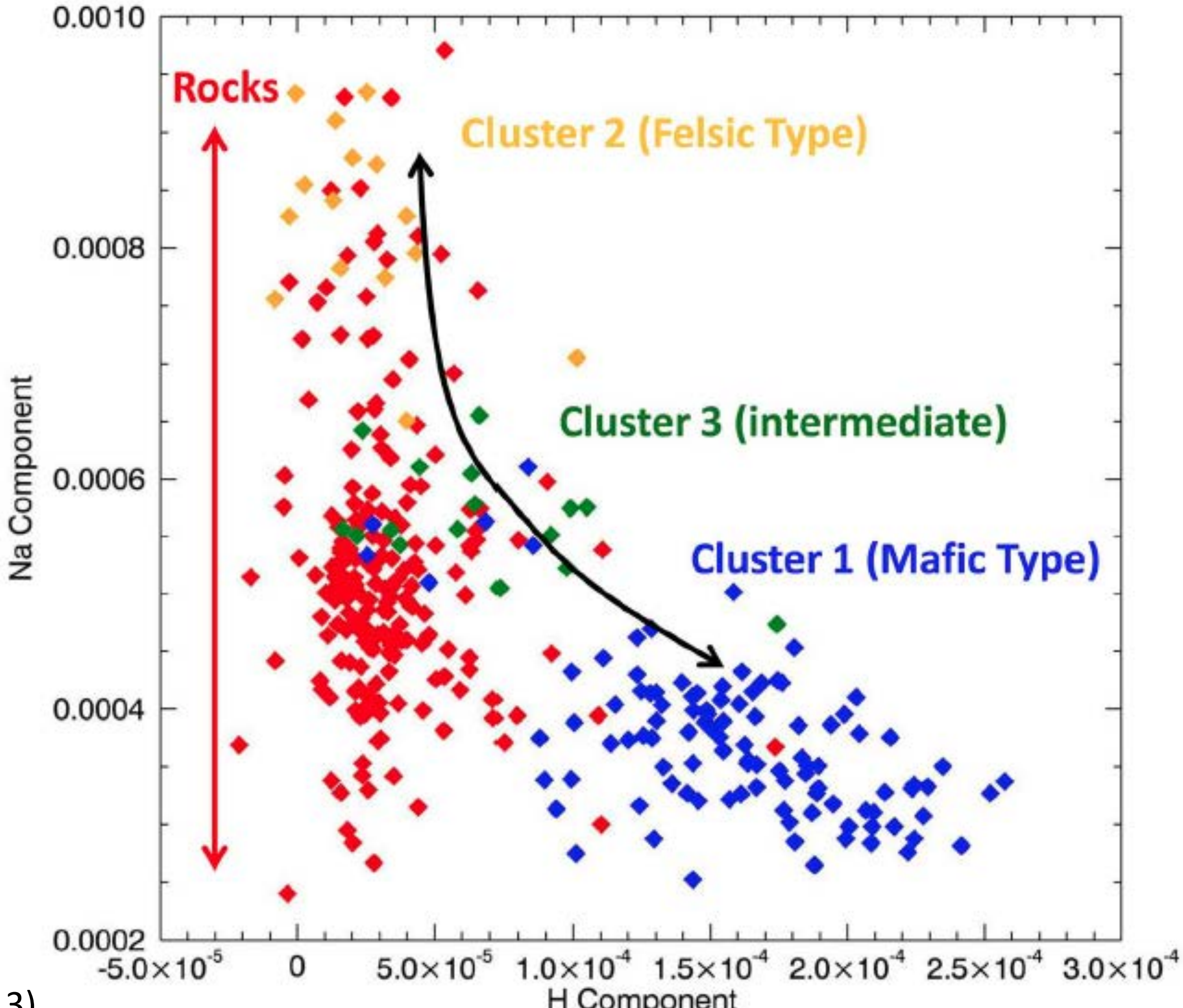
Composition is similar to alkaline basalts on Earth produced by partial melting of the mantle





NASA/JPL-Caltech/MSSS
LANL/IRAP/CNES/IAS/LPGN

Independent Components Analysis of LIBS data *from Mars*



Meslin et al. (2013)

Fig. 5. ICA classification of soils and rocks along Na and H components. A hydration trend from cluster 2 to cluster 1 soils and going through cluster 3 is observed, away from the rocks (the *x* and *y* axis represent the covariance between each of the spectra and the independent components) (*34*). It suggests mechanical mixing between fine hydrated particles and drier coarse grains.

Principal Components Analysis applied to LIBS

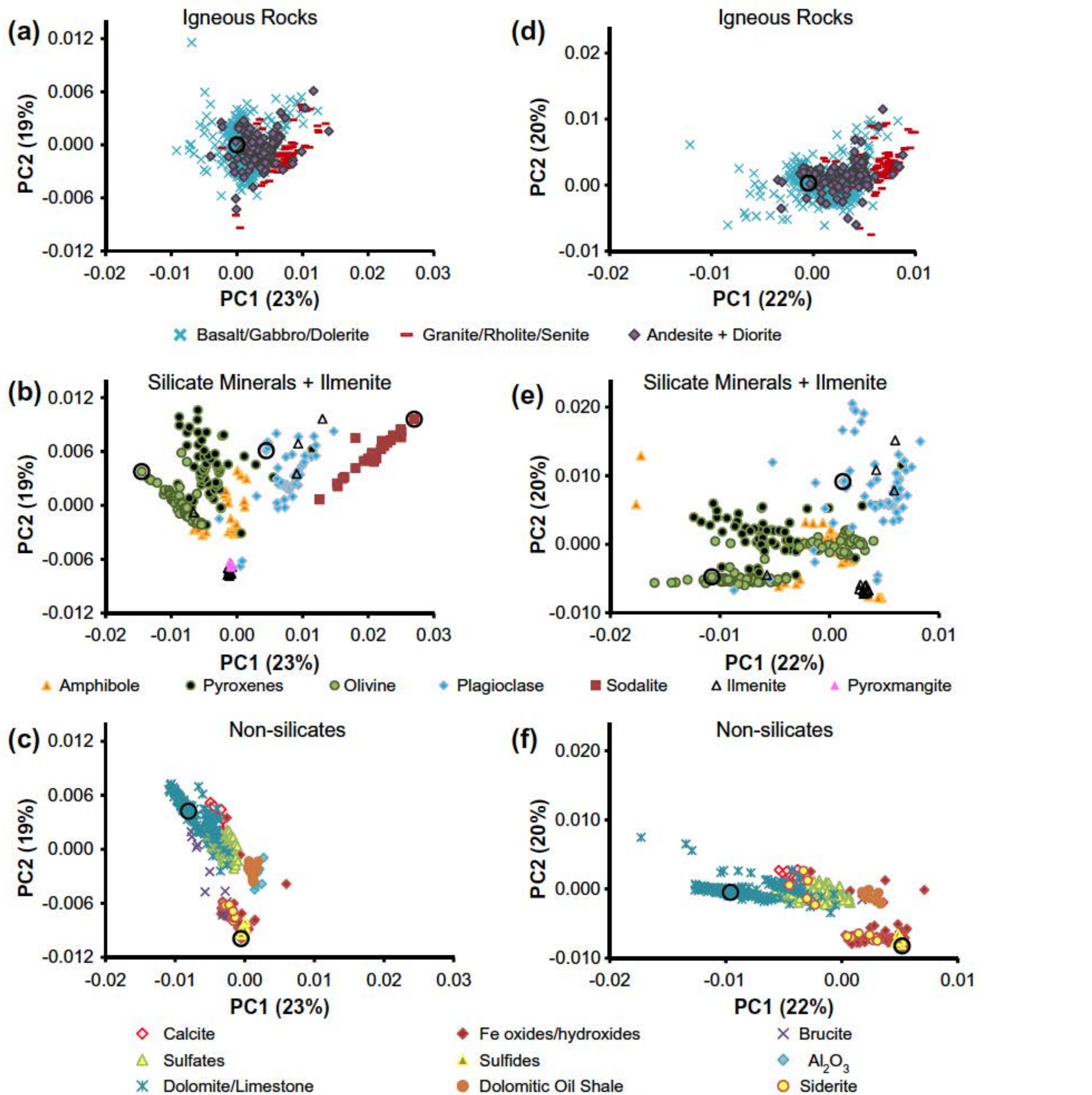
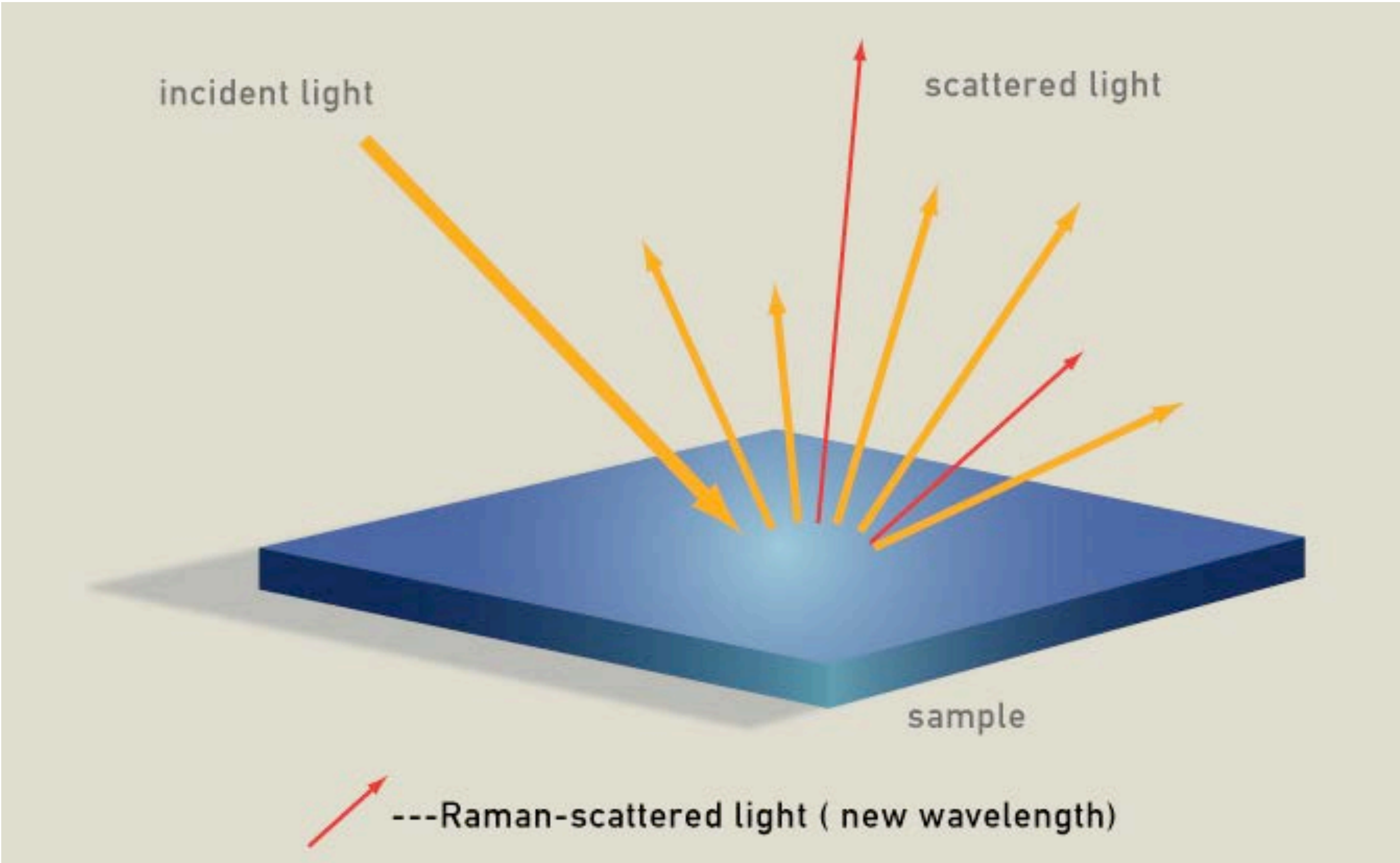


Fig. 3. Scatter plots of the first two principal components of the LIBS dataset. The percentage of total variance in the dataset explained by each component is indicated. Points have been color-coded according to the known sample type, and similar samples tend to cluster together. (a and d) Silicate rock samples. (b and e) Silicate minerals and ilmenite. Some of the samples classified as olivine contained calcium as well, causing them to form a separate cluster closer to pyroxenes in (e). (c and f) Non-silicates. For plots (d), (e) and (f) sodalite, pyroxmangite and synthetic Al_2O_3 were excluded from the PCA model. Refer to Fig. 4 for the spectral loadings for PC1 and PC2 in (a), (b) and (c). The circles in the scatterplot correspond to the spectra shown in Fig. 5. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

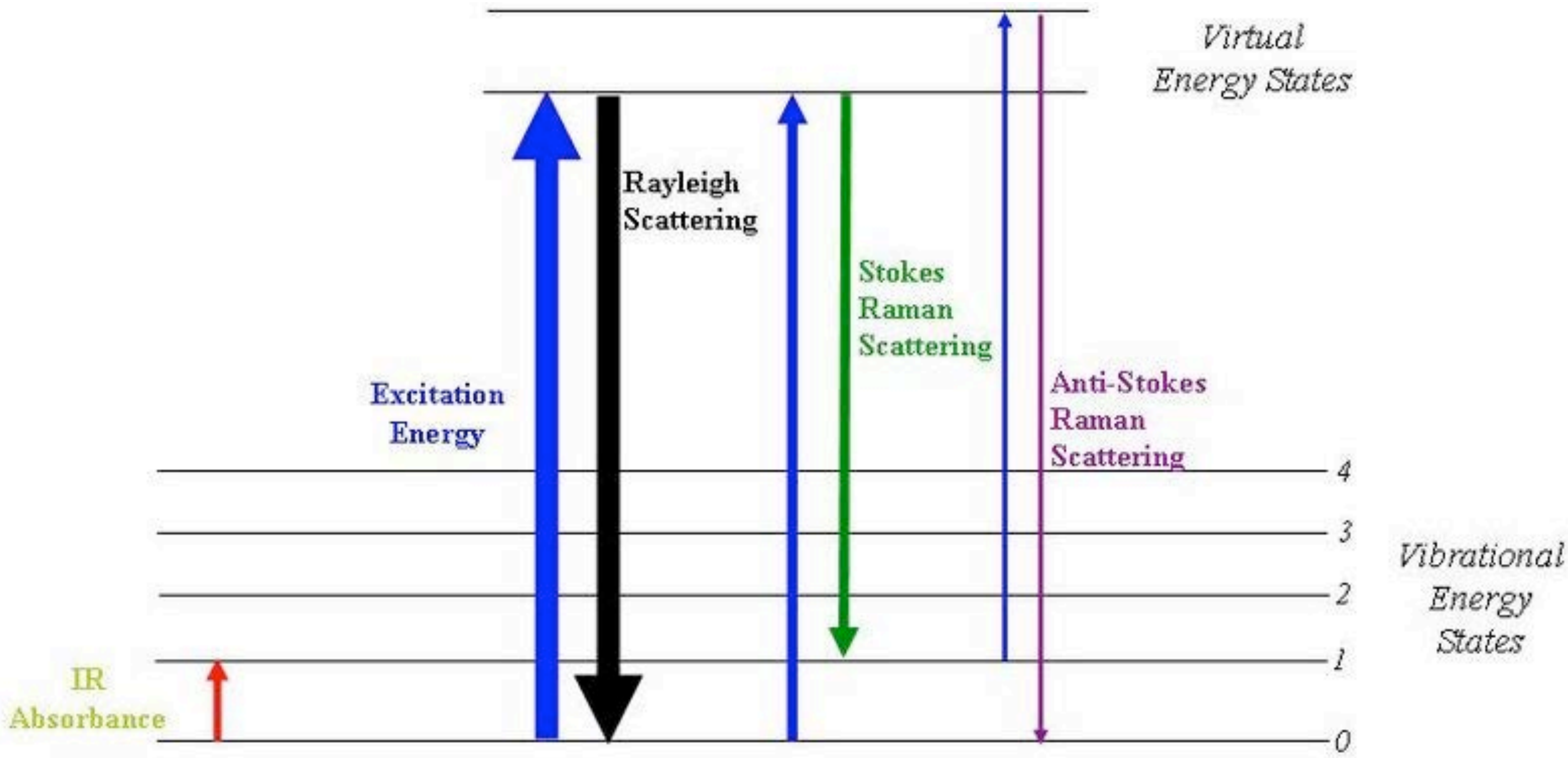
Anderson et al. (2011)

Raman Spectroscopy



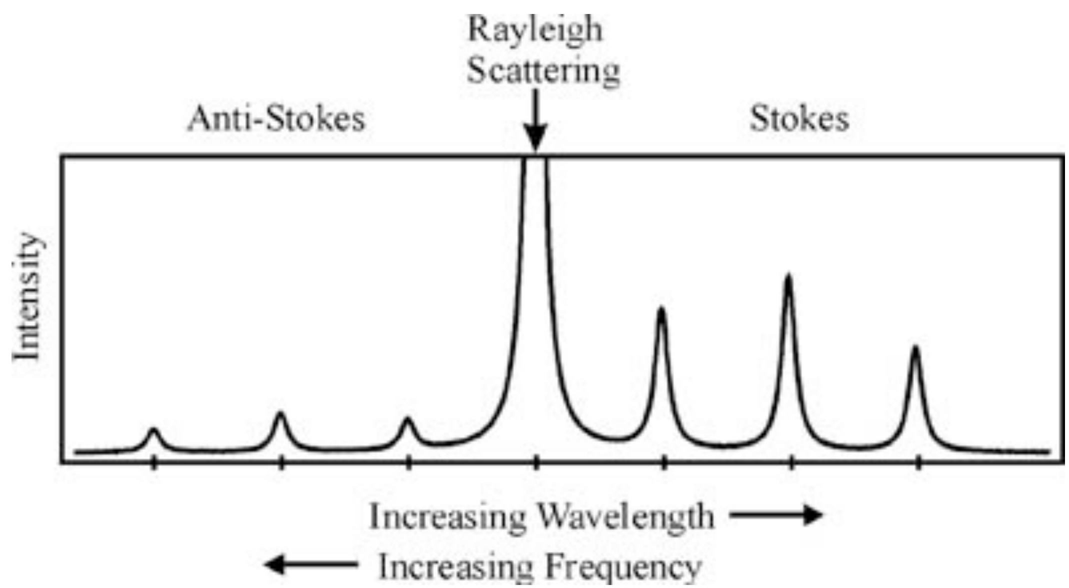
Active Remote Sensing of Mineralogy

Raman effect: inelastic photon scattering

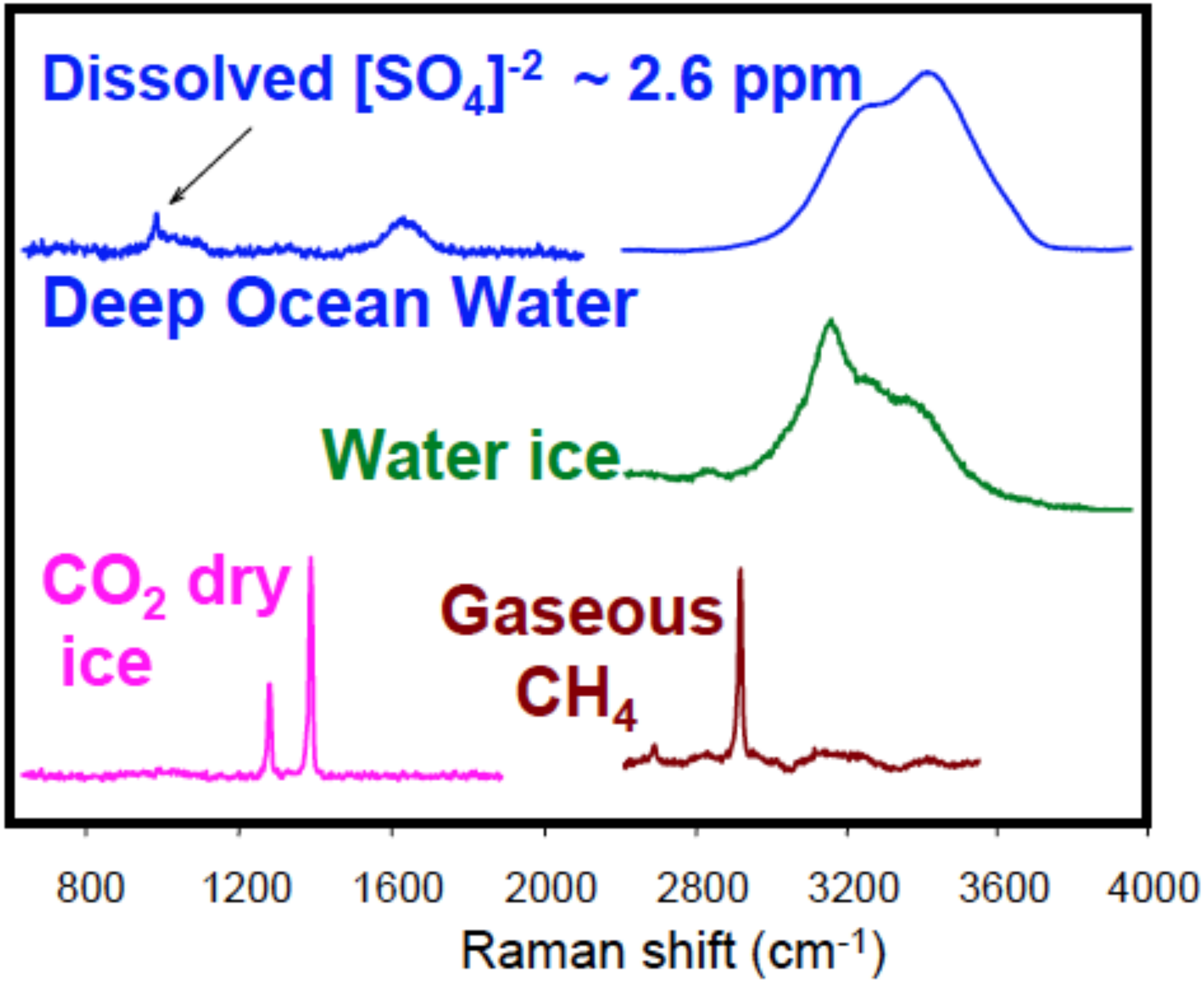


- Rayleigh-scattered photons ~10^7 times more abundant than Raman-scattered photons!
- Stokes > Anti-Stokes because excited states are minimally populated at room temperature

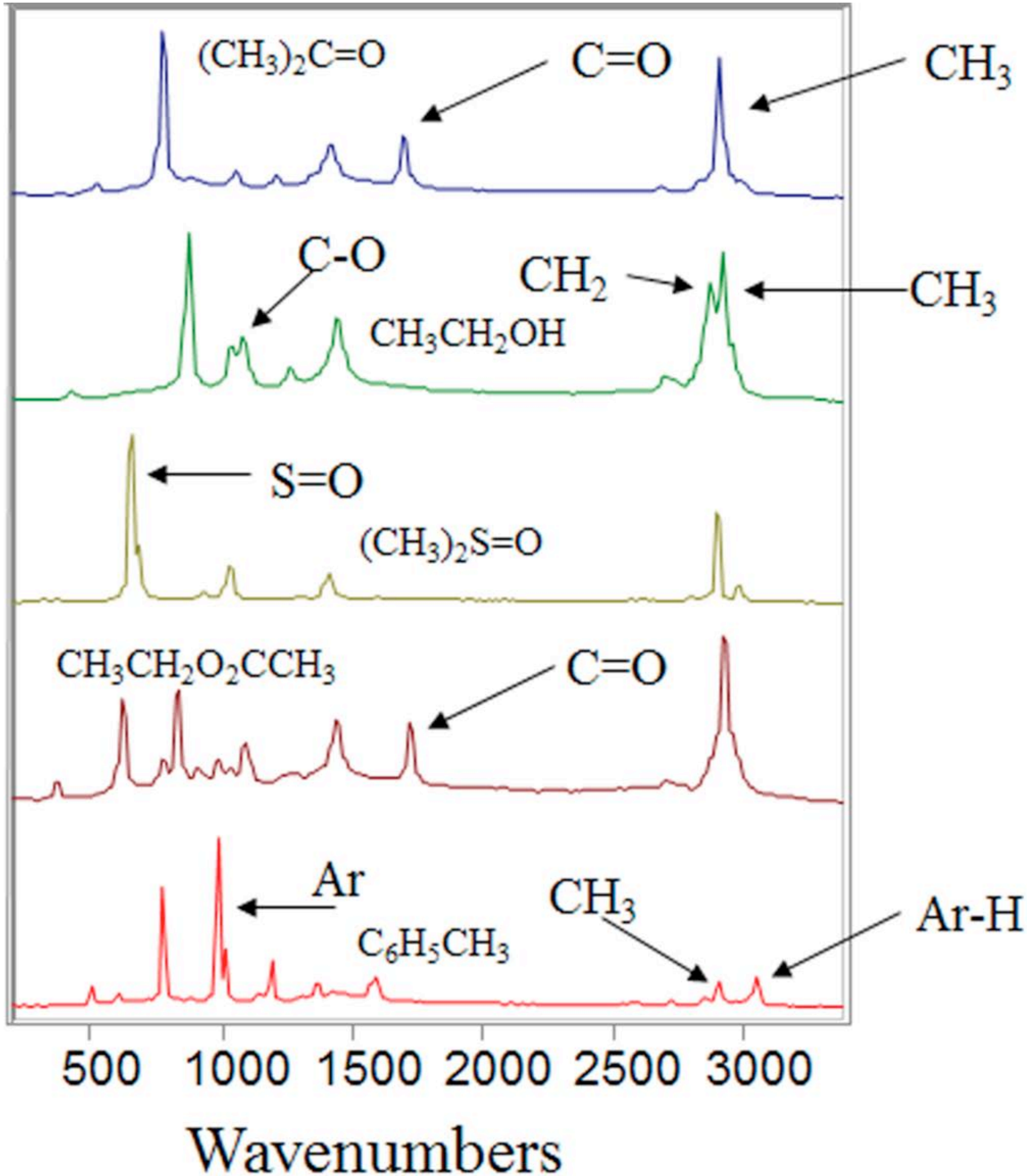
Raman: ***emission*** line spectroscopy



It's all about the ***shift***

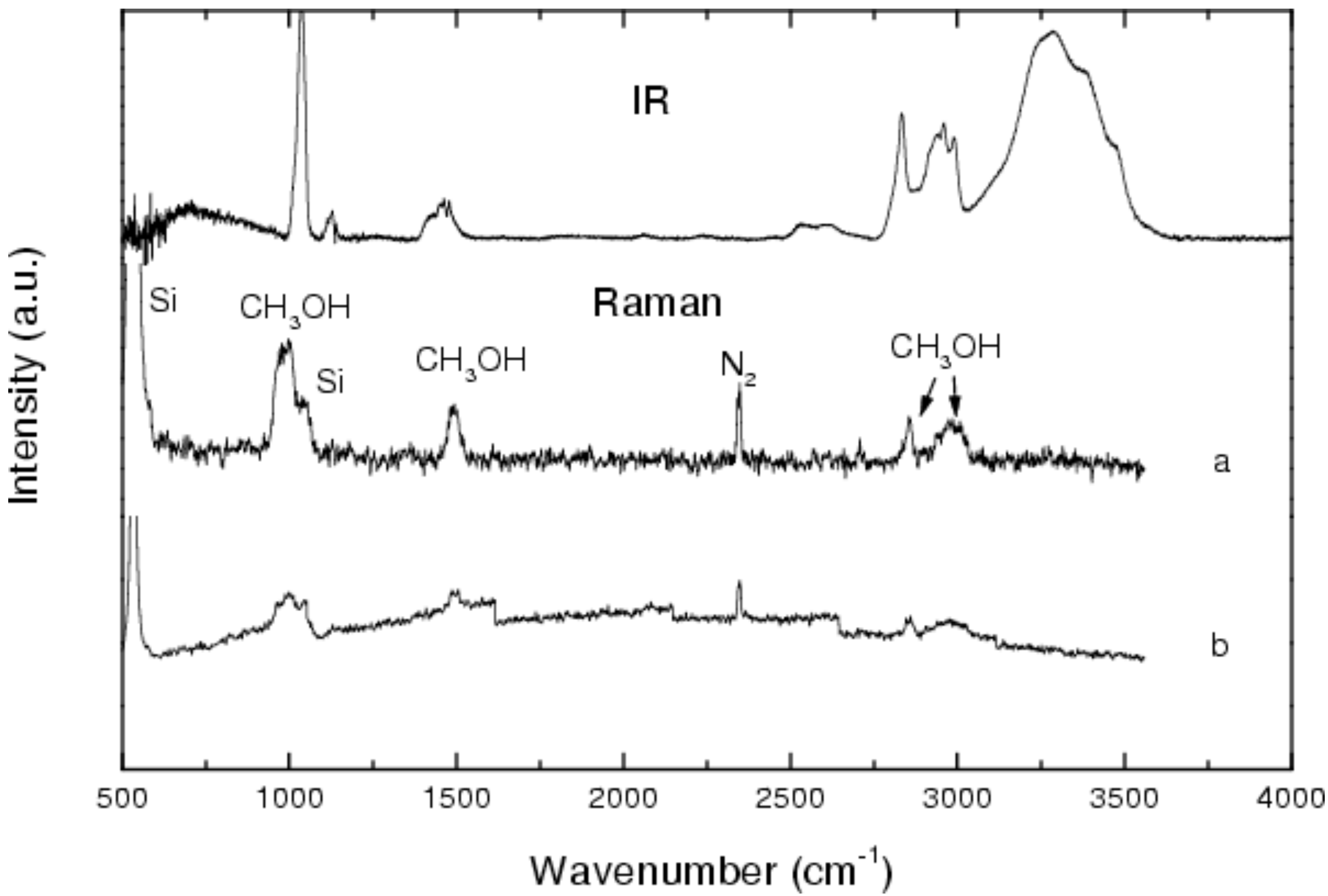


Organics



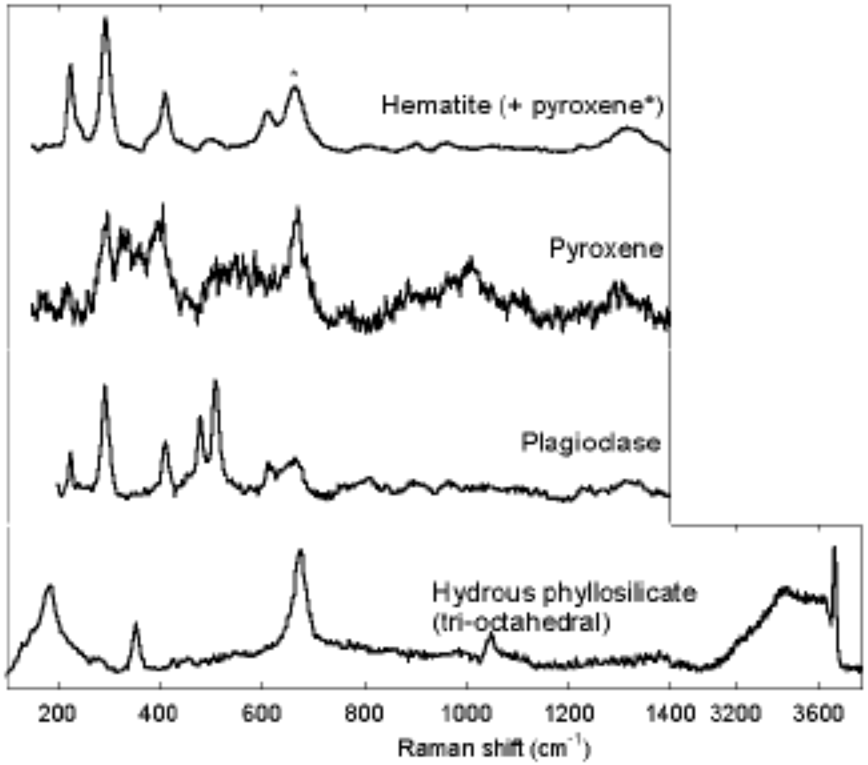
$(CH_3)_2C=O$
C=O
CH_3
C-O
CH_2
CH_3
CH_3CH_2OH
S=O
$(CH_3)_2S=O$
$CH_3CH_2O_2CCH_3$
C=O
Ar
CH_3
Ar-H
$C_6H_5CH_3$
500
1000
1500
2000
2500
3000
Wavenumbers

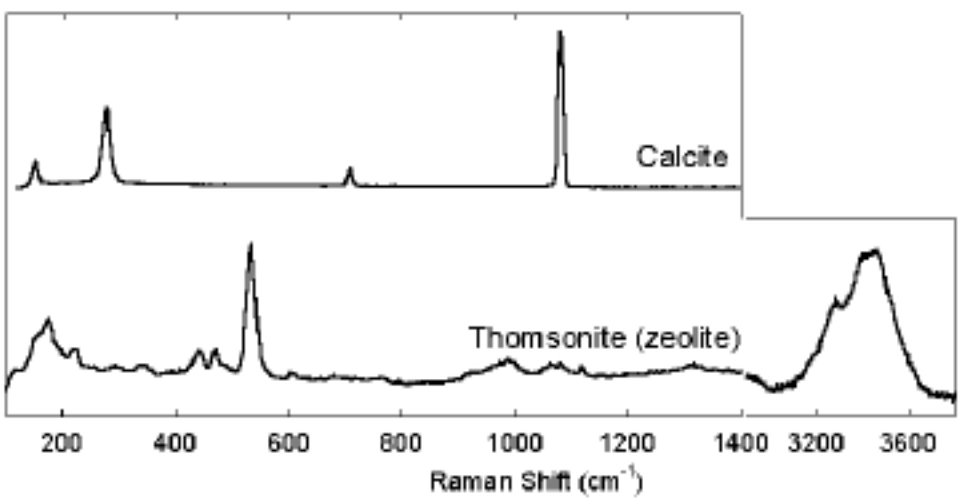
Raman vs. IR spectra: related but different



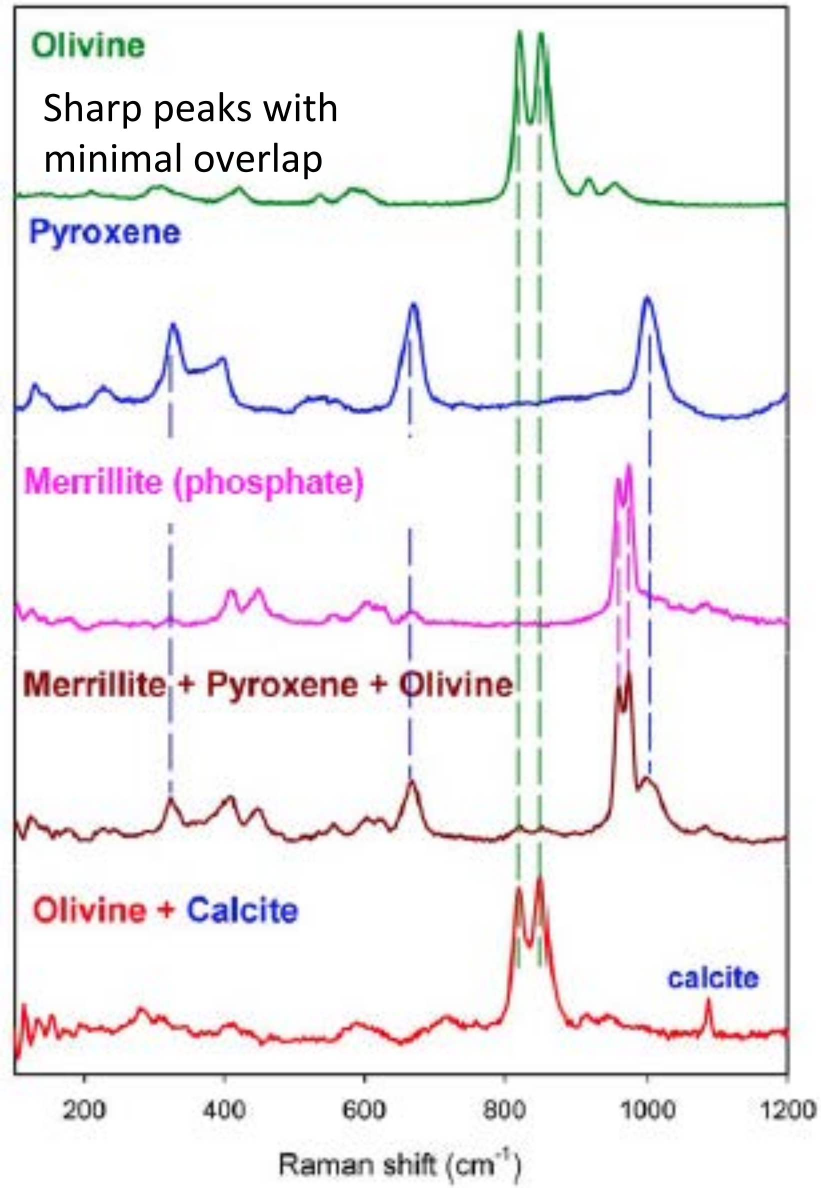
Ferini et al. (2004)

Can detect a range of minerals

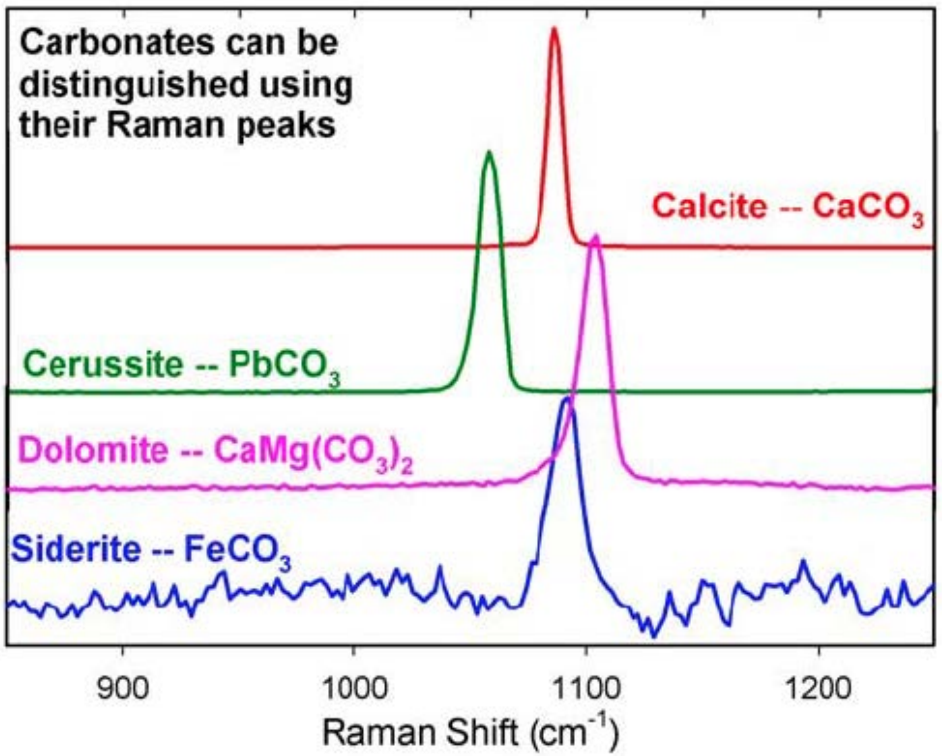


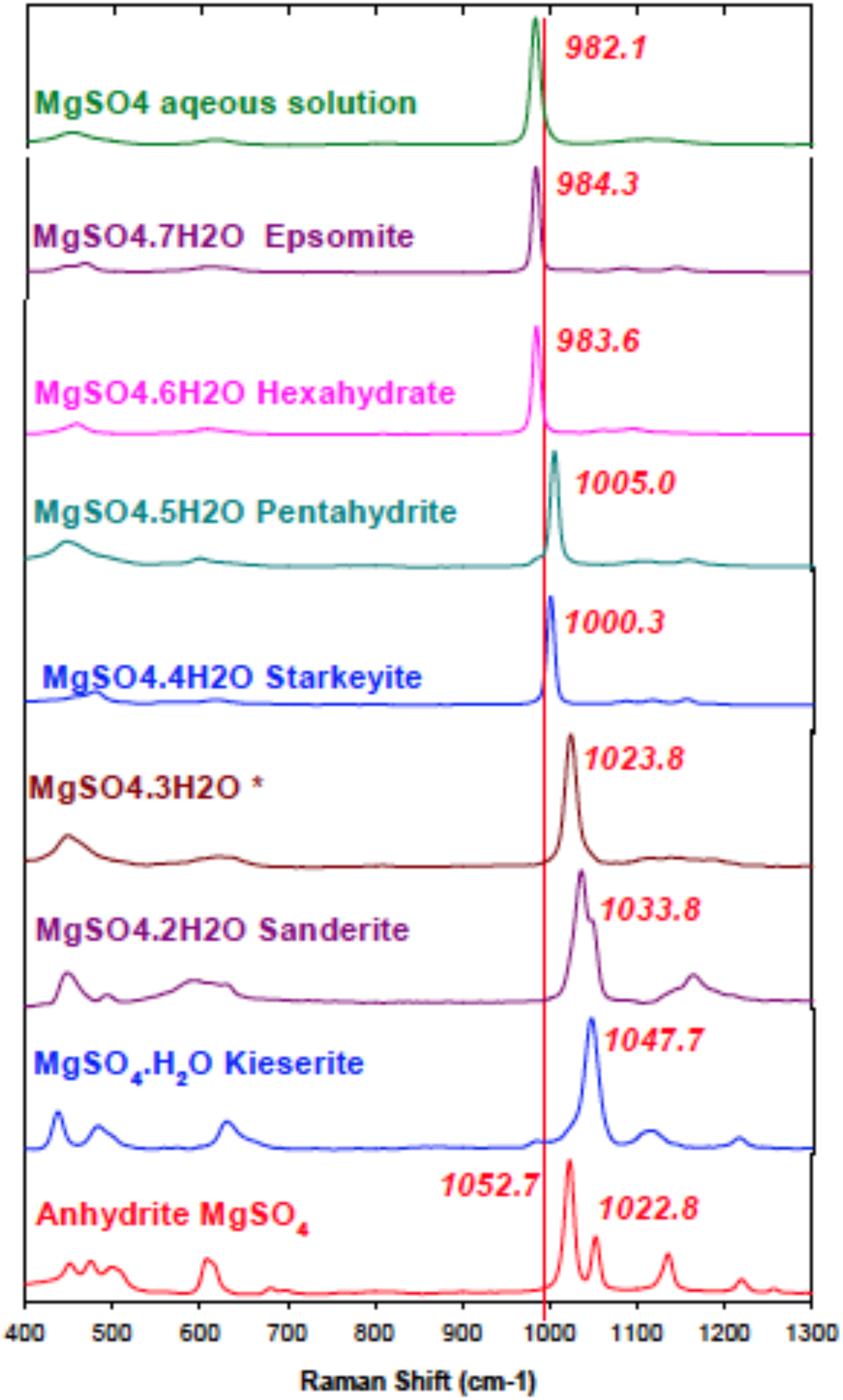


…and mixtures!



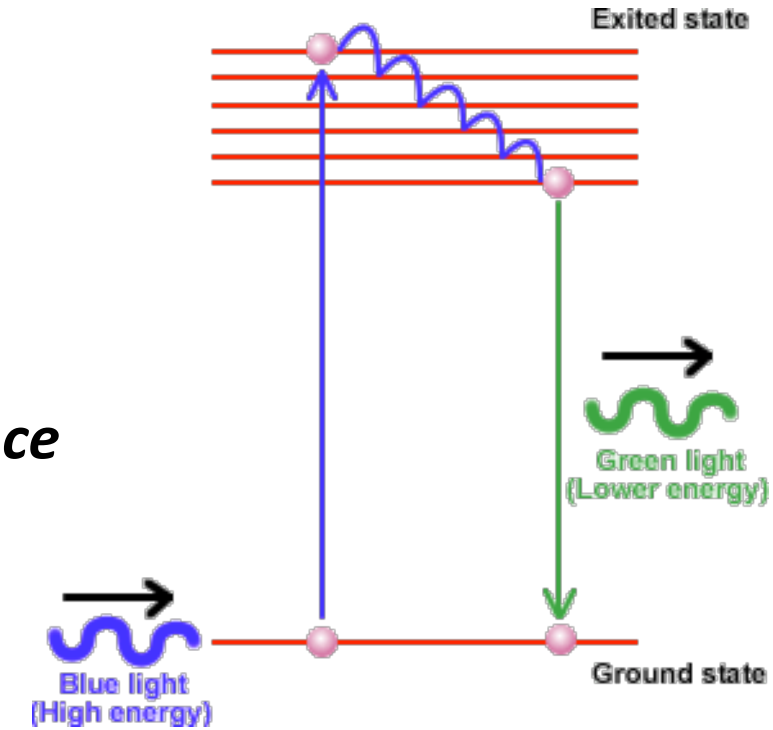
Peaks shift with chemistry and hydration state

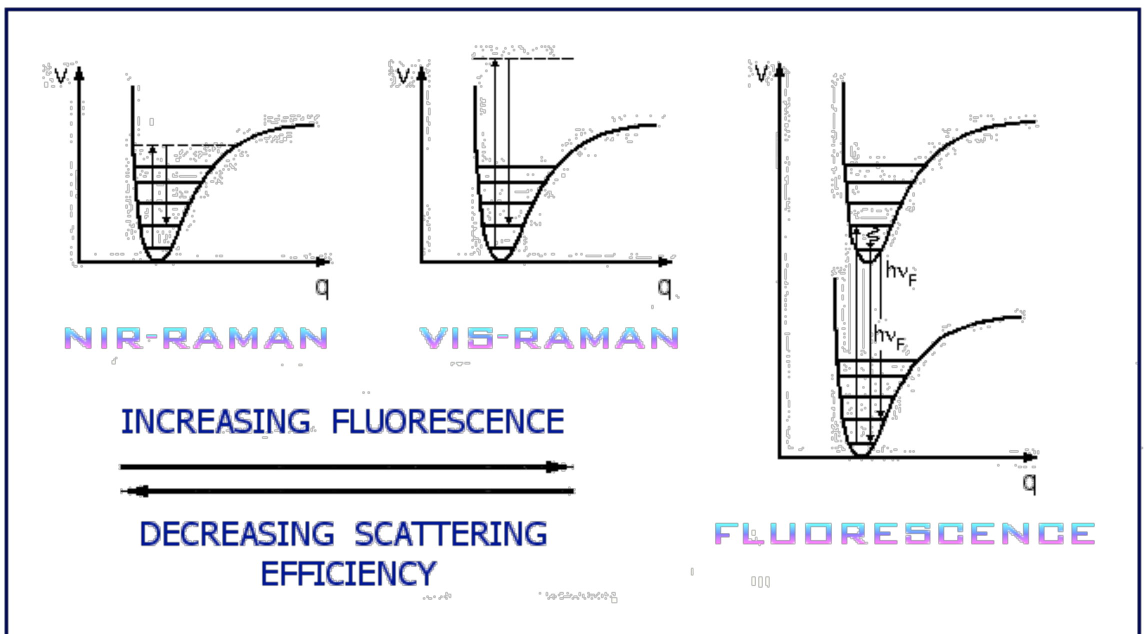




What laser λ to use?

- Scattered power proportional to $1/\lambda^4$
- But shorter λ also increases ***fluorescence***





Raman+LIBS: Chemical and mineralogical remote sensing with a single instrument!?

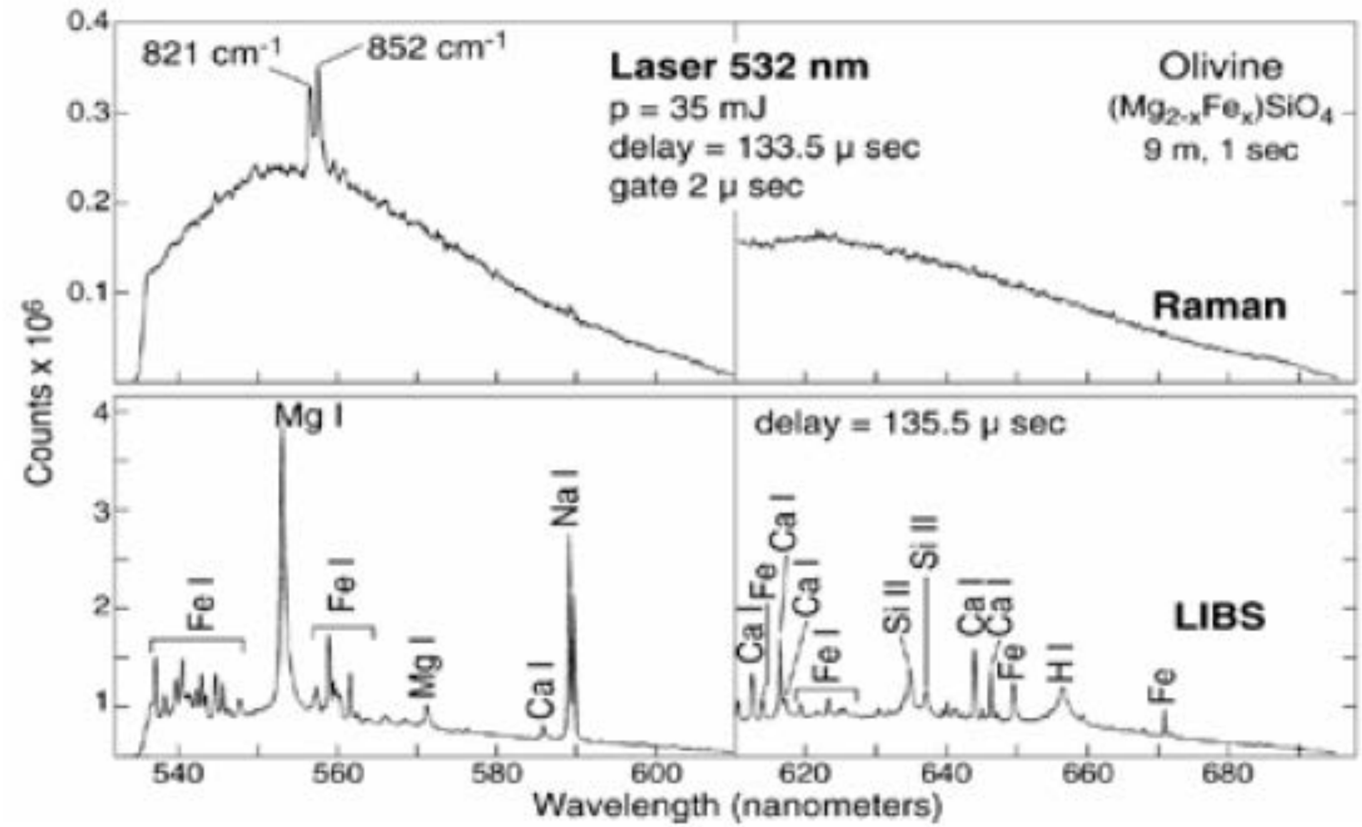


Fig. 2.Stand-off Raman spectrum (a) of olivine excited with 12 mJ/pulse, and LIBS spectrum (b) of olivine at 9 m excited with 532 nm pulse laser of p=35mJ/pulse. Spectra were recorded with 2 μs gate.

Wiens et al. (LPSC 2012)