# CIRS and MMRS: TWO HIGH PERFORMANCE IN SITU RAMAN INSTRUMENTS FOR LANDED PLANETARY MISSIONS.

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Our team has developed two high performance Raman instruments capable of performing definitive minerology for landed missions: The Mars Microbeam Raman Spectrometer (MMRS) and the Compact Integrated Raman Spectrometer (CIRS)[1, 2]. Both MMRS and CIRS scan a highly focused green laser beam (532nm, 30-micron diameter) over samples to perform geochemical analysis. Both instruments collect Raman scattered light using f/2 optics that is routed to a spectrometer of the same design to provide a spectral resolution of 6-8 cm$^{-1}$ covering Raman shifts from 200-4000 cm$^{-1}$. MMRS uses two optical fibers to convey excitation and collection light between a small probehead and a pump laser and the spectrometer, respectively (Fig 1). CIRS is a direct-coupled instrument (no fibers) with fore-optics, laser, and spectrometer, as well as a context imager, all integrated within the CIRS instrument head (Fig 2).

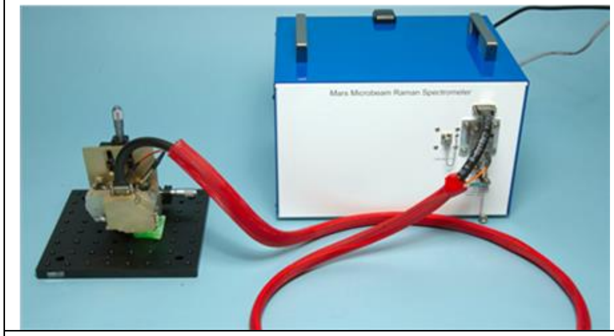

**Fig 1(Left):** MMRS Probehead; **(Right):** MMRS Controller with spectrometer and pump laser

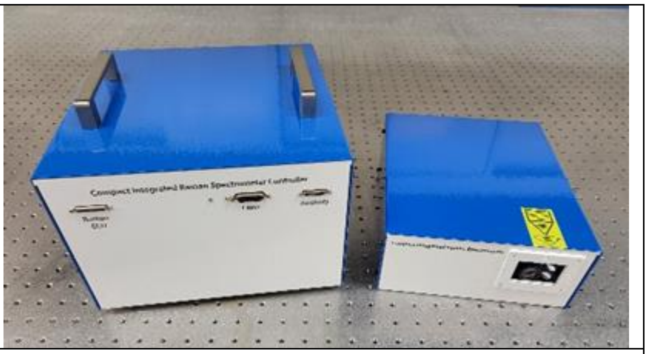

**Fig 2 (Left):** CIRS Controller (COTS) subsystems; **(Right):** CIRS Sensor Head

MMRS was originally proposed to MSL and was rated a category 1 instrument by NASA, but was ultimately descoped during Phase A due to difficulties to route MMRS's optical fibers through the numerous articulations of MSL's robotic arm. MMRS could be suitable for simpler robotic arms. The simpler accommodations needed for the mast joints of MSL and Mars2020 permitted the use of optical fibers between the collection optics of the mast head and the spectrometers in ChemCAM and SuperCAM. Nevertheless, we responded to these concerns by developing CIRS, a direct-coupled, rather than fiber-coupled, analog to MMRS. Thus, at this time, we have two TRL 5 instruments with nearly identical performance specs that may have their respective advantages depending on the specific needs/constraints of the mission[3].

Currently CIRS is being developed to enable future scientific discovery under two funded NASA programs: ICEE-2 (Instrument Concepts for Europa Exploration 2) and DALI (Development and Advancement of Lunar Instrumentation). Under ICEE-2 and previously under MatISSE funding, we have raised the technology readiness level of the necessary subsystems including mechanical, optical, and detector/detector electronics subsystems to TRL5, in order to allow the instrument to survive the high levels of ionizing radiation present on Europa as well as tolerate the launch loads and thermal conditions expected (Fig 3)[4]. Additionally, an integrated sampling handling system allows the CIRS to examine icy samples (1 cc each) in their frozen, melted and desiccated states. CIRS uses a green laser and a high-resolution spectrometer to collect Raman spectra of each sample with resolution necessary to perform definitive mineralogy and quantitively measure concentrations levels, as well as detect organic and potentially biogenic molecules at extremely low concentration levels ($\leq 10^{-9}$ w/w).

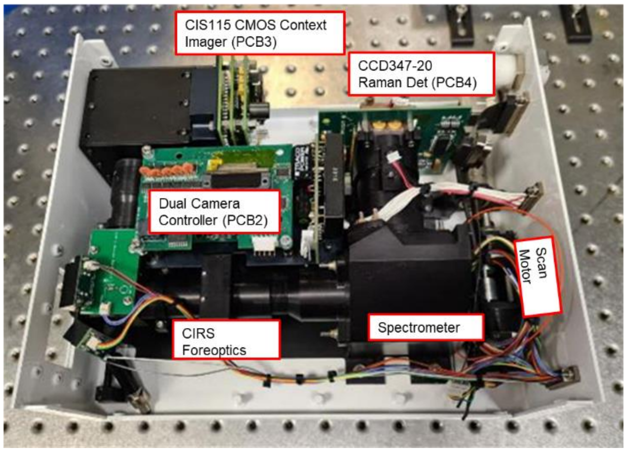

**Fig 3:** CIRS Sensor Head with radiation resistant Raman CCD and context imaging (CMOS) detectors.

During the ICEE-2 mission to Europa, icy samples would be excavated from 10 cm below the surface and placed into a clear bottomed cup and robotically conveyed to the CIRS sample handling system (SHS) (Fig 4). After the icy sample is received within the SHS, CIRS would initially collect spectra through the bottom window of the SHS (and cup) to determine its provenance by measuring the Raman spectra of any entrained salts such as $MgSO_4$. CIRS is capable of differentiating salts that are in a glassy state, which may originate from one of Europa's plumes, from those in the crystalline form indicative of much older surface ice. Younger plume ice could be a valuable find, since it should have less long-term exposure to ionizing radiation and be more likely to contain less degraded putative biogenic material that older surface ice.

After CIRS examines the icy sample, it will be melted in order to randomize the Raman cross-section of its soluble constituents to allow CIRS to quantitatively measure their concentrations. Finally, the sample will be freeze-dried to remove all of the water and thereby concentrate solid constituents on the cup's bottom window. To increase the sensitivity of the measurement even further, the cup's window is specially treated to provide surface enhanced Raman (SERS) capabilities. SERS can often boost the Raman spectra of trace compounds by many orders of magnitude. While conventional SERS substrates have lifetimes that are typically limited to just a few weeks, the CIRS cup window is coated with a thin film of silver chloride which can remain in an inactive state indefinitely. However, this substrate can be photo-activated by the CIRS laser *in situ* to form a highly SERS active layer of silver nanoparticles years after launch. The unique approach provides CIRS with the sensitivity needed to make measurements with detection limits for organic molecules at parts per billion concentration levels. We have demonstrated this in salty brines at pH's ranging from 2 to 10[5]. Although a mission to Europa is not likely to occur within the next decade, the capabilities described may be relevant to Lunar or other Icy world venues.

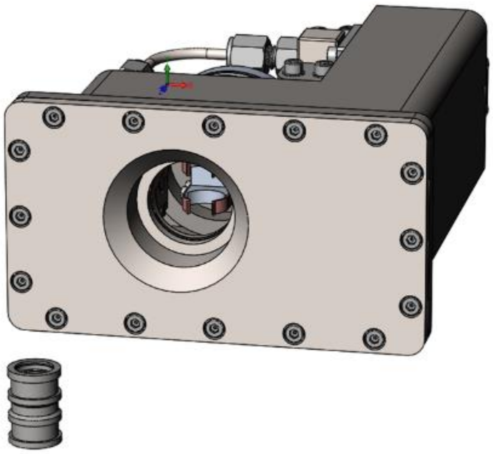

**Fig 4:** CIRS Cup and Sample Handling System Brassboard (currently being fabricated)

CIRS is also being matured to explore the Moon through funding provided by NASA's DALI program. For Lunar missions CIRS can perform detailed investigations of lunar mineralogy to study the effects of space weathering, and to locate regions containing water-ice and hydrated minerals so that they may be used in ISRU (In-situ Resource Utilization) processing systems. Under the DALI project, we will leverage many of the opto-mechanical subsystems already developed under ICEE-2 and instead focus our efforts on developing the control electronics and firmware needed to drive the instrument's subsystems and communicate with the spacecraft. These efforts are also directly applicable to the control of the MMRS instrument as well since the optomechanical and laser subsystems to be controlled are quite similar.

JPL is developing a flight qualified control board in support of another mission called the Common Instrument Electronics (CIE) board. Development of the CIE is an effort running in parallel to our DALI project. Under DALI funding, we are developing firmware to allow CIRS or MMRS to be controlled by the CIE as well as a pair of mezzanine cards which will provide electrical control of the specific subsystems of CIRS (or MMRS). The CIE controller uses the Kintex XQRKU060 FPGA, which is rad-hard to a TID of 100 krad and is designed to exploit triple modular redundancy (TMR) in its firmware architecture to minimize the effects of cosmic-ray induced single event upset and latch-up events. The control system is arranged in slices of hardware, a power module, the CIE board, and the mezzanine cards, that are fastened together to form a single integrated housing. This flight-qualified control system is intended to replace the COTS-based MMRS controller (Fig 1(Right)) and the CIRS controller (Fig 2(left)).

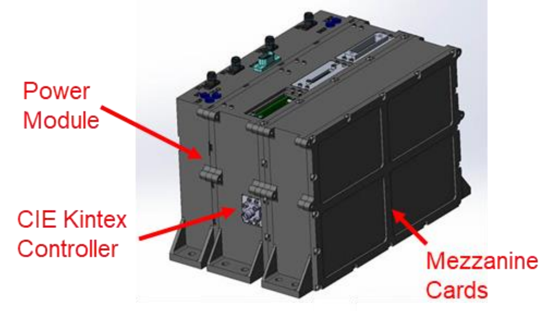

**Fig 5:** CIRS Flight Controller (underway)

Overall, these development activities are intended to reduce the costs needed to credibly propose CIRS and/or MMRS for a future mission opportunity by striving to mature the TRL of the optomechanical, thermal, and structural subsystems (as measured on the TRL scale) as well as the electrical and software subsystems often regarded as standard engineering, which are nevertheless very expensive to render into flight hardware.

**Acknowledgement:** The work performed in this document was performed under contract with the National Aeronautics and Space Administration.

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