The EMU-65: Designed for LIBS on Mars (and Earth)

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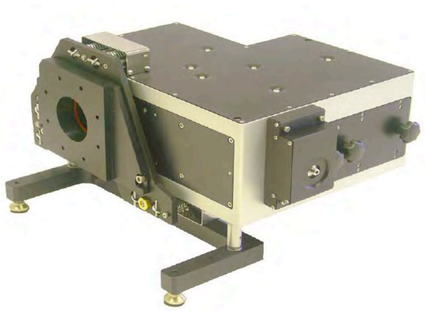
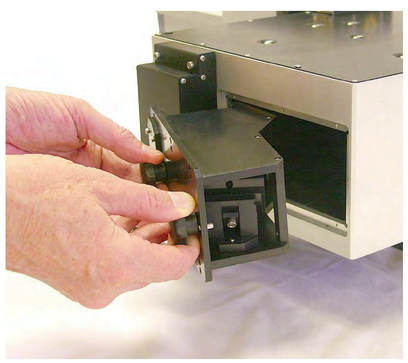


The ***EMU-65*** was developed in collaboration with Los Alamos National Laboratory with support from a 3-year NASA contract. The goal was to create a compact prototype of an echelle spectrograph for stand-off LIBS on a future Mars rover.

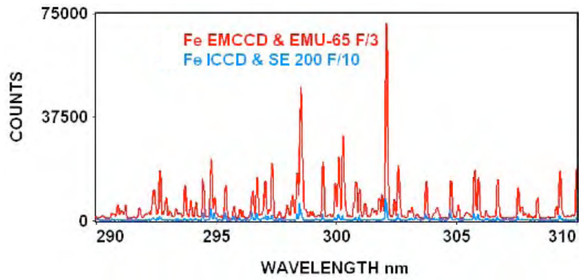
Specifications (patents pending)

- *Input:* F/2.0 to F/3.3
- *Focal Length* (collimator): 65mm
- *Magnification:* ~ 1:1
- *Resolving Power:* up to 12,000 (λ/FWHM) with 8x8 µm pixels
- *Stray Light:* < ~2E-06
- *Scattered Light:* 2E-05 at 1 nm from laser peak
- *Unit Volume:* 6120 cm^3 (360 cubic inch) Fits into a 265 (10.5) x 210 (8.5) x 110 (4.5) mm (inch) box
- *Weight:* 5 kg (11 lbs) without camera
- *Wavelength range:* 190-1100nm
- *Slits:* User interchangeable
- *Dispersion Cassettes:* User interchangeable custom designs. (Illustration below.)

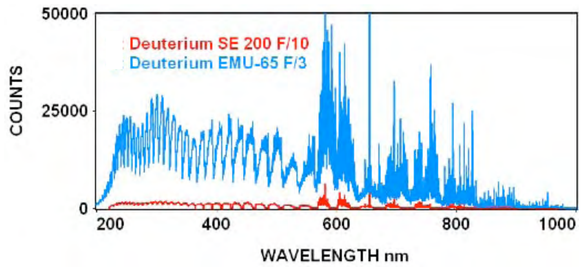


Light-Collection Efficiency

Compared to a standard echelle spectrograph (SE 200), the EMU-65 achieves 10-20 times greater signal count values when used with identical grating, slit, exposure conditions, light source and collection optics (adjusted for correct f/#).



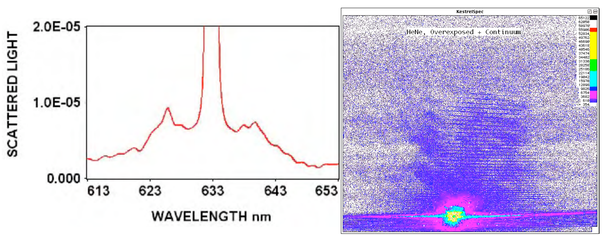
Comparison LIBS Spectra for EMU-65 and SE 200 (Same CCD Used for Both)



Comparison Deuterium Spectra, EMU-65 and SE 200 (EMCCD on EMU-65, ICCD on SE 200)

Scattered Light & Stray Light

Light with the wrong wavelength for a location in the image is a combination of scattering from optical surfaces, and multiple reflections inside the spectrograph. For the EMU-65 we distinguish between these two effects as "scattered light" and "stray light", and measure different values for them.



Curve: Made from overexposed HeNe 633nm laser peak image shown at right. Wavelength range covers slightly less than one order. Scattered Light, as fraction of peak HeNe intensity, is $2x10^{-5}$ at 1 nm from laser peak. Scattering for small wavelength range around peak is mostly from grating surface. (EMU-65 with HR-2 cassette.)

Image: Pseudocolor display shows scattering localized near HeNe peak & (much weaker) stray light. Image shows effective $4x10^{5}$ over-exposure beyond saturation of laser peak, with image of continuum light source added to show order locations. Horizontal line centered on HeNe peak is mostly scattering from grating surface & does not exactly track order location. Concentric rings around HeNe peak are interference fringes due to CCD window. Stray light, measured outside scattering area, is < ~$2x10^{-6}$ of laser peak.

Blaze Function Flat Fielding

For a ruled grating with perfectly reflecting planar grooves, throughput efficiency at the EMU-65 CCD should depend on horizontal distance from the "blaze center" for each diffraction order, per the *Blaze Function:*

$$\mathbf{BF = \{ \sin(\Psi) / \Psi \}^2} \qquad \text{where: } \Psi = [\, \pi\, d \cos(\theta) / \lambda \,] \sin(\theta - \beta)$$

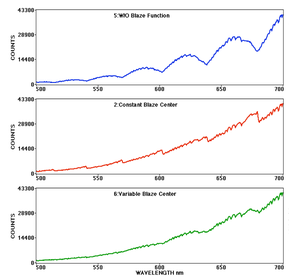
(d = grating constant, β = groove blaze angle, θ = diffraction angle, λ = wavelength)

The blaze centers should all fall on the same CCD column. However the blaze centers actually vary, and the width of the BF is greater, because of deviations in groove shape.* BF flat fielding of the spectrum should take these effects into account.

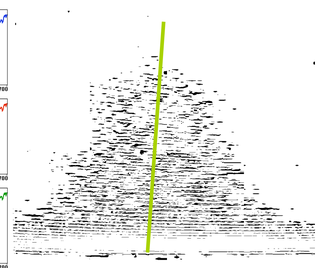
The BF width increase can be largely offset with an "optical correction" coefficient. This method is used in software for all CSI spectrographs, including the EMU-65.

The blaze center dependence on the groove shape is mathematically complex. However much of this dependence can be simply modeled with a linear fit to blaze center location. The EMU-65 is the first echelle spectrograph to which we have applied this technique.

*S. Engman & P. Lindblom, Applied Optics **21**, 4356 (1982)



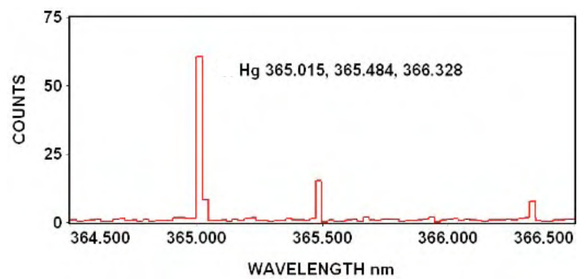
Spectra made from image at right



Green line: blaze centers for continuum spectrum

Image Spatial Resolution

The EMU-65 minimum image spot size is approximately 7 microns, making it a good match for CCDs with high resolution, small size pixels. These include EMCCD designs, which enable LIBS without an intensifier. The EMU-65 can also be used with ICCDs, e.g., for gate times < 1 µs.



Hg 365.015 nm line is less than 1 image pixel (8 µm) wide