Mineralogy

The basic building blocks

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How Many?

As of last night, there were 4635 recognized minerals

Olivine
Forsterite

Orthopyroxene
Enstatite

Perovskite
Perovskite

Sequence of Mineralogy

Condensation ~100

Primary Igneous Minerals – few 100's

Interaction with Water and CO_2 - 1000 +

Oxidation Reactions - 1000's

Metamorphism

USGS

Minerals From Condensation

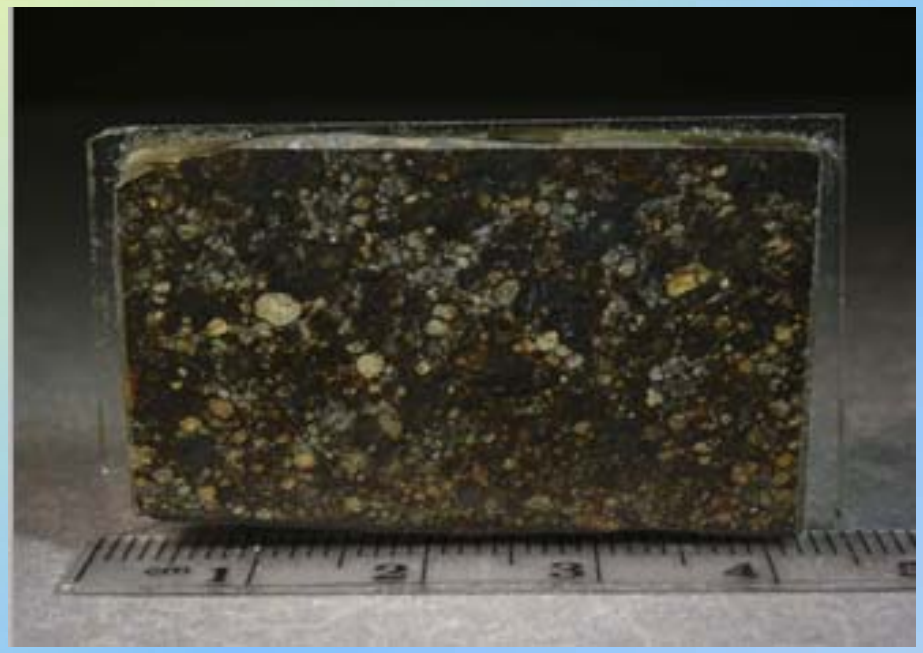
Graphite	C
Pt Metal Alloys	Pt,Os,Ir
Forsterite	Mg_2SiO_4
Perovskite	$CaTiO_3$
Corundum	Al_2O_3
Spinel	$MgAl_2O_4$
Hibonite	$CaAl_{12}O_{19}$
Moissanite	SiC
Khamrabaevite	TiC

Primitive

Condensation, Melting or Shock

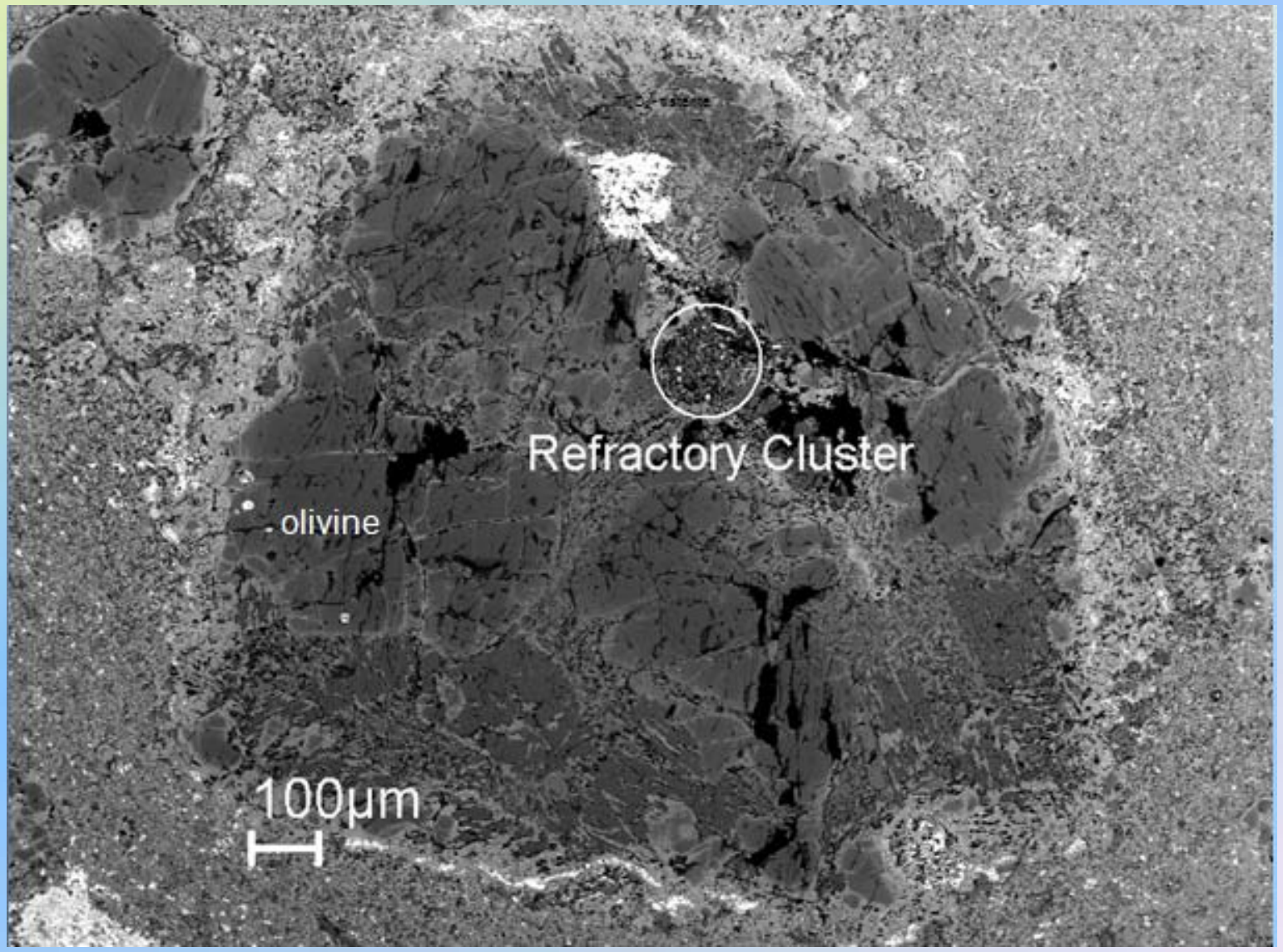
Forsterite	Mg_2SiO_4
Orthopyroxene	$(Mg,Fe)SiO_3$
Augite	$Ca(Mg,Fe,Al)(Si,Al)_2O_6$
Anorthite	$CaAl_2Si_2O_8$
Spinel	$MgAl_2O_4$
Magnetite	Fe_3O_4
Tridymite	SiO_2
Chromite	$FeCr_2O_4$
Ilmenite	$FeTiO_3$
Iron	(Fe,Ni)
Troilite	FeS
Fayalite	Fe_2SiO_4
Schreibersite	$(Fe,Ni)_3P$

Ordinary Chondrite



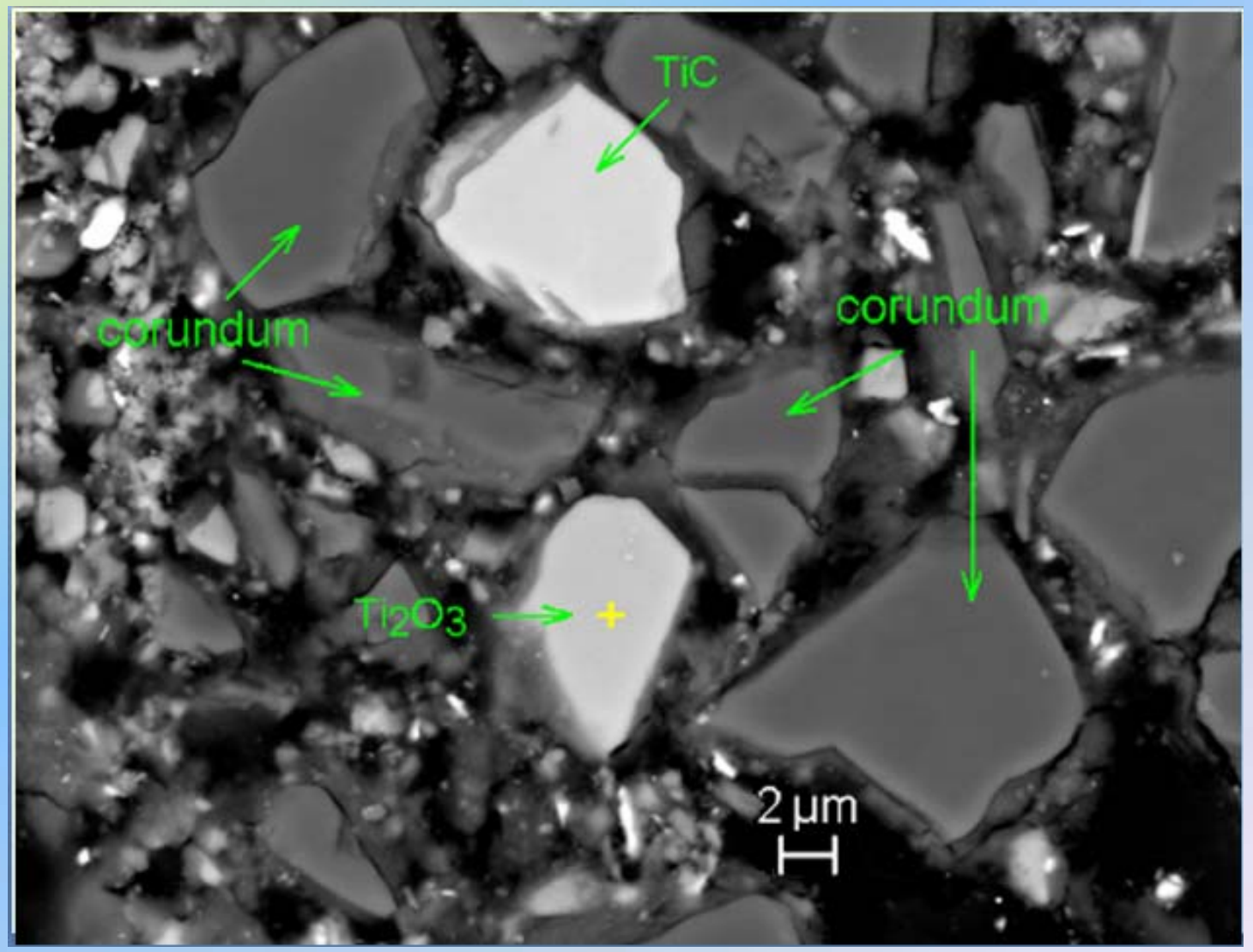
L3 - Barratta

The Minerals Can Be Tiny

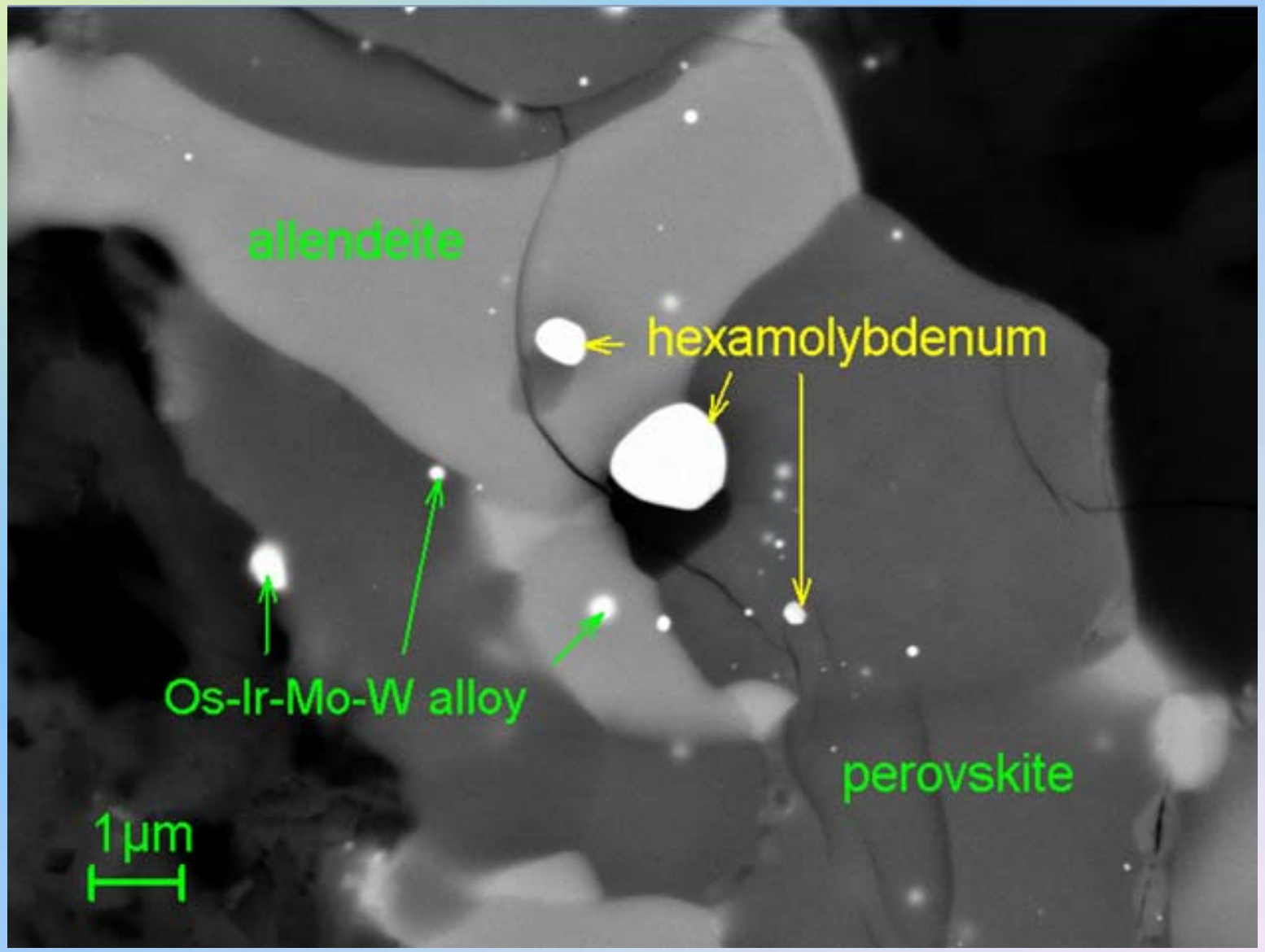


Allende

Tistarite – Ti_2O_3



Allendeite ($Sc_4Zr_3O_{12}$)



Igneous Minerals

Primary Igneous Minerals

Olivine Group	$(Mg, Fe)_2SiO_4$
Clinopyroxenes	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
Orthopyroxenes	$(Mg,Fe^{2+})_2Si_2O_6$
Feldspars	$CaAl_2Si_2O_8$ - $NaAlSi_3O_8$
Oxides	iron and titanium oxides
and many others	

Oxide Minerals

Oxides

Hematite	α-Fe_2O_3	hexagonal
Maghemite	γ-Fe_2O_3	cubic
goethite	α-FeO(OH)	orthorhombic
lepidocrocite	γ-FeO(OH)	orthorhombic

goethite

lepidocrocite

Carbonate Minerals

Carbonate Minerals

Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Magnesite	$MgCO_3$
Ankerite	$Ca(Fe^{2+},Mg)(CO_3)_2$
Siderite	$Fe^{2+}CO_3$

Complex Carbonates

Artenite	$Mg_2CO_3(OH)_2 \cdot 3H_2O$
Coalingite	$Mg_{10}Fe_2(CO_3)(OH)_{24} \cdot 2(H_2O)$

Sulphate Minerals

Sulphates

Jarosite group $(H_3O^+, K, Na)_2Fe^{3+}{}_6(SO_4)_4(OH)_{12}$

Magnesium sulfates $MgSO_4 \cdot nH_2O$ cementing agent

Epsomite	$MgSO_4 \cdot 7H_2O$
Hexahydrite	$MgSO_4 \cdot 6H_2O$
Pentahydrite	$MgSO_4 \cdot 5H_2O$
Starkeyite	$MgSO_4 \cdot 4H_2O$
Sanderite	$MgSO_4 \cdot 2H_2O$
Kieserite	$MgSO_4 \cdot H_2O$
Amorphous	$MgSO_4 \cdot nH_2O$

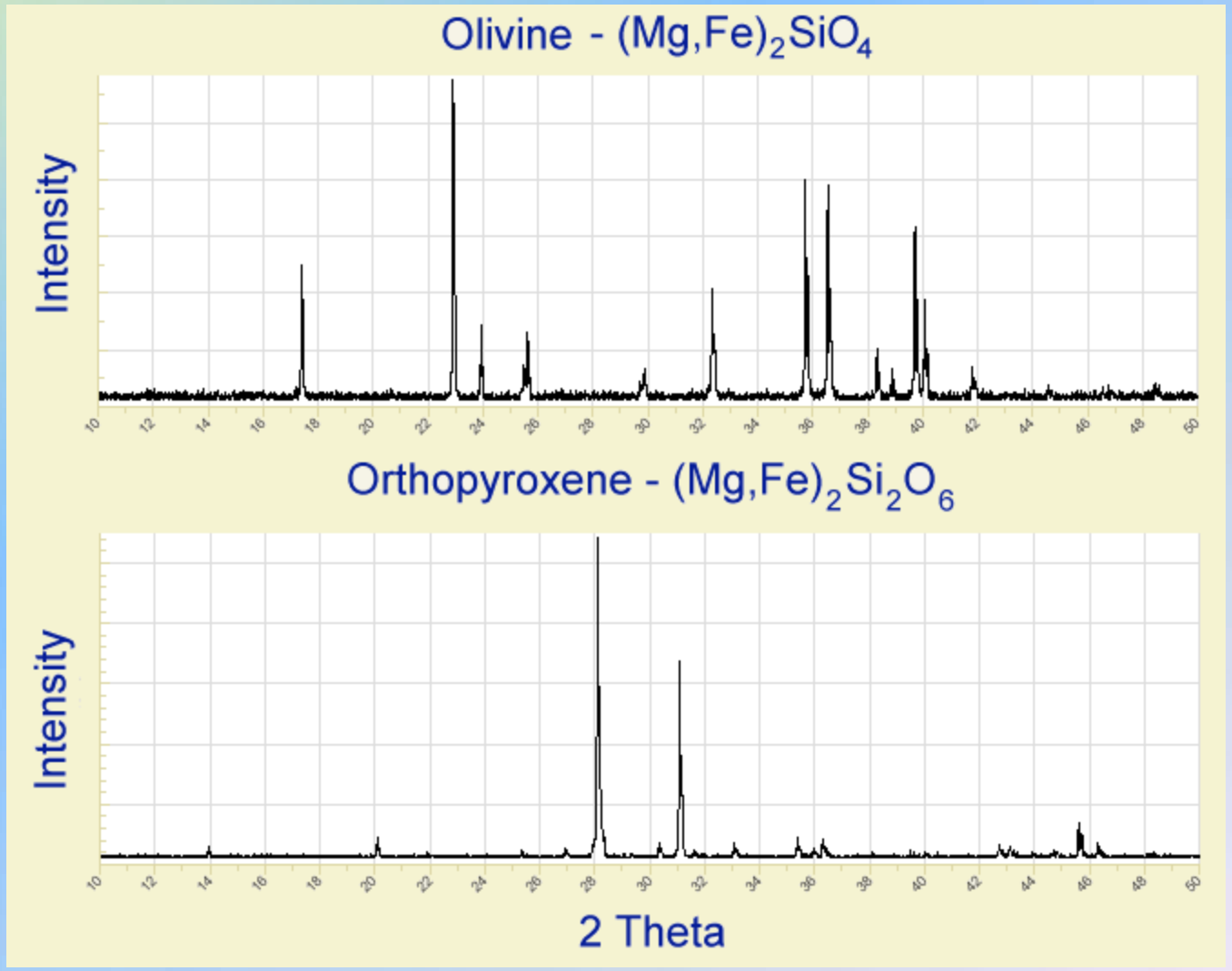
Clay Minerals

Clay Minerals - indicate reaction with water

They are layer silicates

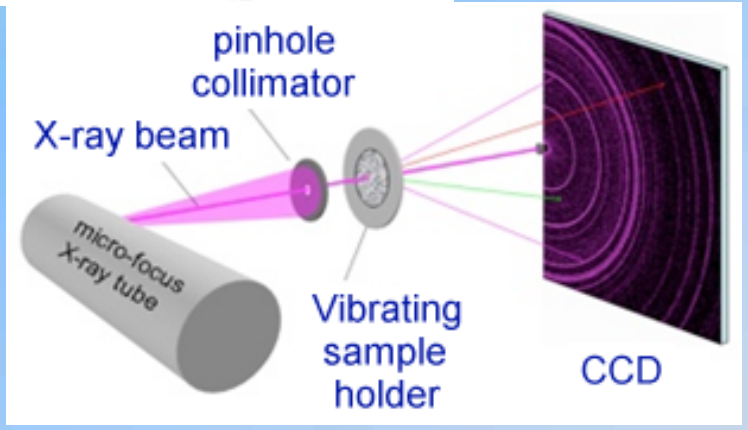
There are many mineral species

Minerals are Defined by XRD and Composition



Minerals are Defined by XRD and Composition

CheMin Enroute to Mars



Mars-XRD Prototype

^{55}Fe self-emitting X-ray source prototype
European Space Agency

Other Ways to Identify Minerals

Chemical Composition - not sufficient by itself

Spectroscopic Methods

Infrared – proven in space

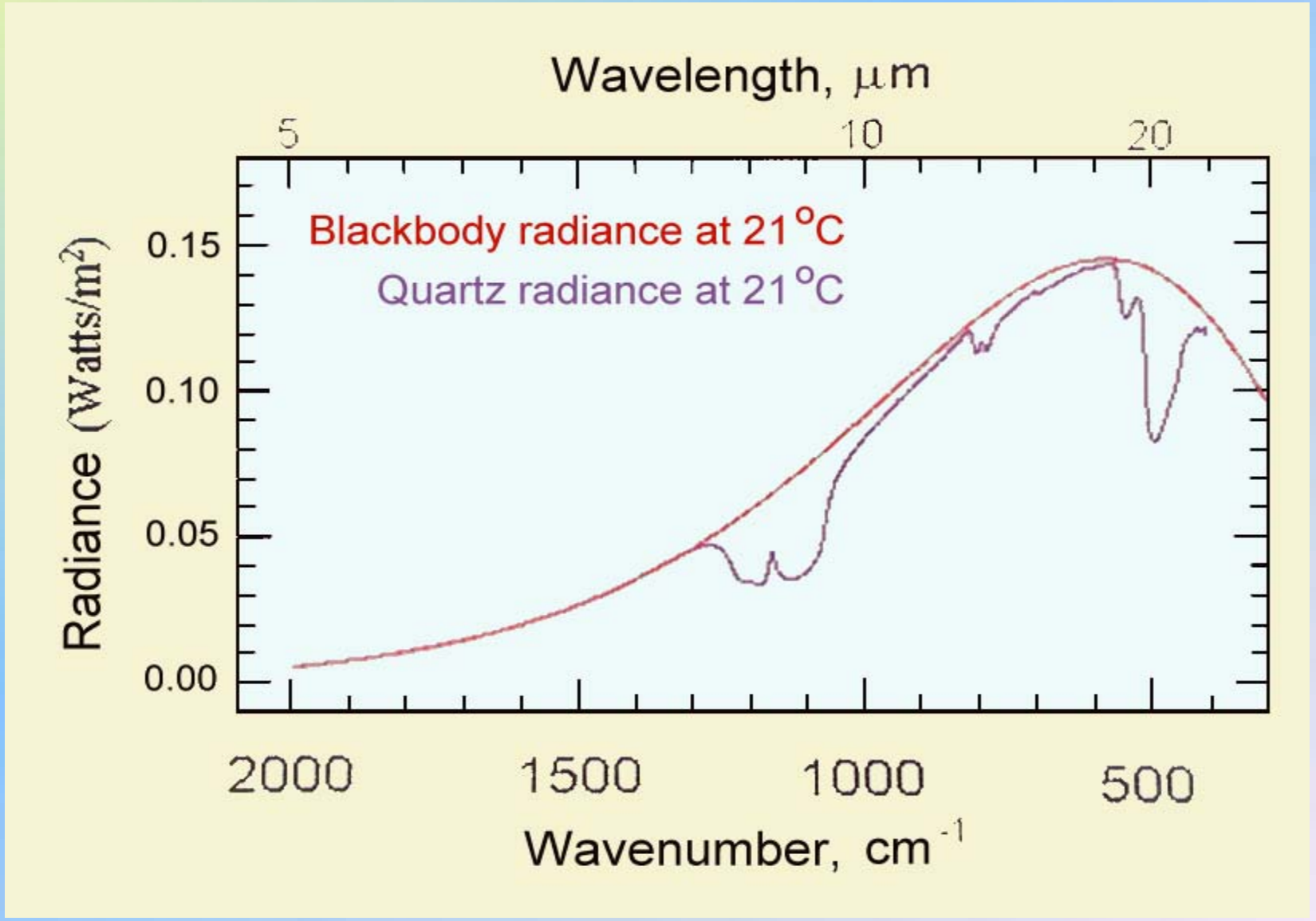
Raman - proven in the lab

Mössbauer - limited to Fe

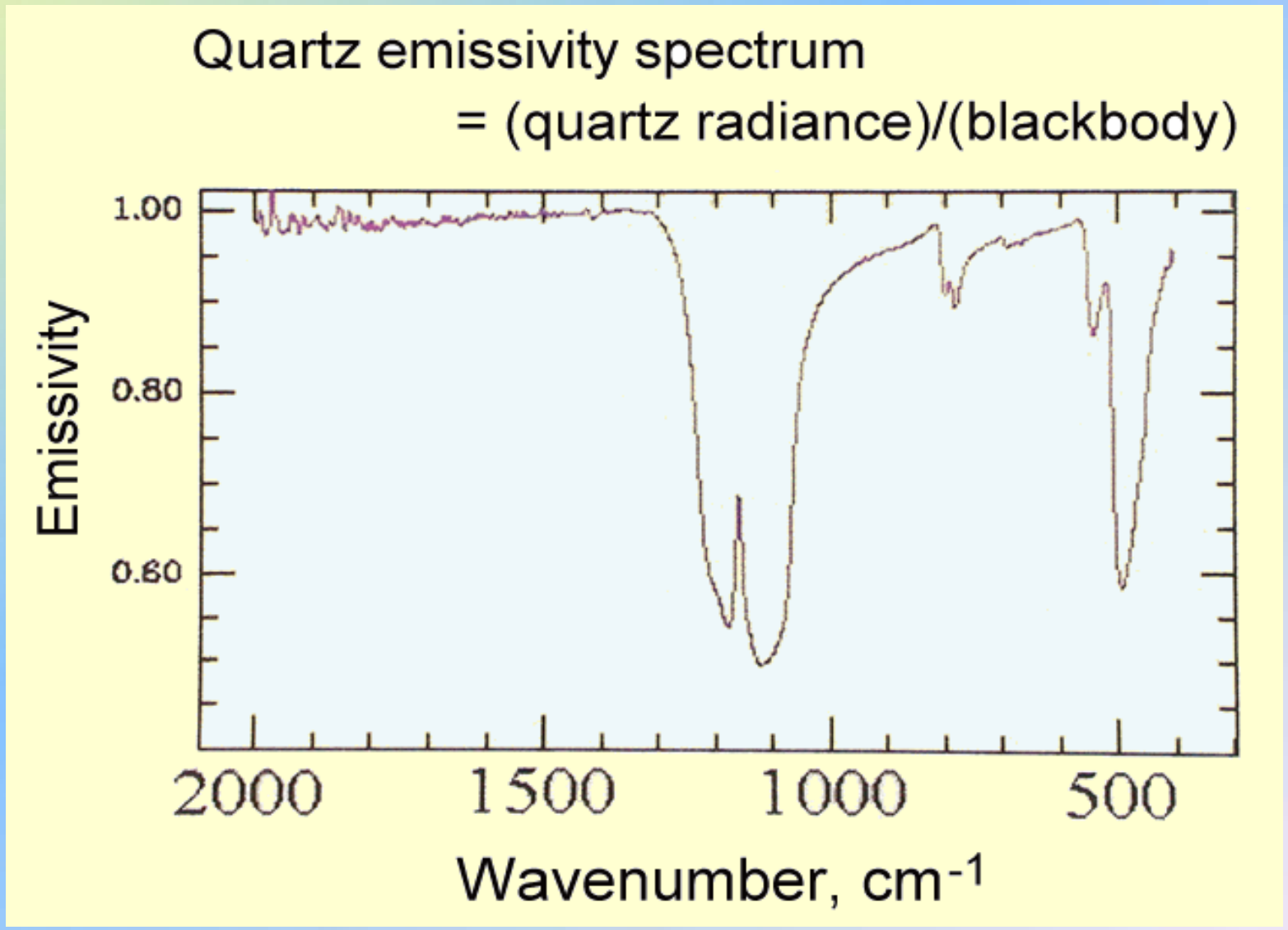
EPR - many limitations

Magnetic Properties – limited to Fe

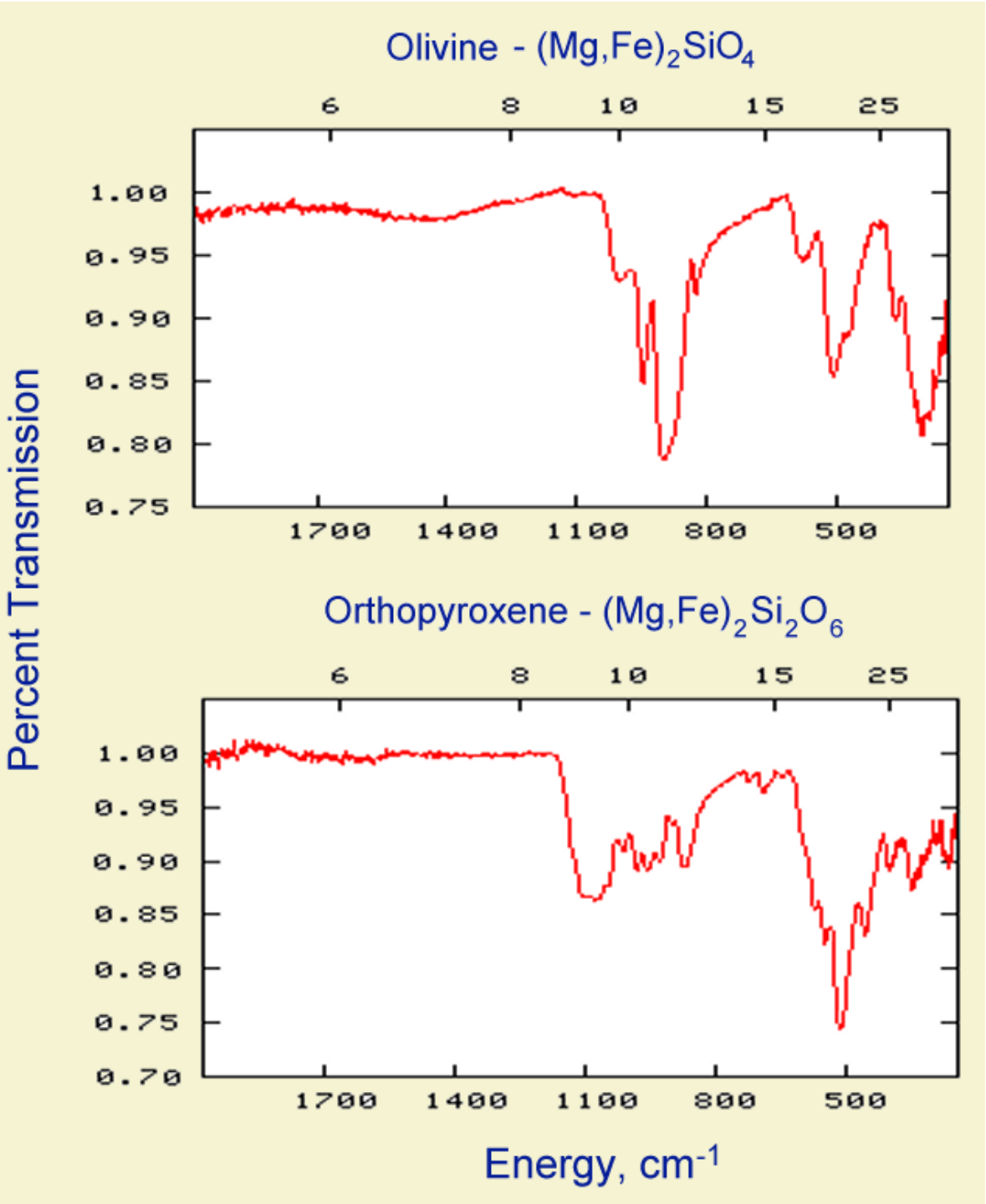
Thermal Emission Spectra



Thermal Emission

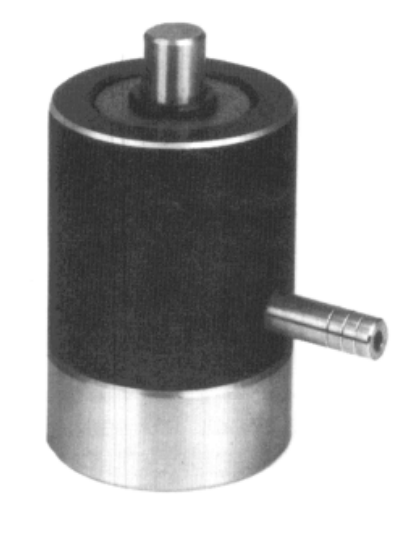


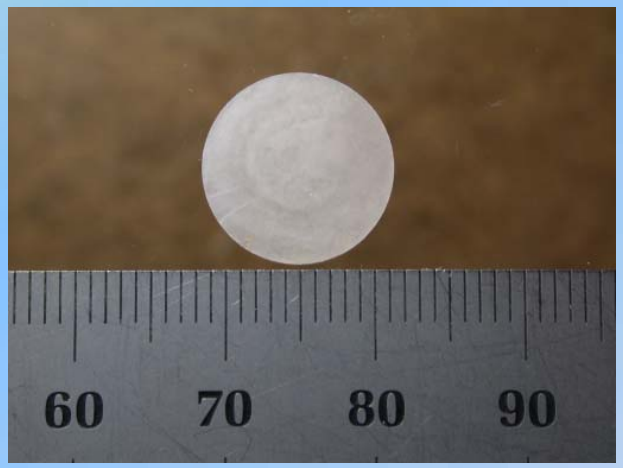
Thermal Emission Spectra



ASU Spectral Library

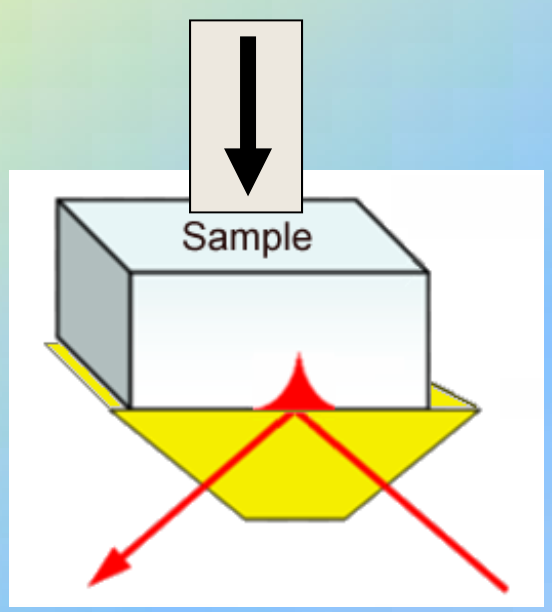
Infrared Spectra – the old way



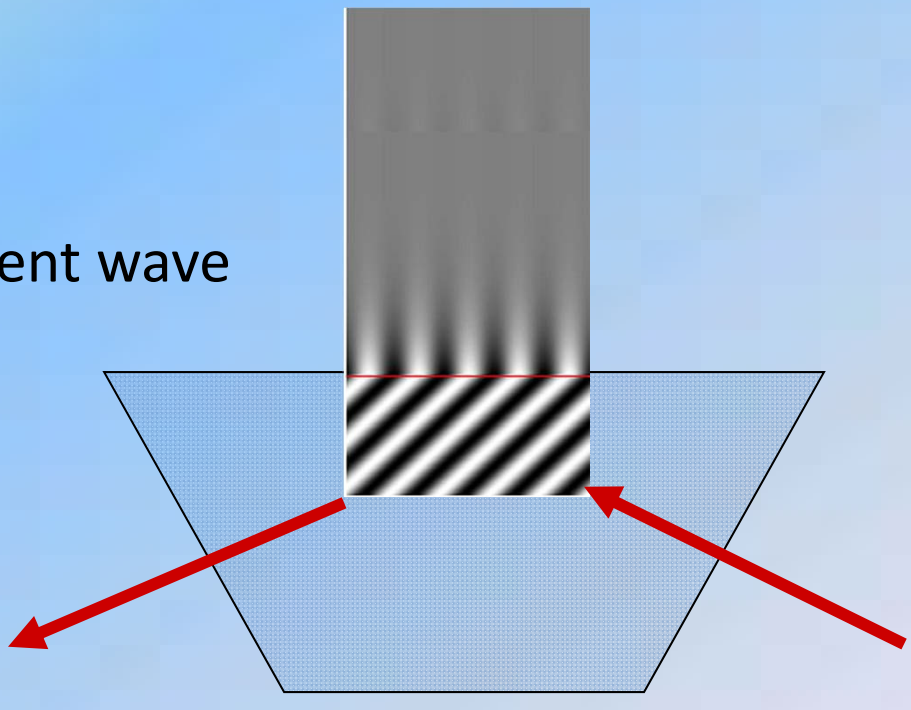


KBr pellets

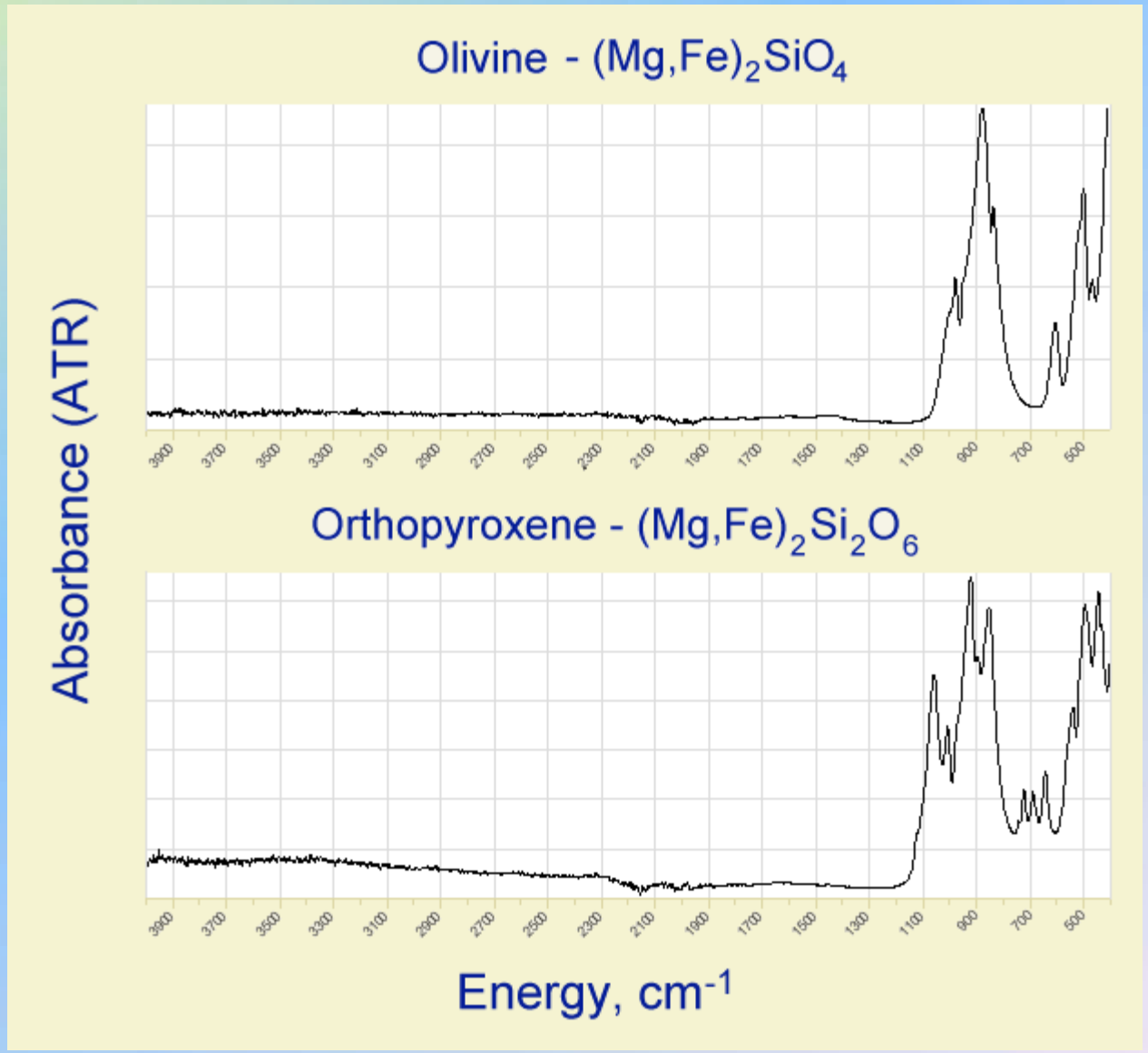
ATR: Attenuated Total Reflectance



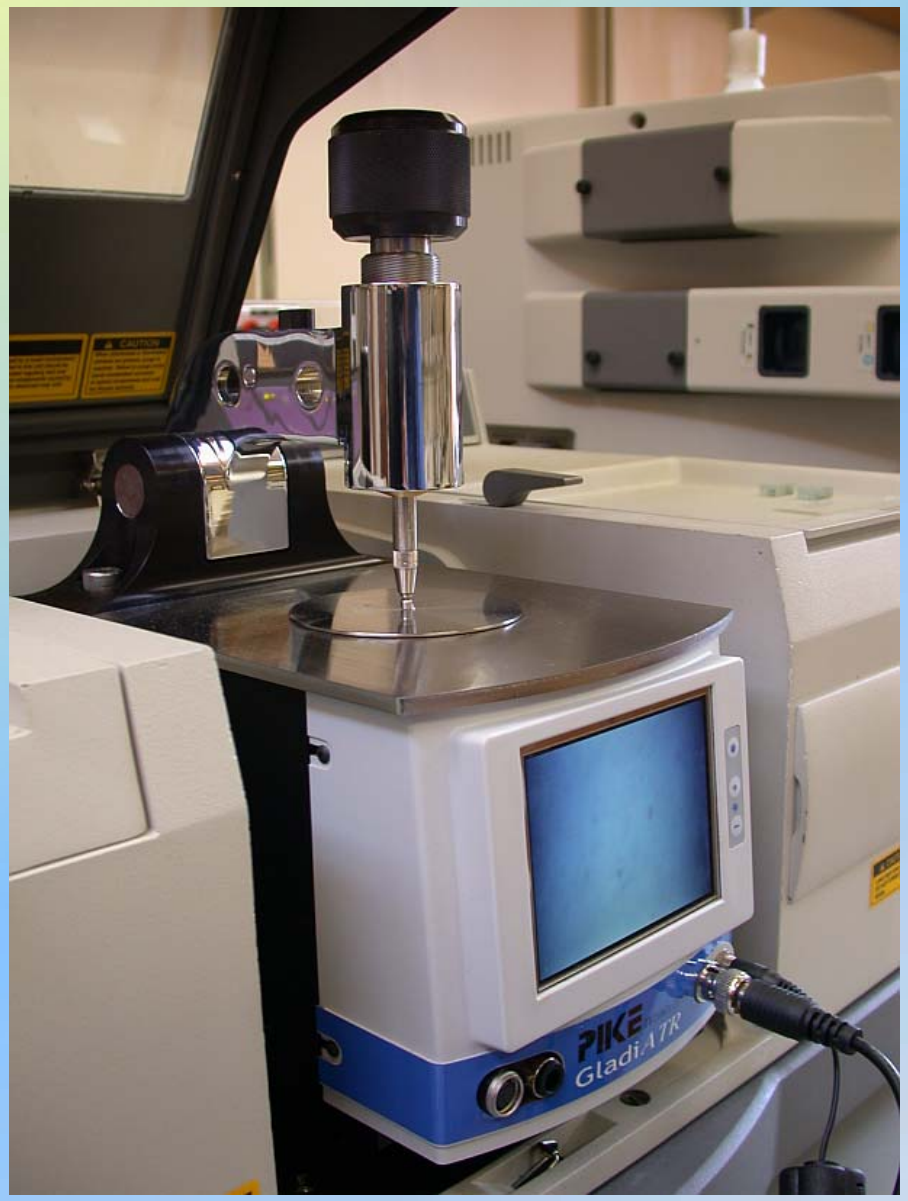
evanescent wave



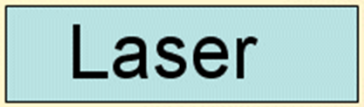
Infrared Spectra (ATR)



ATR: Attenuated Total Reflectance



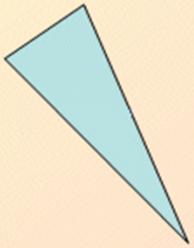
Raman Spectroscopy



Sample

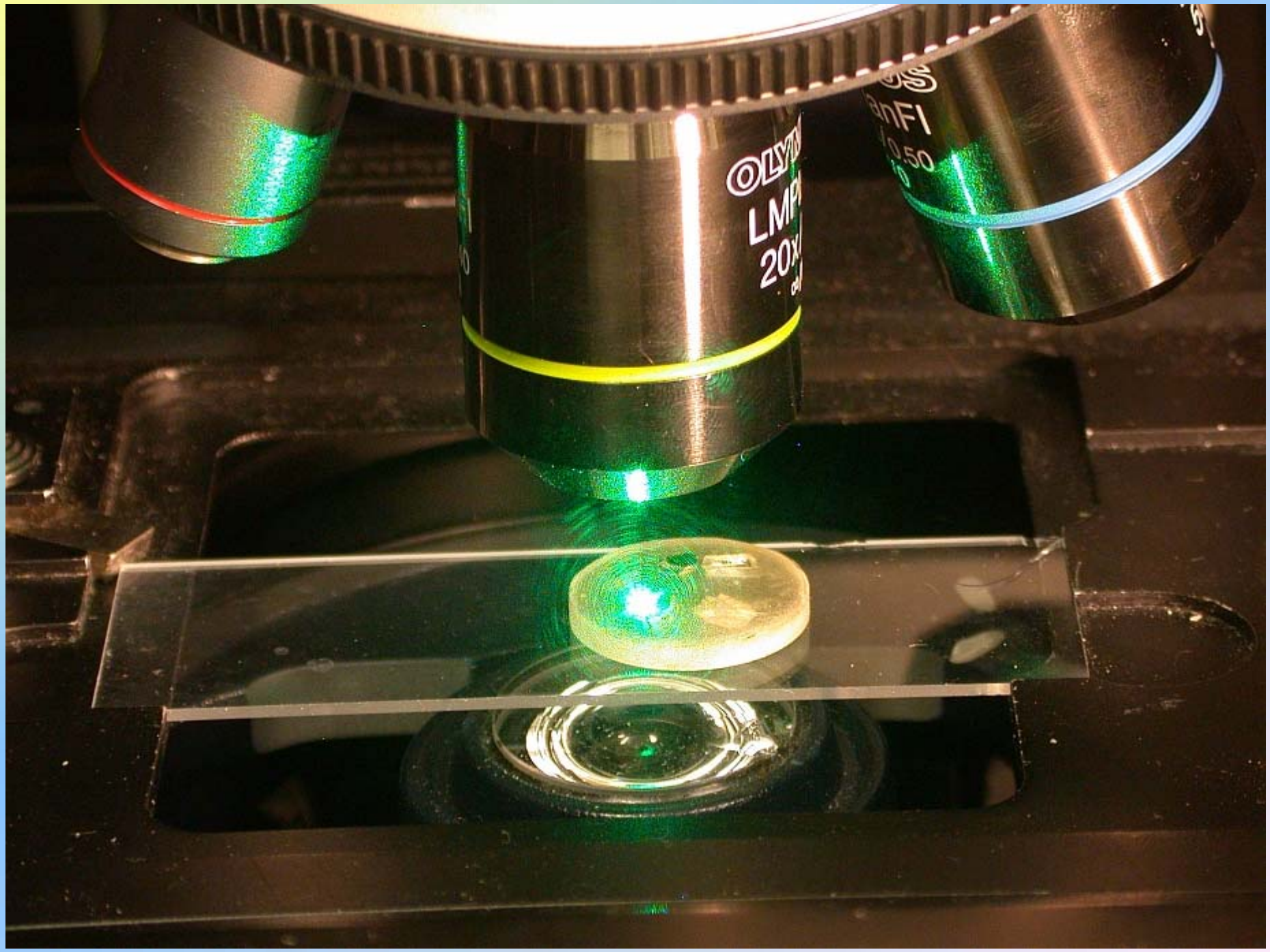
Spectrometer

Magic Filter

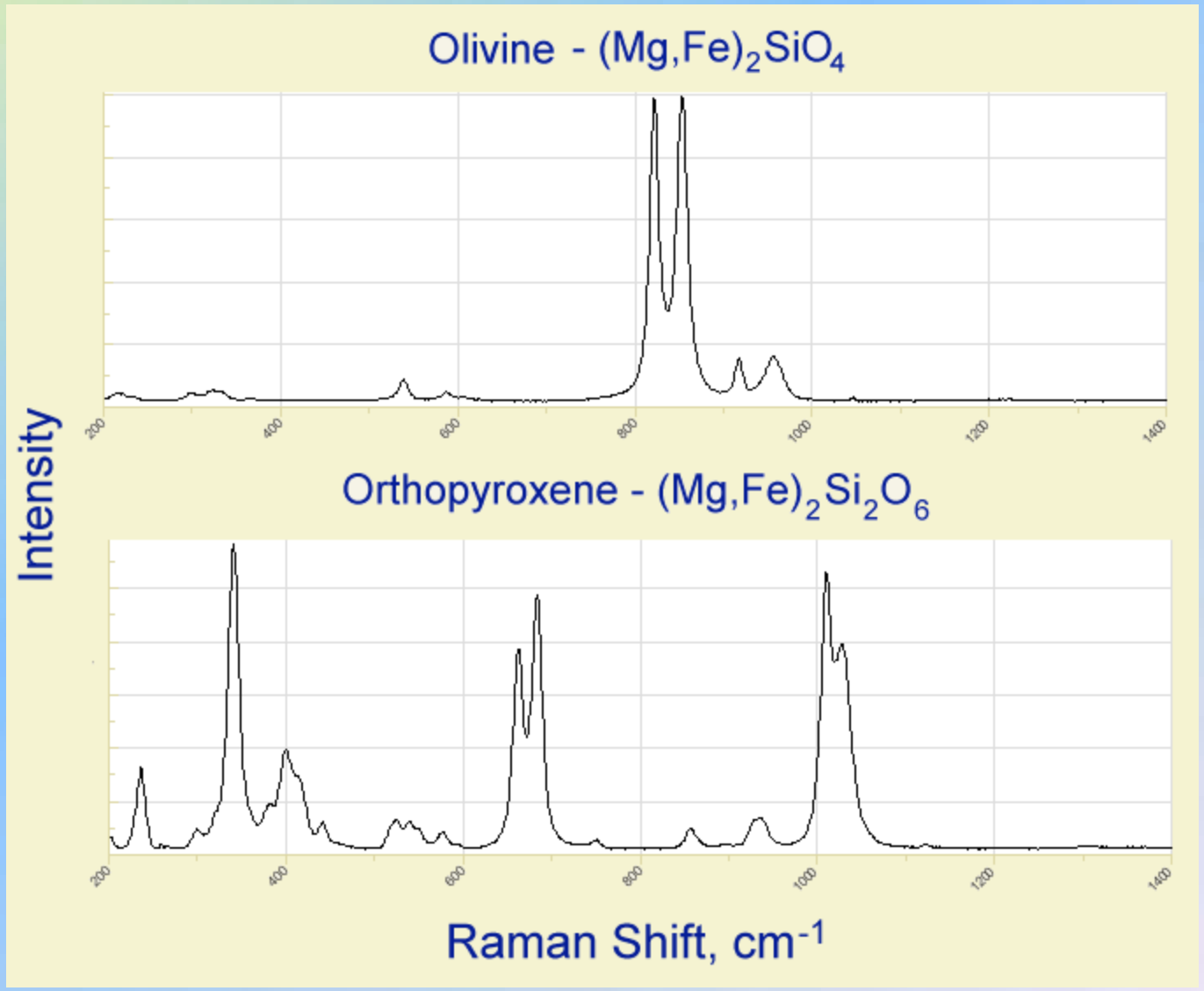


CCD Photodetector

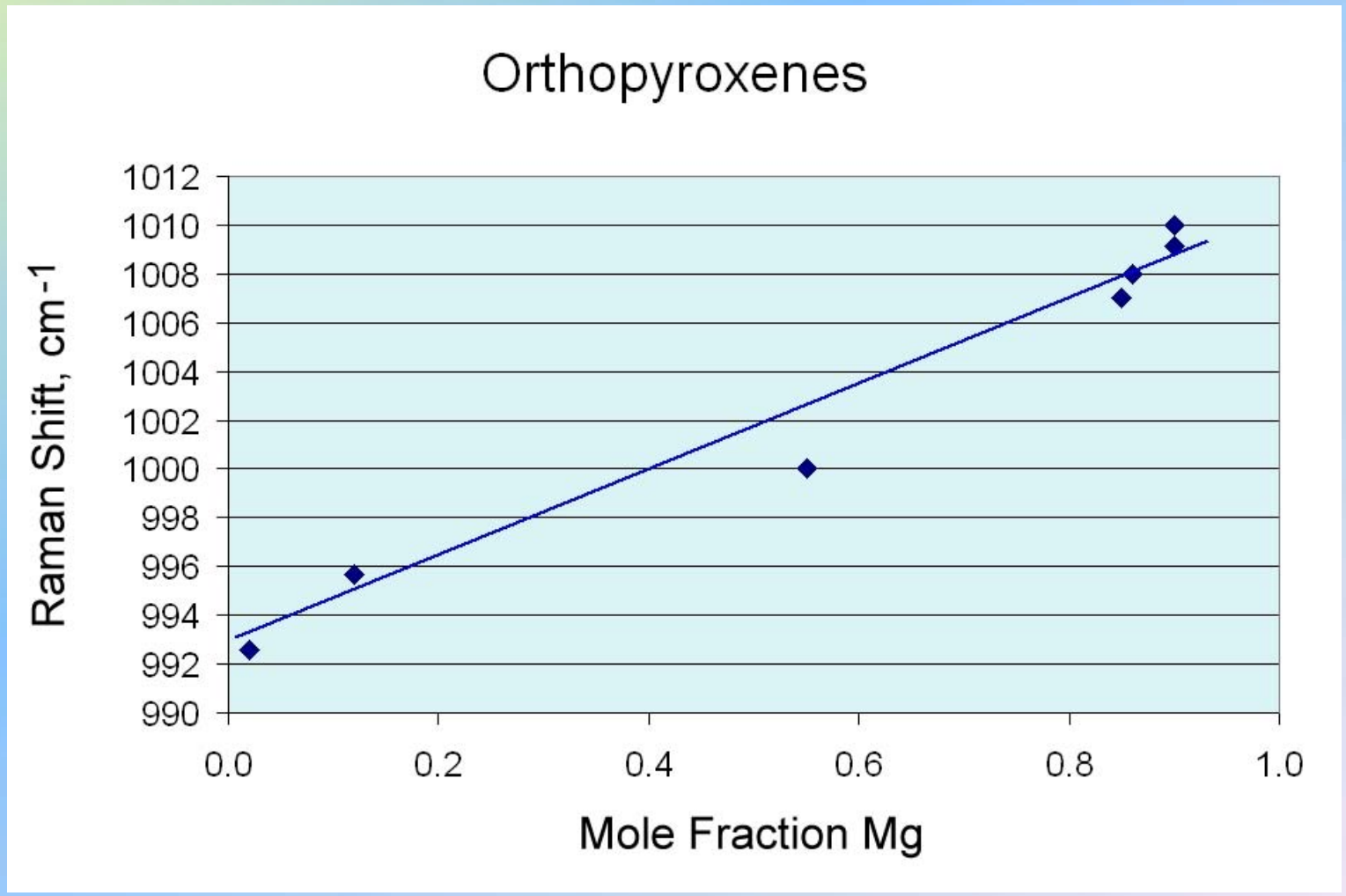
Phase identification
Inclusions



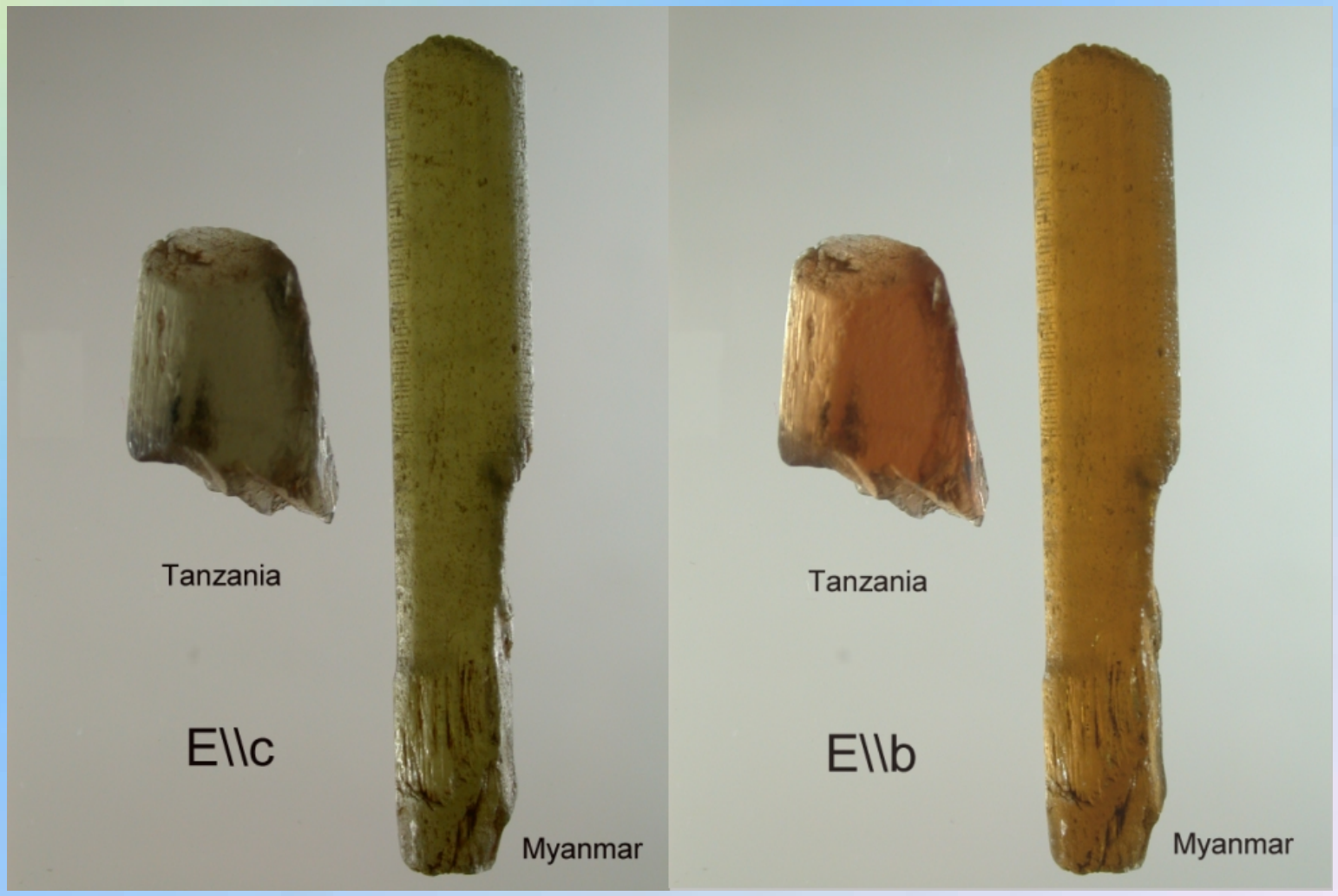
Raman Spectra



Raman Bands vary with Composition

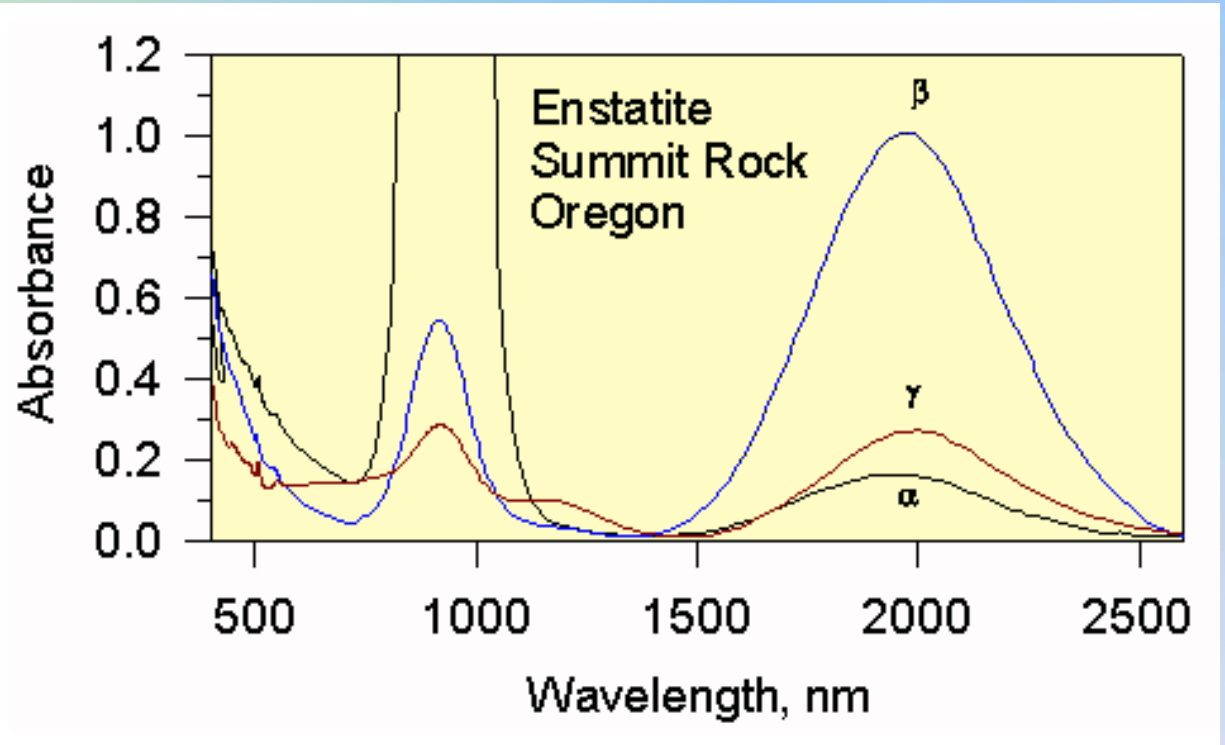


Visible to the Near-Infrared

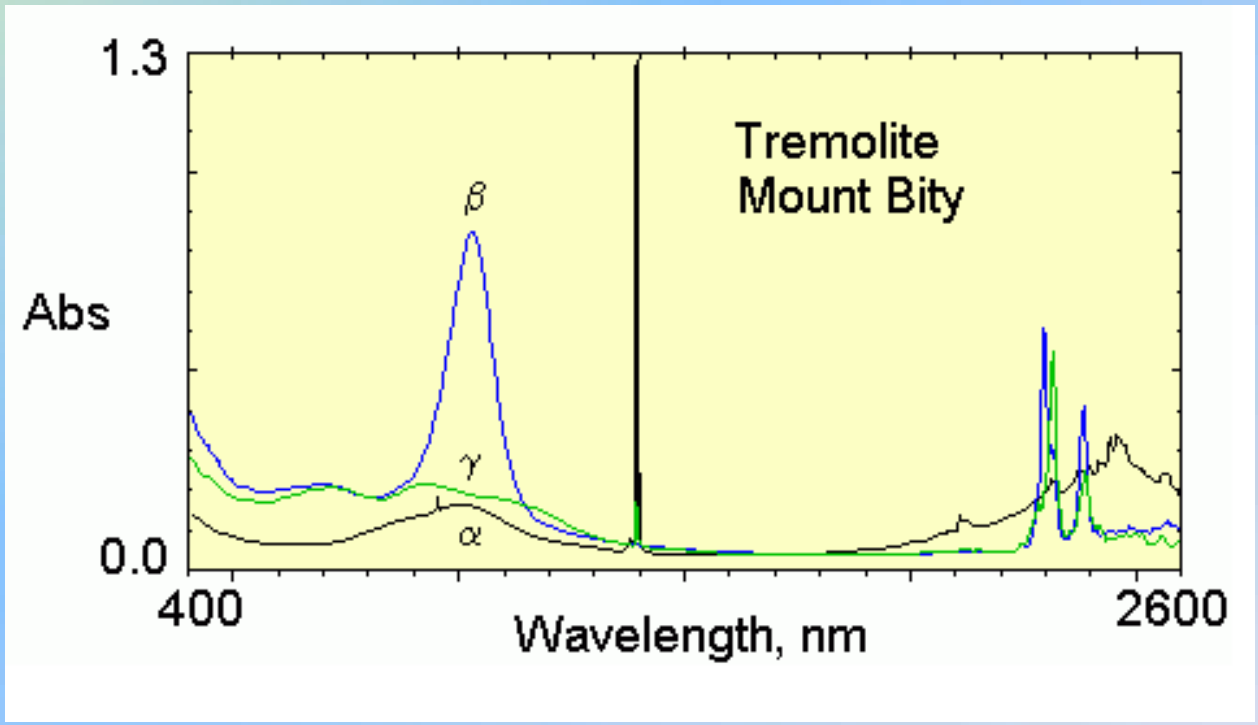


Enstatite

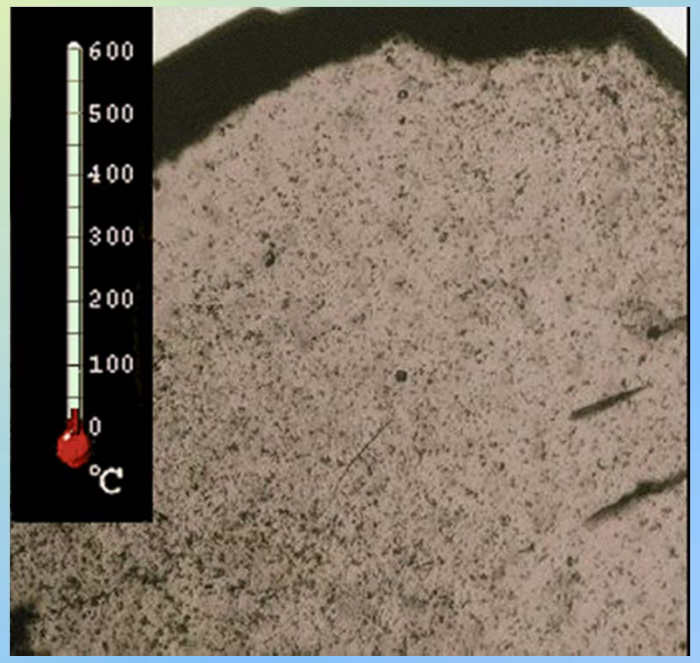
Visible to the Near-Infrared



Visible to the Near-Infrared

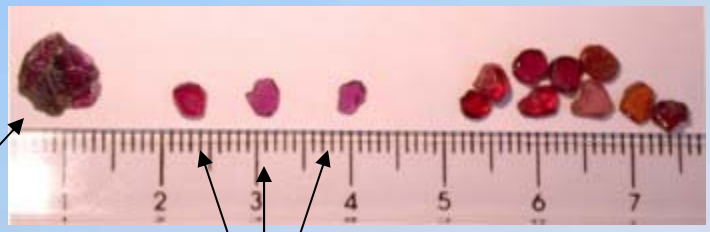


Color Change with Temperature



Koherab, Namibia

Garnet Ridge, Dinnehotso, Apache Co., Arizona



Koherab, Namibia

Garnet Ridge

Thermochromic

Pyrope with Cr^{3+}

Strengths and Weaknesses

Different Methods Have Different Strengths

X-ray - Works on mixtures
Extensive library for “known” phases

Raman - Small sampling area
Powders can prove difficult
Some samples dehydrate or decompose
Luminescence can be problematic
Large library

Infrared - Particle size issues
Mixtures are problematic
Always get data
Libraries less-well developed

Vis-NIR - Particle size issues
Iron minerals, OH, and H_2O