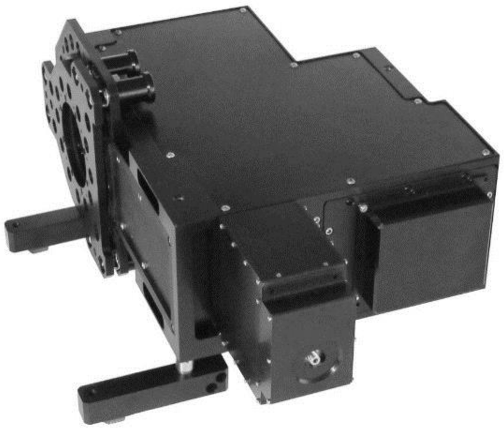
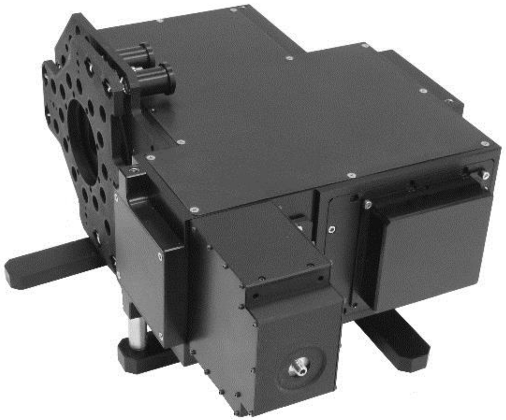
The EMU-120/65 Echelle Spectrographs



EMU-120/65 UV/VIS/NIR

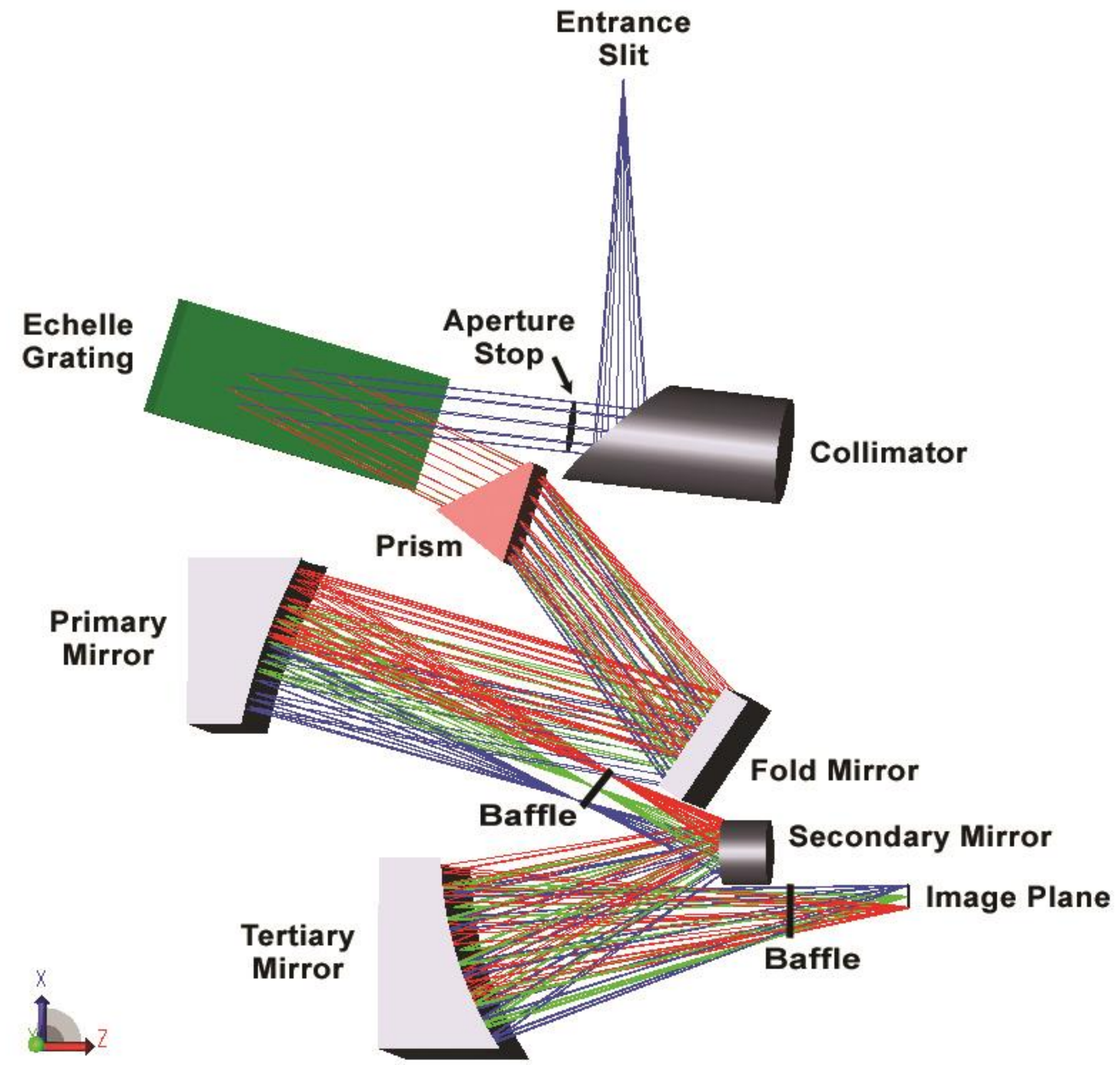


EMU-120/65 VIS/NIR/SWIR

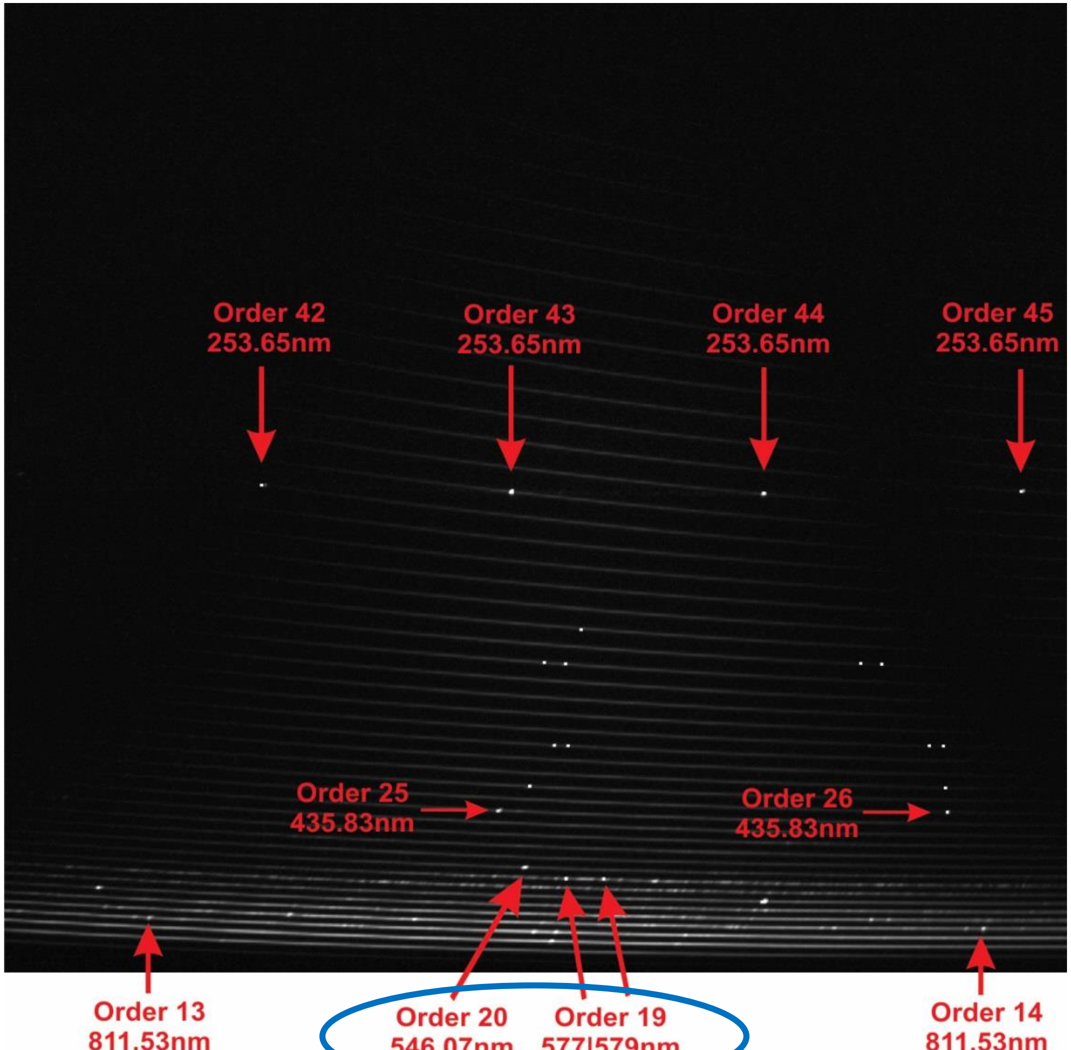
EMU (Echelle Multiplex Unit) Series of Spectrographs

- Commercially available since 2009
- No moving parts. One exposure covers the full range of the spectrum
- Resolving power (λ / $\Delta\lambda$) up to R = ~60,000 depending on grating and camera
- For use with CCD, ICCD, CMOS, SWIR and gateable EMCCD cameras
- Interchangeable cassettes (gratings), entrance slits and aperture stops
- 120mm collimator input ($\geq$ F/4); 65mm camera focusing output ($\geq$ F/2)

EMU Optical Design Using 3-Mirror Anastigmat Camera Focusing Optics

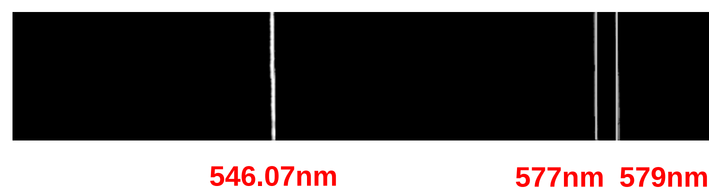


Multiple vs. Single Order Spectrographs



Multiple Order Spectrograph uses an echelle grating with a cross-dispersing prism to separate the spectral orders

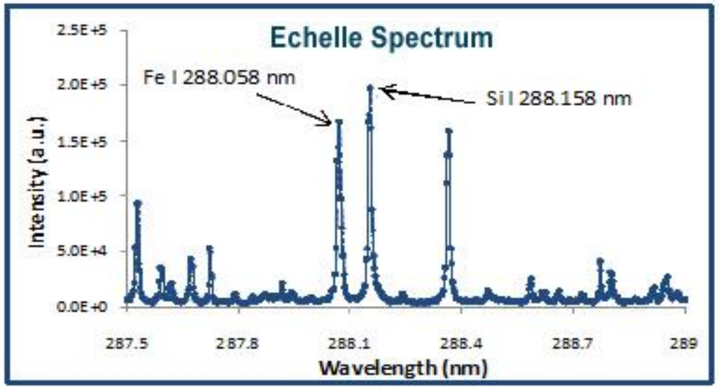
Single Order Spectrograph uses a grating with no cross-dispersion

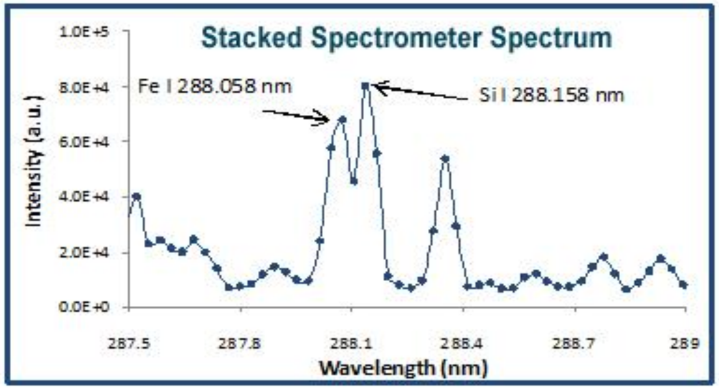


Multiple vs. Single Order Spectrographs

To cover a broad wavelength range with a single order spectrograph, there are two options:

- **Scan across the full wavelength range in incremental steps with the grating mounted on a motor-driven turret.**
- **Stack multiple gratings with each grating covering a different wavelength range. The Mars Curiosity Rover uses a spectrometer of this design.**

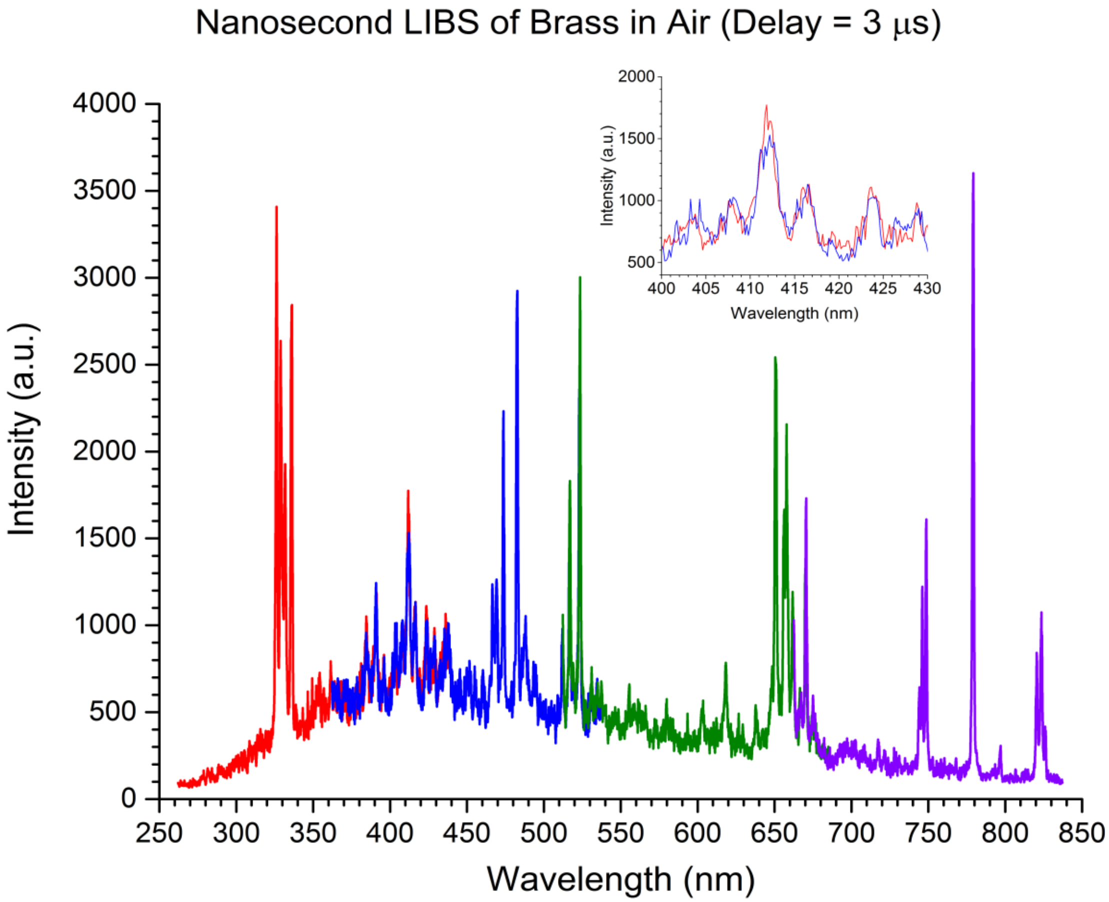




Performance comparison between an EMU echelle spectrograph (Left) and a stacked spectrometer system (Right) in spectra of stainless steel. Different grades of stainless steel have different compositions of iron (Fe) and silicon (Si), and both elements have an emission line at 288nm. The emission peaks of Fe (288.058nm) and Si (288.158nm) are clearly resolved with an echelle spectrograph.

Courtesy of Applied Photonics Ltd.

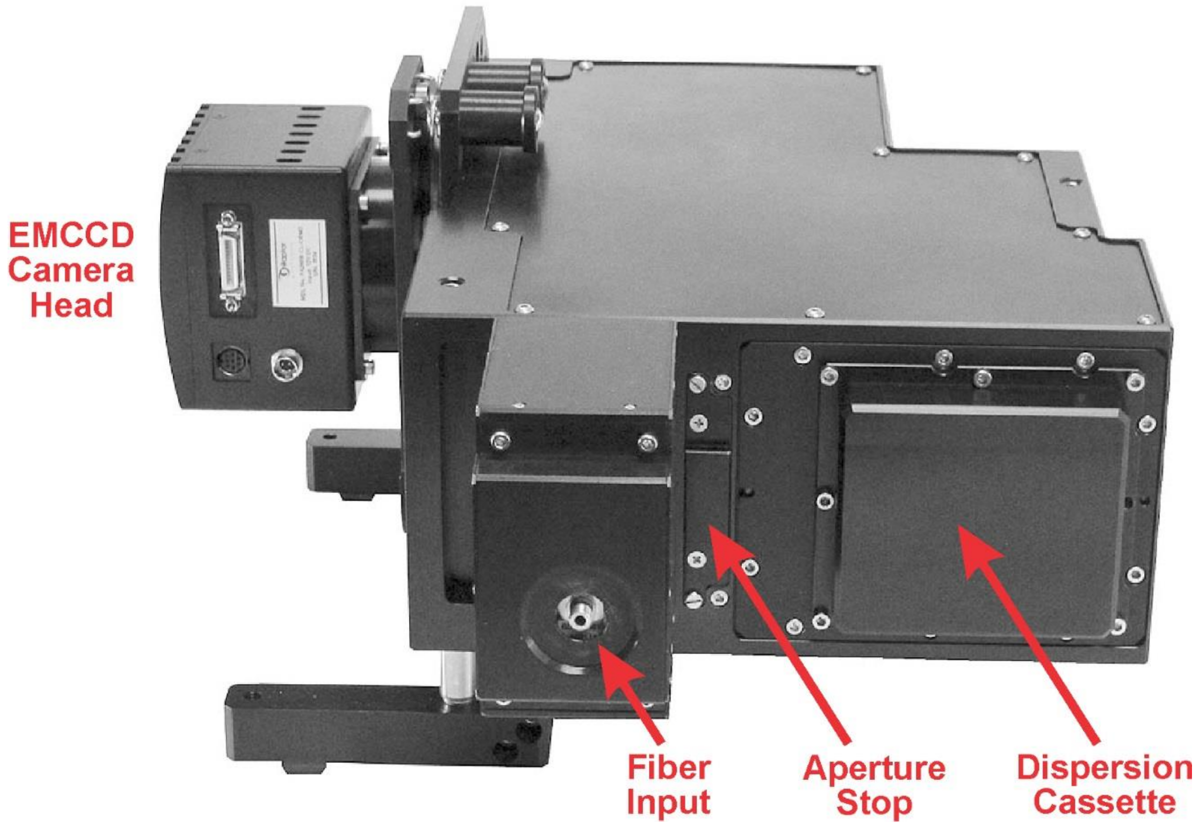
Multiple vs. Single Order Spectrographs



Nanosecond LIBS spectra of brass in air, acquired with a scanning Czerny-Turner spectrometer that has four gratings (shown by the four distinct colors) to capture the entire spectrum from 250 - 850nm. The inset shows the overlapped spectrum from two different gratings, which demonstrates the inconsistency in the LIBS spectra when multiple gratings are used.

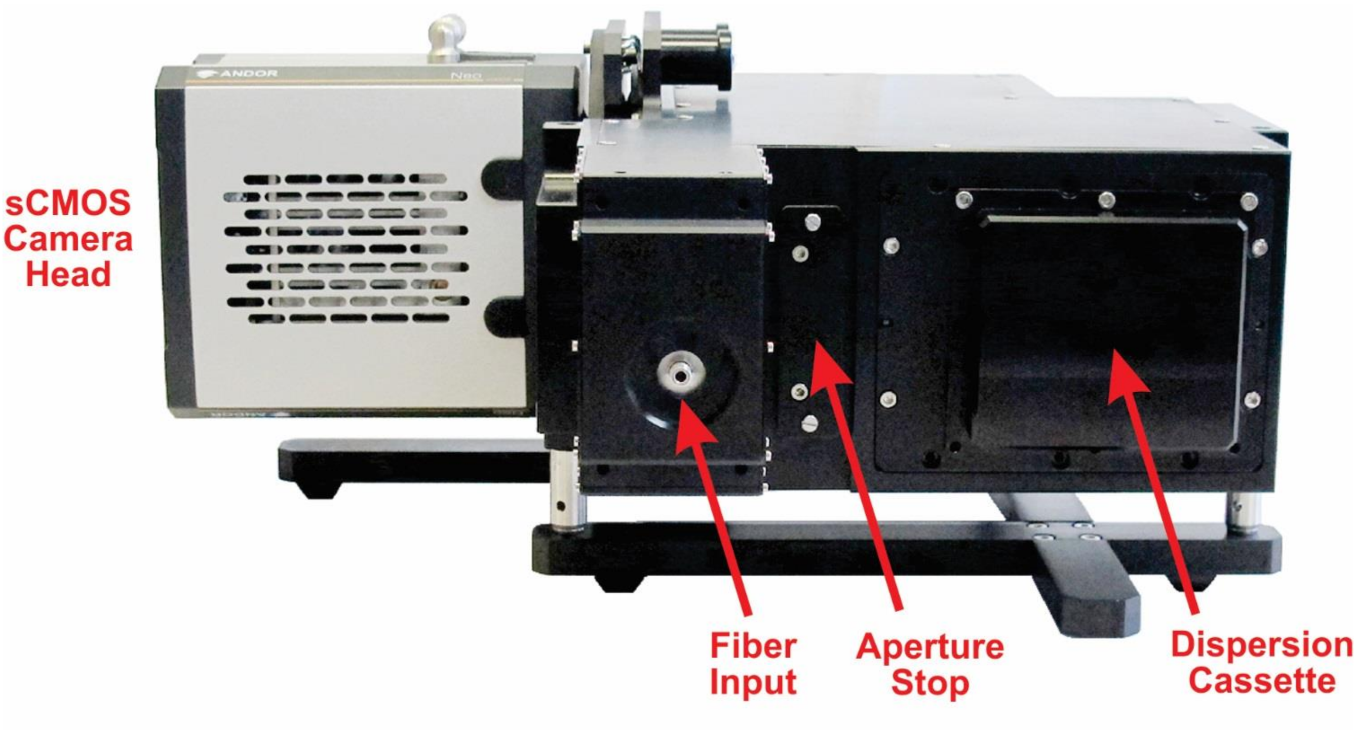
Courtesy of Opticslah, LLC

UV/VIS/NIR Model of the EMU-120/65



The electron multiplying (EMCCD) is a frame-transfer sensor can be gated down to 10 microseconds in some circumstances. There are 1004 x 1002 pixels on the sensor, and each pixel is 8x8 microns. This EMCCD is sensitive from 190nm up to 1100nm.

VIS/NIR/SWIR Model of the EMU-120/65



This sCMOS sensor is sensitive from 350nm up to 1100nm. There are 2560 x 2160 pixels on the sensor, and each pixel is 6.5 square microns in size. The sCMOS camera has rolling and global shutter modes, but it cannot be gated. Other available InGaAs sensors can cover ~400-1600nm wavelength range.

Changing Resolution/Throughput with EMU Spectrograph

grating

R is λ/FWHM with 8μ pixels and 8μ slit width

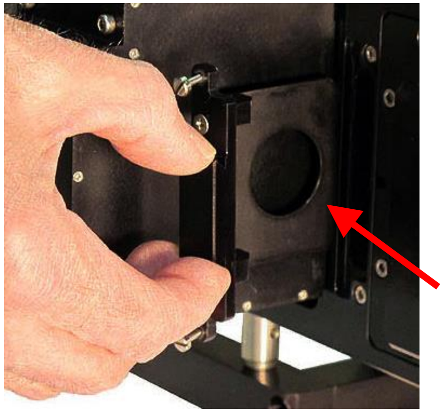
HT Series (32° blaze angle):	up to R = 9,500
HR Series (45° blaze angle):	up to R = 12,000
UV Series (63° blaze angle):	up to R = 30,000
IS Series (70° blaze angle):	up to R = 40,000
IX Series (76° blaze angle):	up to R = 60,000

Interchangeable Cassettes (gratings)

Pixel Size on the Detector
(Smaller for higher resolution)

s**CMOS**	**6.5 microns**
EMCCD	**8 microns**
ICCD	**13 microns**

Pixel Size

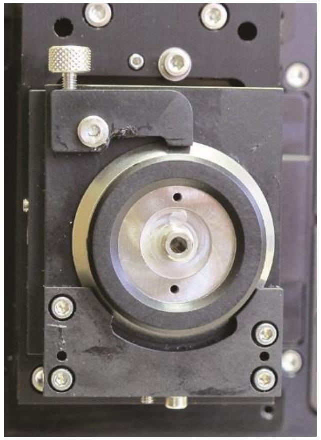


Aperture stops range from 12mm to 30mm in diameter.

The smaller the stop, the higher the resolution and the lower the throughput.

The larger the stop, the higher the throughput and the lower the resolution.

Interchangeable Aperture Stops



Entrance slits can be 8 to 128 microns wide, 12 to 128 microns tall.

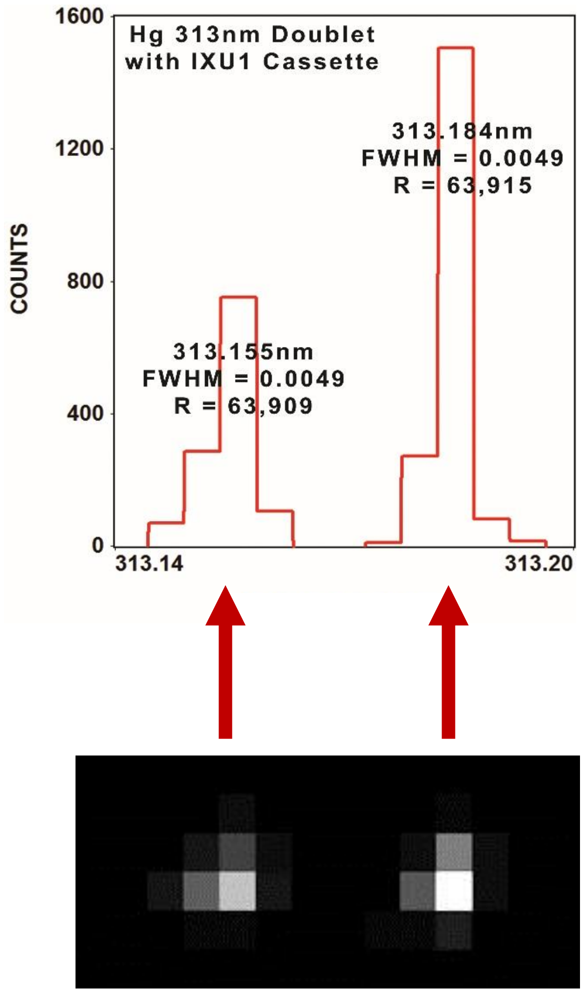
Narrow slits have higher resolution, but they have lower throughput.

Taller slits have higher throughput, but may cause crosstalk between adjacent spectral orders.

Interchangeable Entrance Slits

Catalina Scientific

Resolving Power of the IX Cassettes

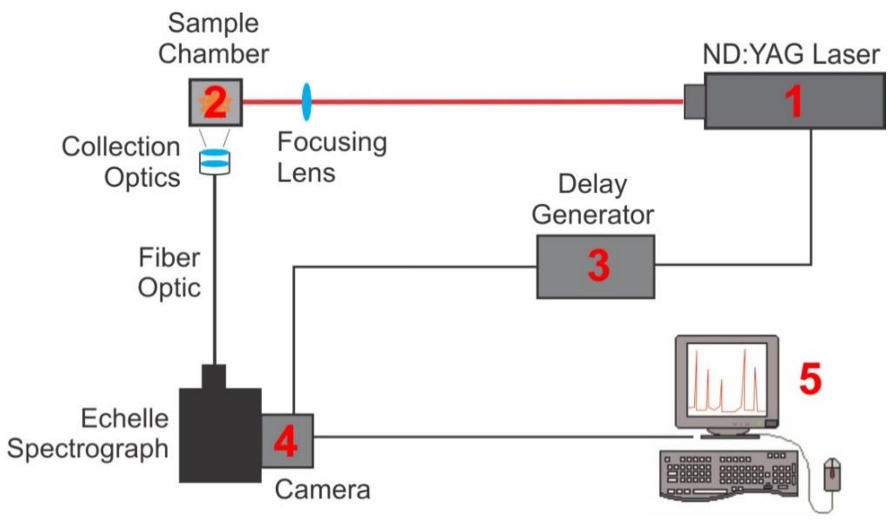


The EMU-120/65 combined with a high blaze angle grating (76°) in the IX series cassette can achieve R = ~64,000 (5pm resolution) at the Hg 313nm doublet.

The 313.155nm and 313.184nm peaks are separated by four pixels on the image from the EMCCD detector with 8µ square pixels.

LIBS (Laser-Induced Breakdown Spectroscopy)

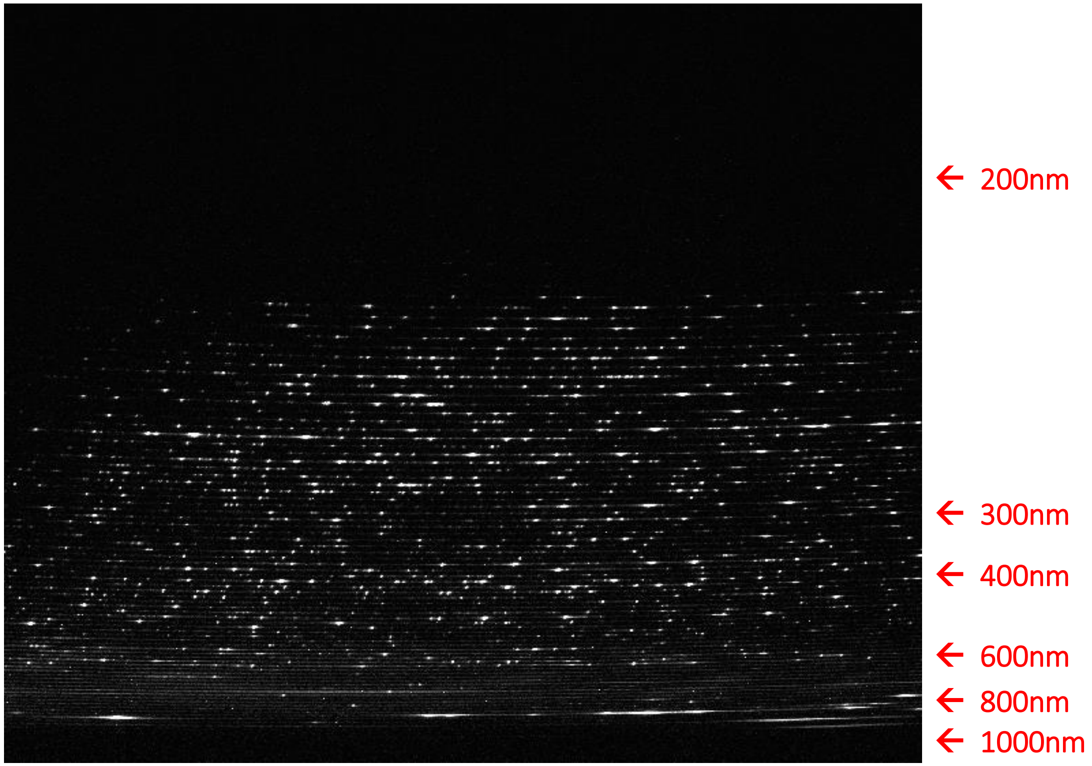
The following diagram illustrates a typical LIBS setup using a YAG laser, a sample chamber, a delay generator, a digital camera, an echelle spectrograph and a computer.



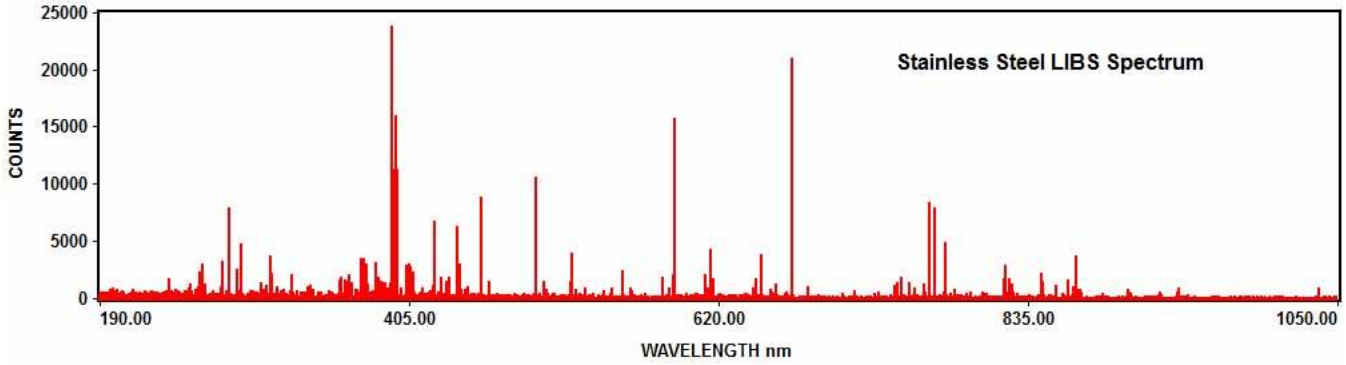
1. The pulsed laser is fired (< 10 nanosecond pulse) at the sample, and at the same time, the laser sends a signal to the delay generator.
2. The sample is excited, the ablated material breaks down and forms a plasma, which emits continuum radiation.
3. As the plasma cools and the electrons recombine with the atoms, they emit atomic radiation. The delay generator sends a signal to the camera to start the exposure.
4. The camera acquires an image of the atomic emission radiation, which is transmitted to the spectrograph through a fiber optic cable connected to the collection optics.
5. When the exposure is complete, the spectral data is sent from the camera to the computer, where it is processed into calibrated wavelength units.

EMU-120/65 used for LIBS

LIBS image
of 416
Stainless Steel
(R > 50,000 with
the IX series
cassette)



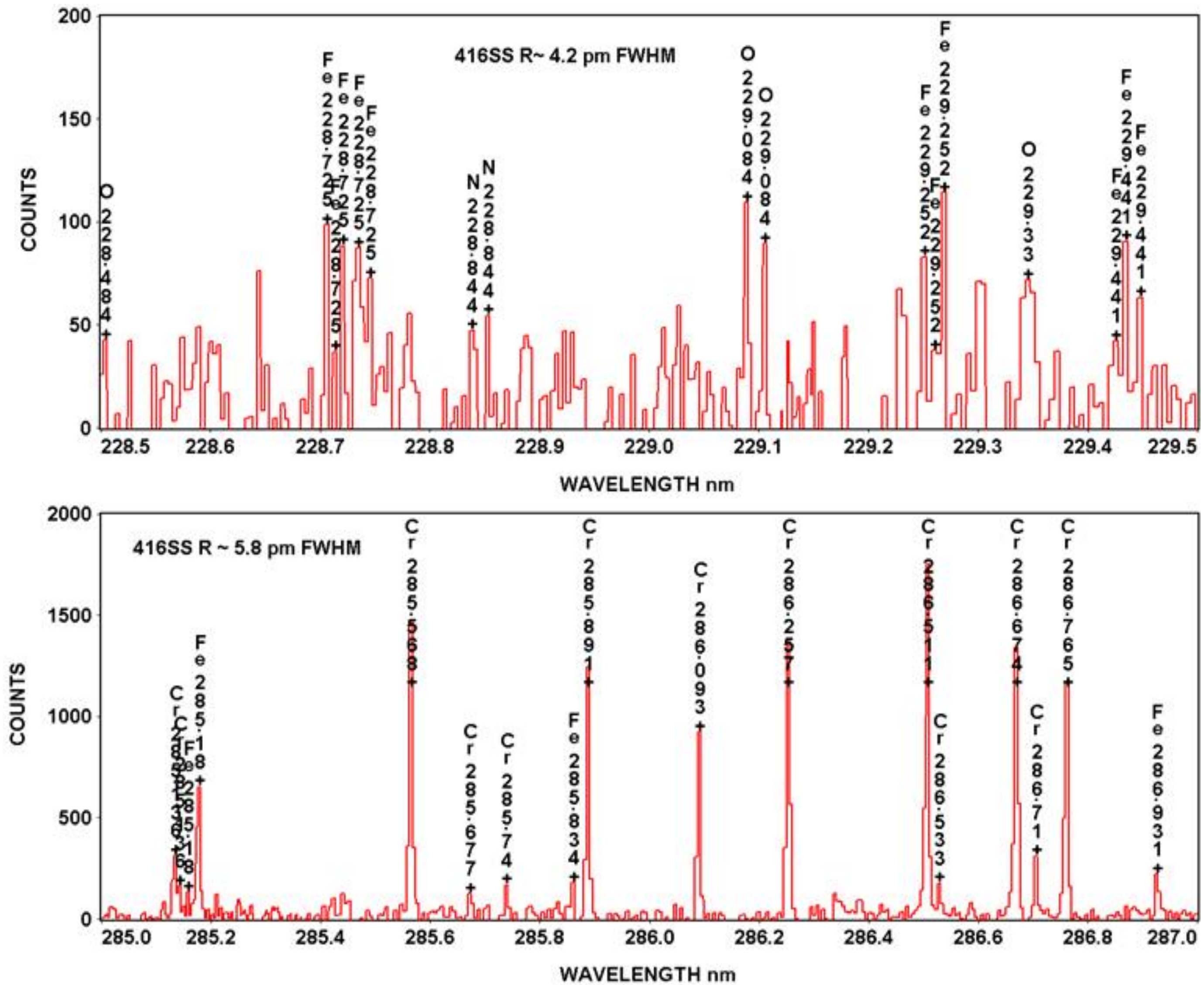
LIBS spectrum
of 416
Stainless Steel
(from the full
wavelength range
of the image)



Catalina Scientific

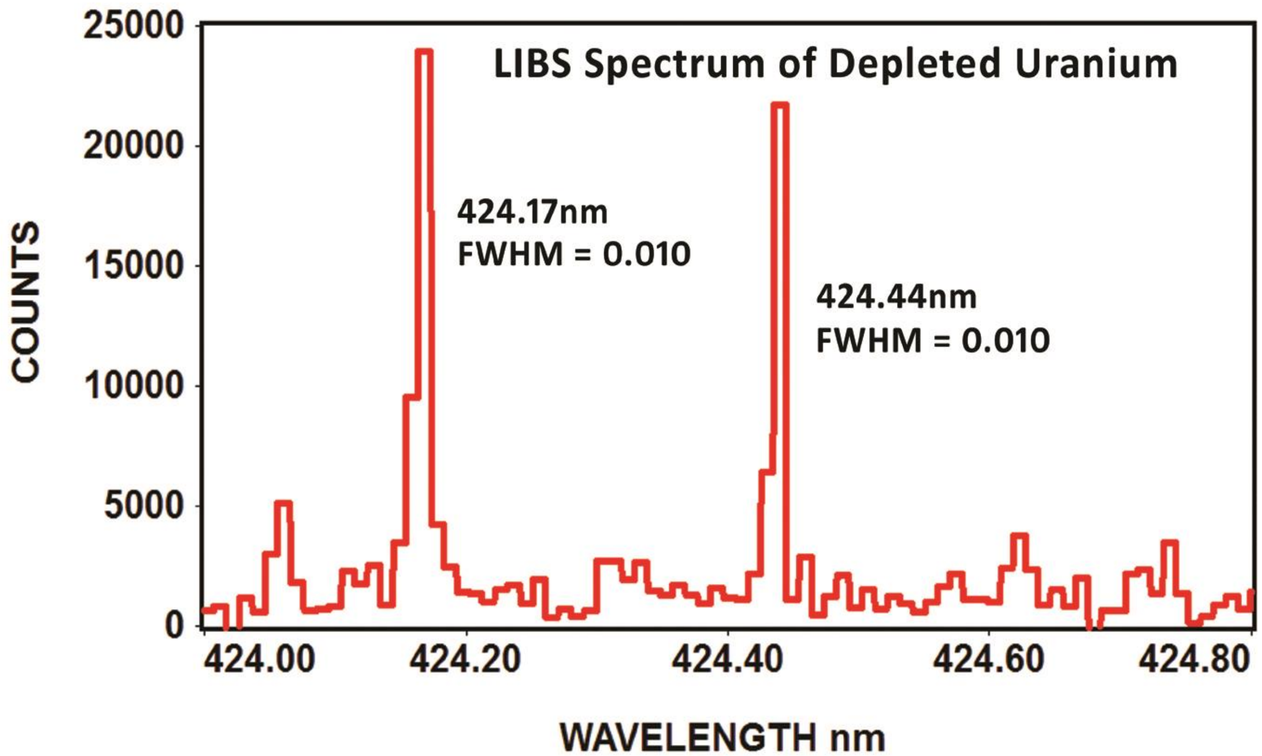
EMU-120/65 used for LIBS

Emission Lines for Fe, N, O, Cr in 416 Stainless Steel
(IX1 Cassette)

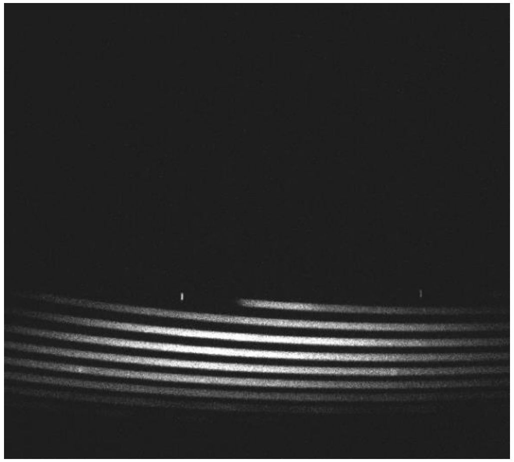


EMU-120/65 used for LIBS

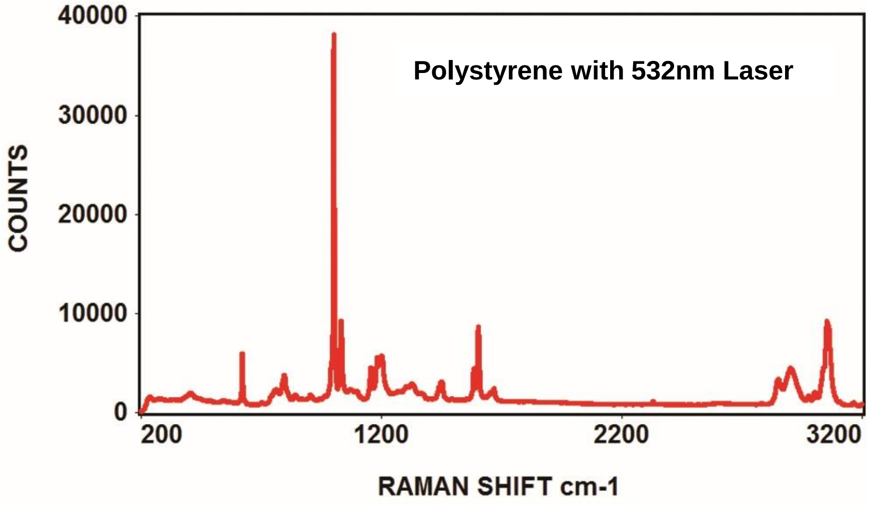
The following spectrum of depleted uranium shows the EMU-120/65 can clearly resolve the isotopic shift at 424nm with a resolving power of ~42,400 (λ / $\Delta\lambda$). This uranium spectrum is courtesy of Applied Research Associates in Albuquerque, New Mexico:

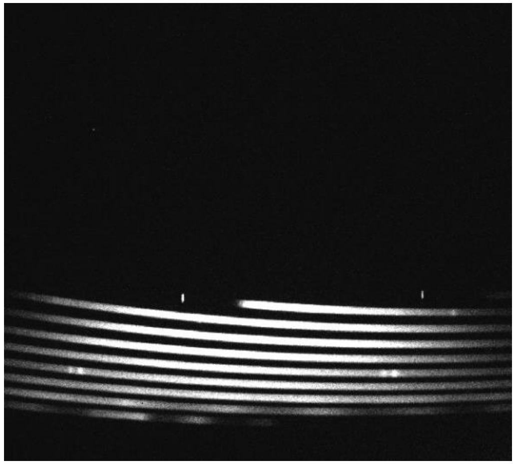


EMU-120/65 VIS/NIR used for Raman Spectroscopy

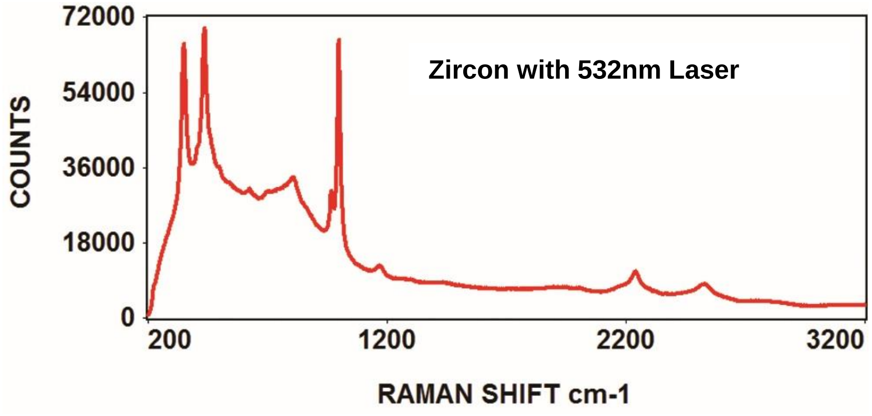


Raman image of polystyrene

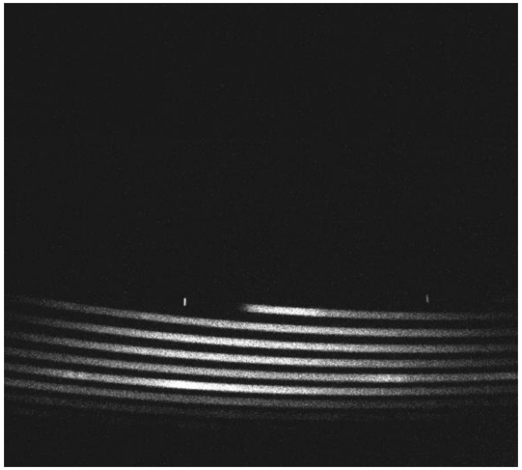




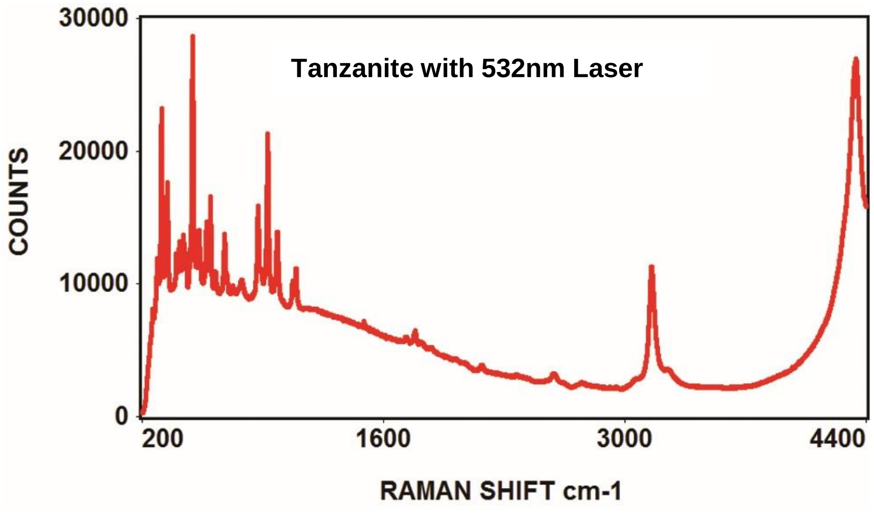
Raman image of zircon

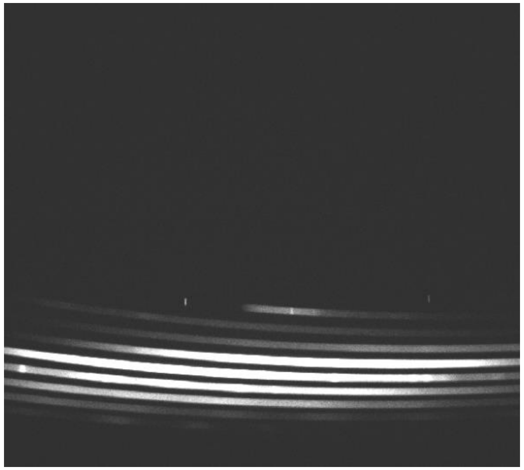


EMU-120/65 VIS/NIR used for Raman Spectroscopy

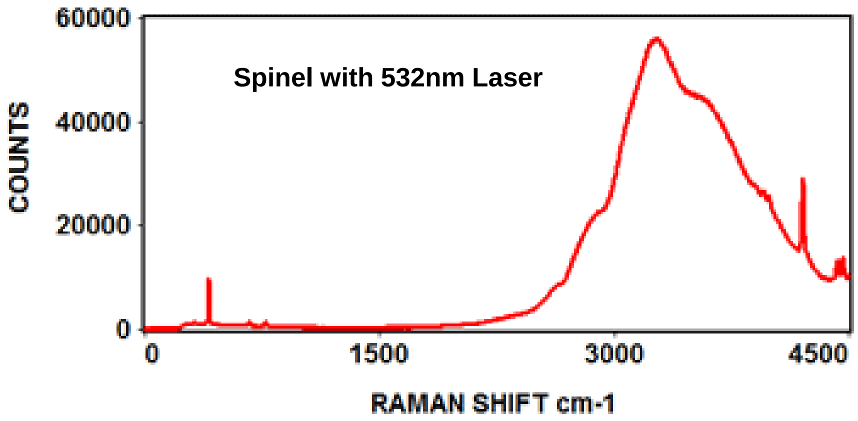


Raman image of tanzanite





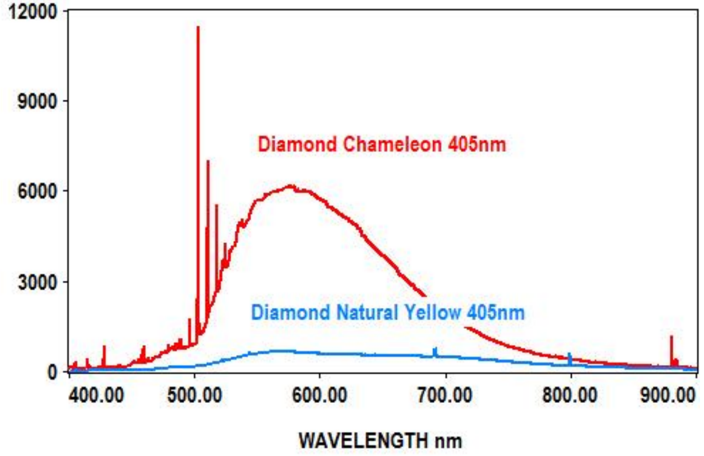
Raman image of spinel



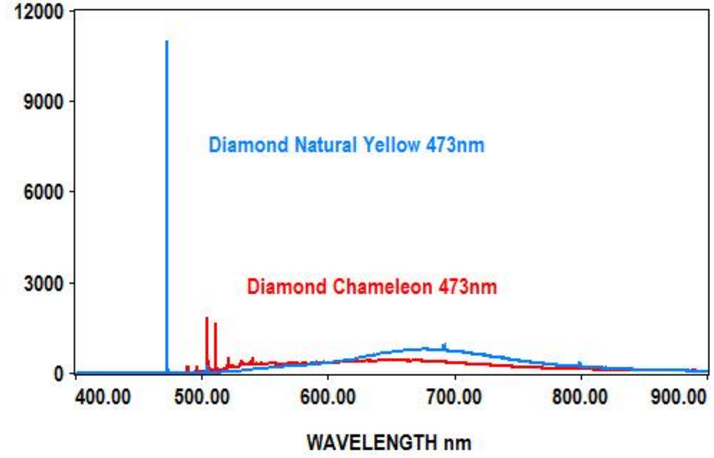
EMU-120/65 VIS/NIR used for Photoluminescence

The following spectra differentiate between two types of diamonds at four laser wavelengths, courtesy of Gemlab (Liechtenstein).

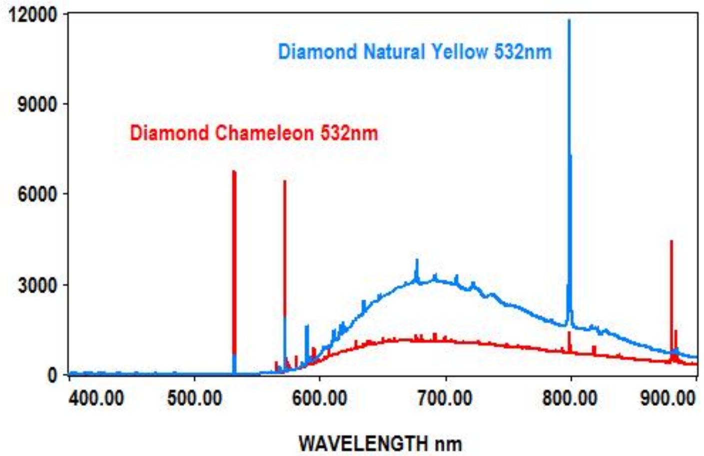
Laser wavelength of 405nm:



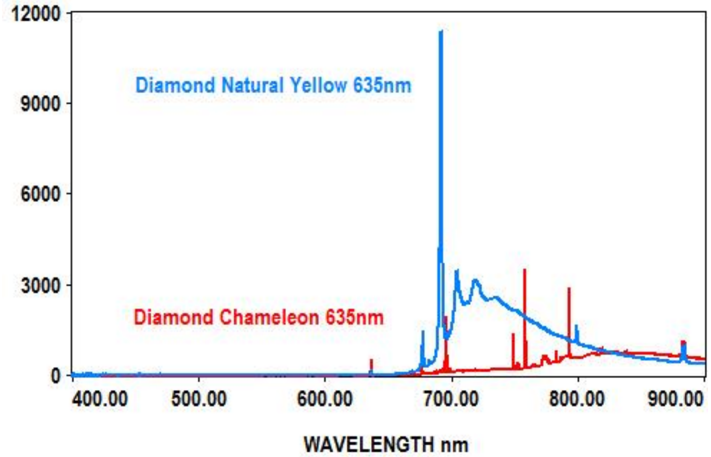
Laser wavelength of 473nm:



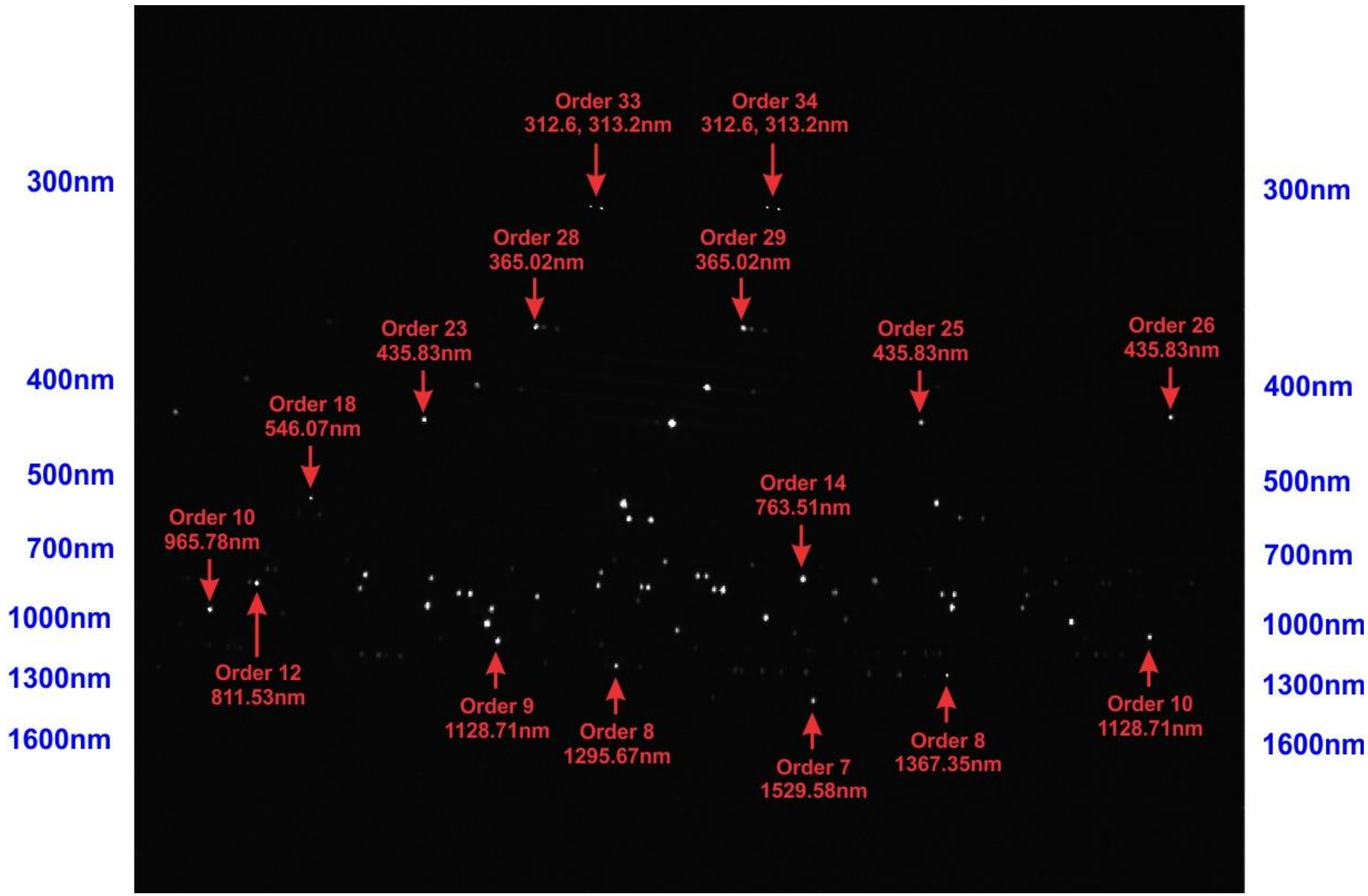
Laser wavelength of 532nm:



Laser wavelength of 635nm:

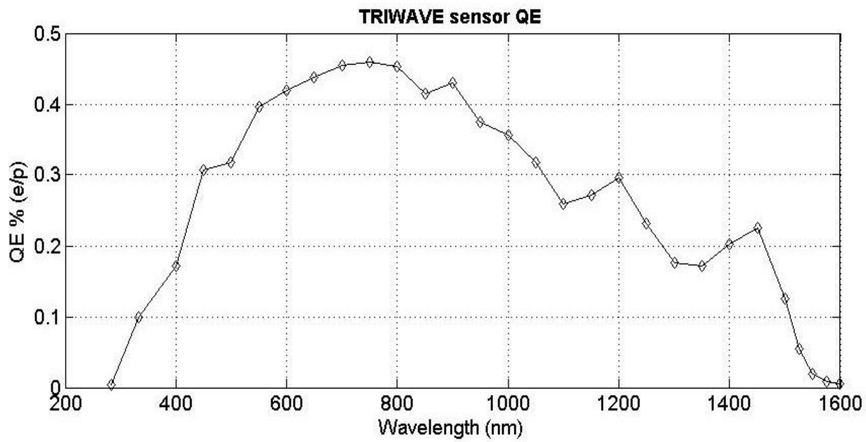


EMU-120/65 in the 300nm to 1600nm Range

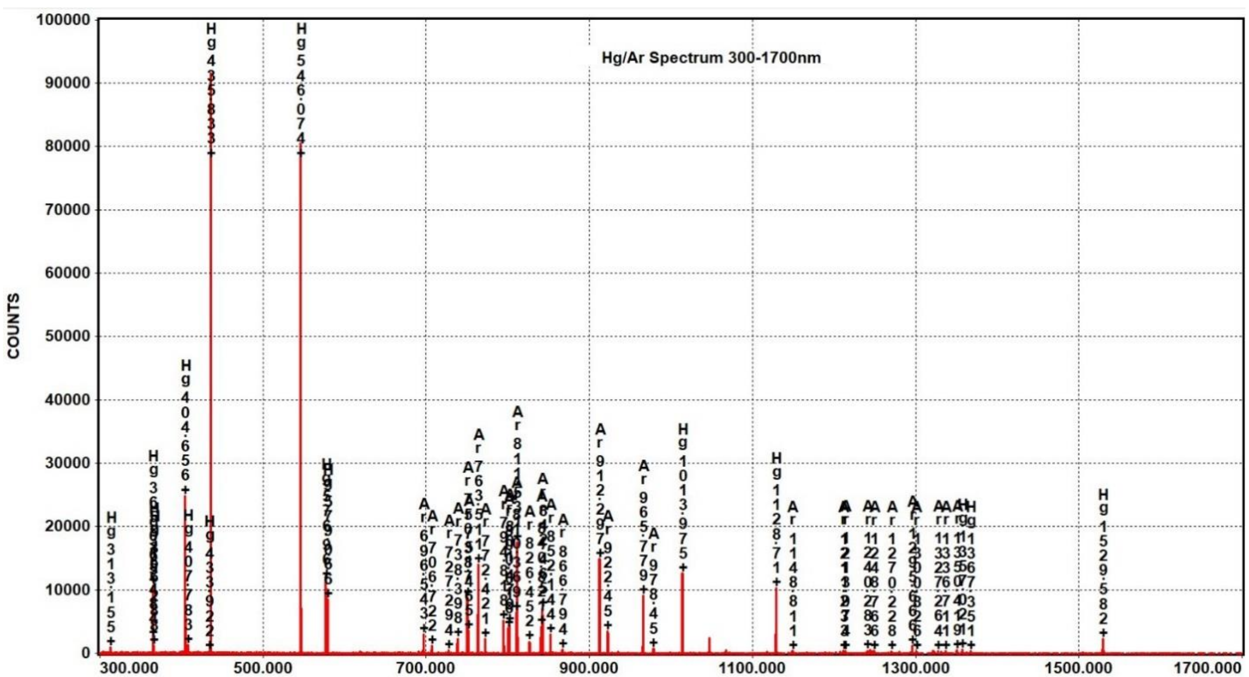


Echelle image of Hg/Ar covering 300nm to 1600nm acquired with the TRIWAVE IR camera from IR LABS and the EMU-120/65 for the VIS/NIR/SWIR wavelength range.

EMU-120/65 VIS/SWIR in the 300nm to 1600nm Range



QE curve for the TRIWAVE IR camera built by Infrared Laboratories in 2013 with their hybrid germanium/CMOS sensor.



Spectrum of Hg/Ar covering 300nm to 1700nm acquired with the TRIWAVE IR camera and the EMU-120/65 for the VIS/NIR/SWIR wavelengths.