



In Situ Instruments for Small Body Exploration

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Caveat:

This presentation represents my own personal opinions and neither JPL nor NASA policy or recommendations.

In Situ Instruments for Small Bodies

- Instruments developed for Mars surface missions (Pathfinder, MER, Phoenix, and especially MSL) are now prime candidates for other in situ applications (Venus, the moon, etc.)
- There are also many exciting new instrument technologies at low- and mid-TRLs, but little funding available
- Universal goals: higher performance, lower risk, lower mass, lower power, & lower cost
- The diversity of small bodies, and the range of sample types (rocky, icy, carbonaceous, mixtures), makes in situ instrument development challenging
- Flight opportunities for in situ instruments are few compared to orbital:
 - Most (not all) Discovery class missions can't afford in situ instruments
 - Small / primitive body community (generally) favors sample return
 - Mars program is moving away from highly capable field laboratories and towards sample return

Trade studies are required to determine which small body missions would most benefit from in situ measurements

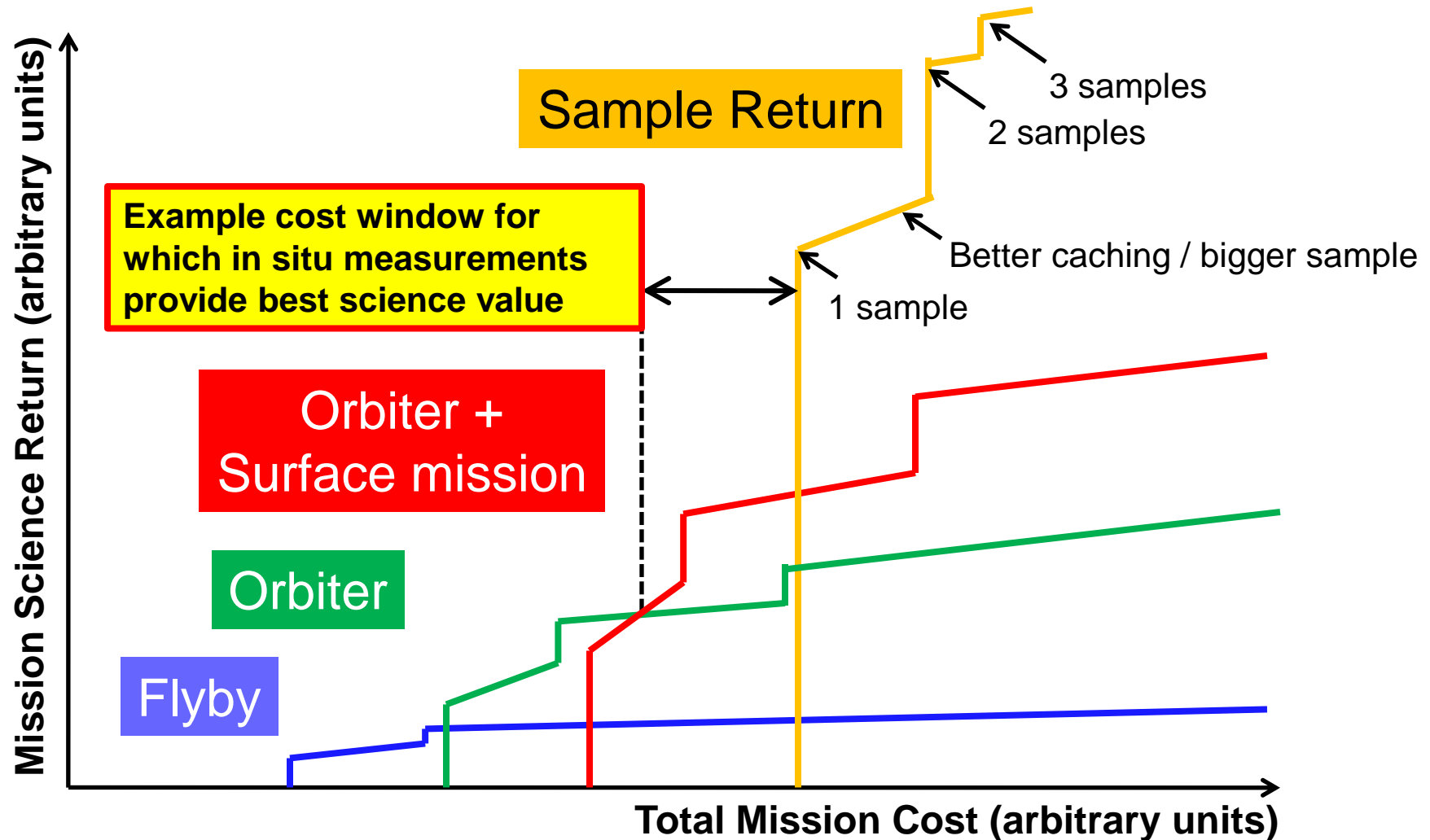


Figure is for illustration purposes only. Lines do not reflect actual trade studies; relative shapes, positions & heights are highly mission/payload dependent.

High precision in situ compositional and isotopic measurements require substantial payload mass
Example: 3 generations of Mars rovers

MER (2003)

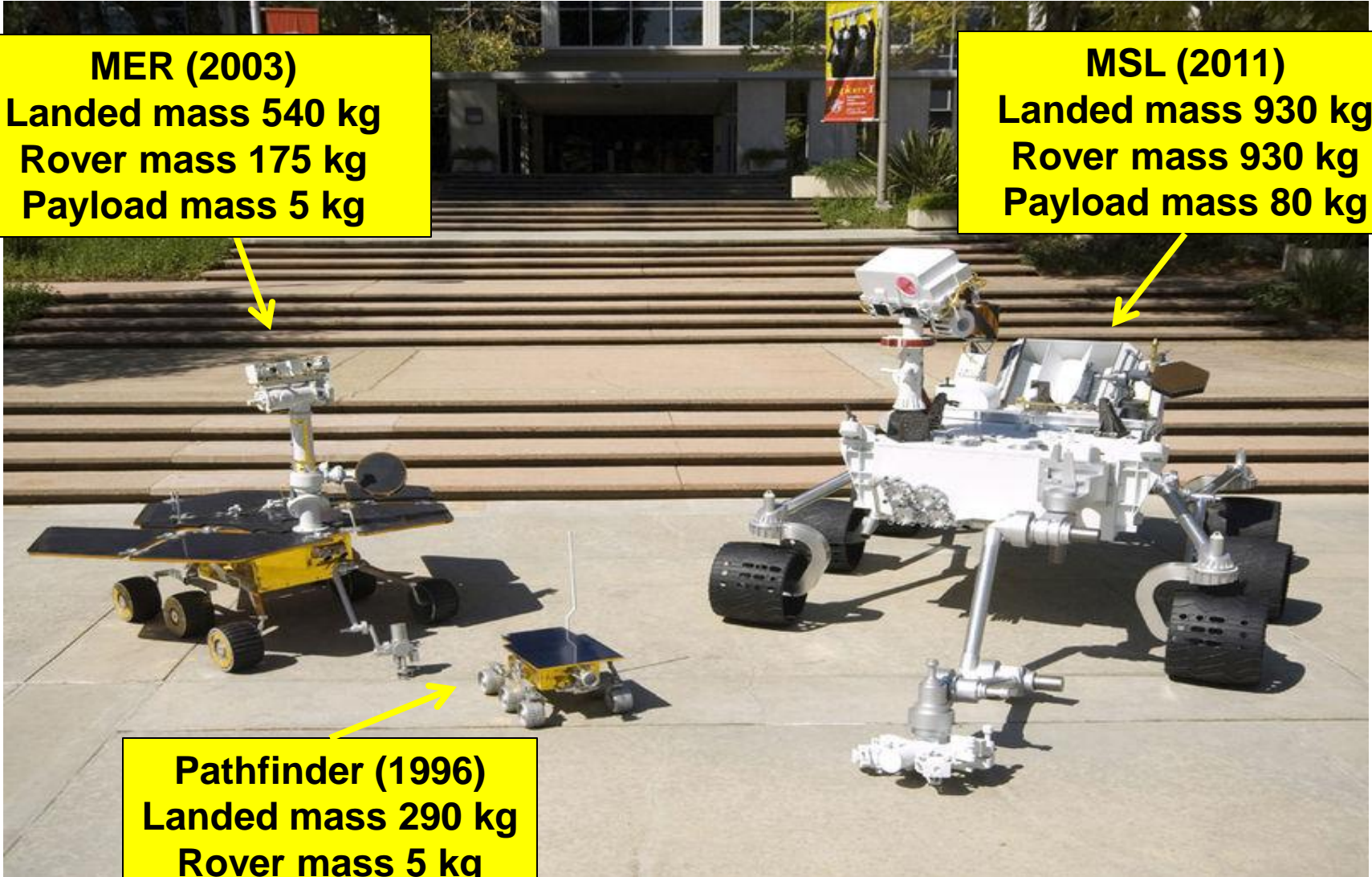
Landed mass 540 kg
Rover mass 175 kg
Payload mass 5 kg

MSL (2011)

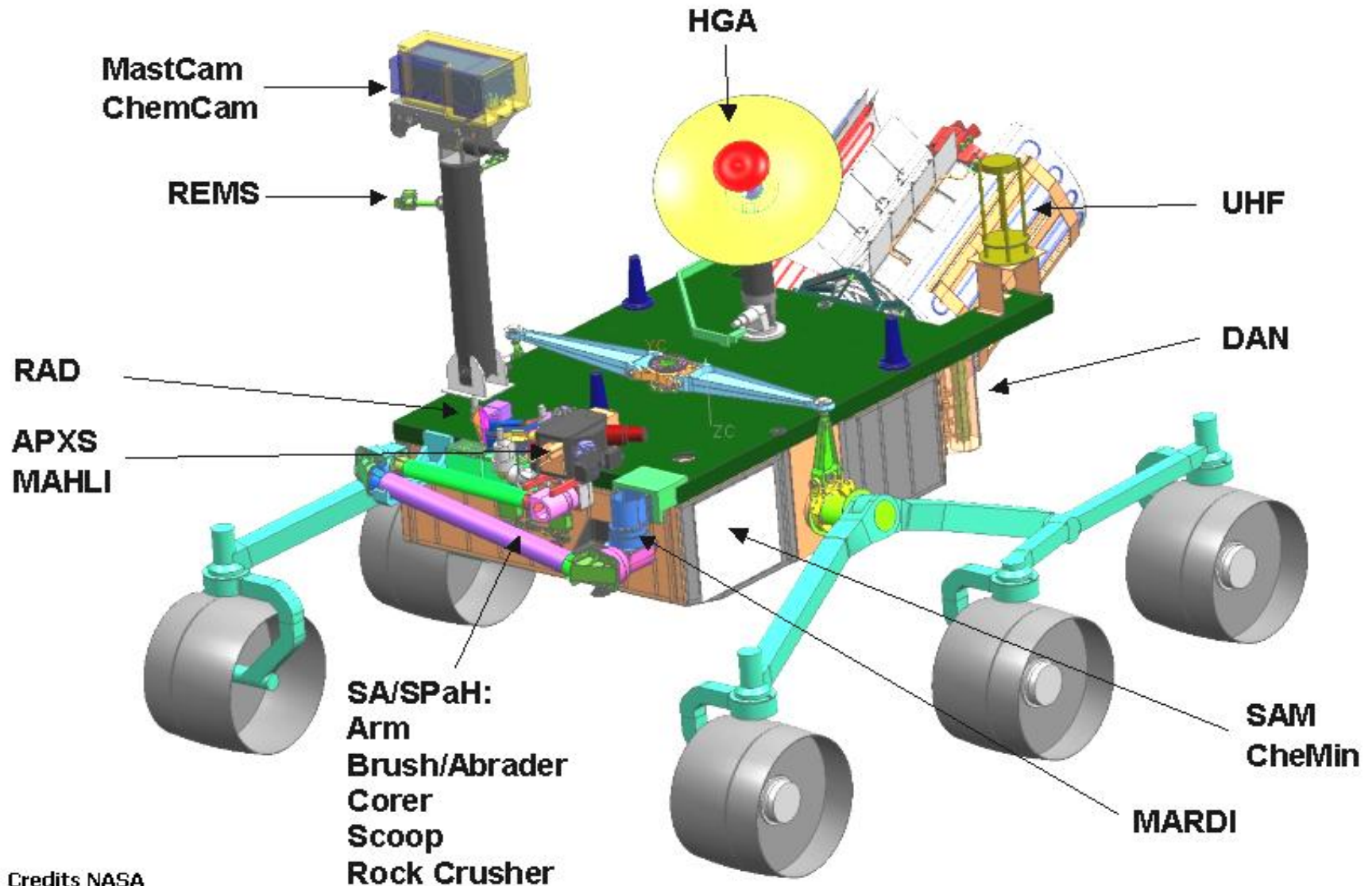
Landed mass 930 kg
Rover mass 930 kg
Payload mass 80 kg

Pathfinder (1996)

Landed mass 290 kg
Rover mass 5 kg
Payload mass 1 kg



MSL Payload defines current state-of-the-art for *in situ* investigations: Suite of Mast-, Arm-, and Platform-mounted instruments



Credits NASA

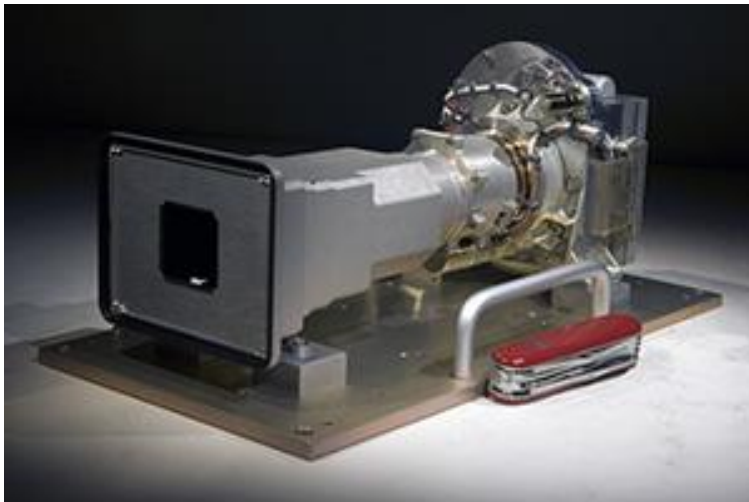
Trends for Mast-Mounted Instruments

(Examples)

Mast-Mounted Imagers

Trends (covered at greater length in Robert Gold's talk):

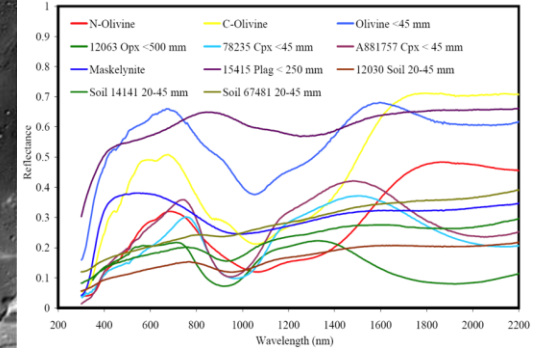
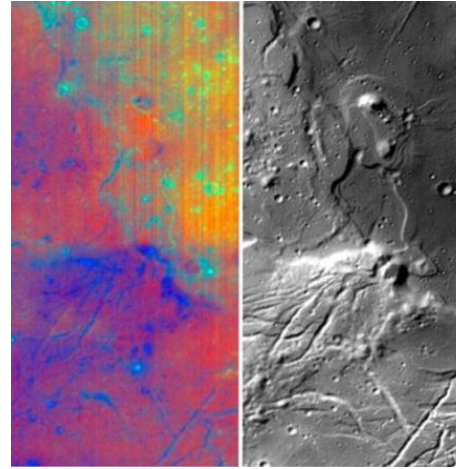
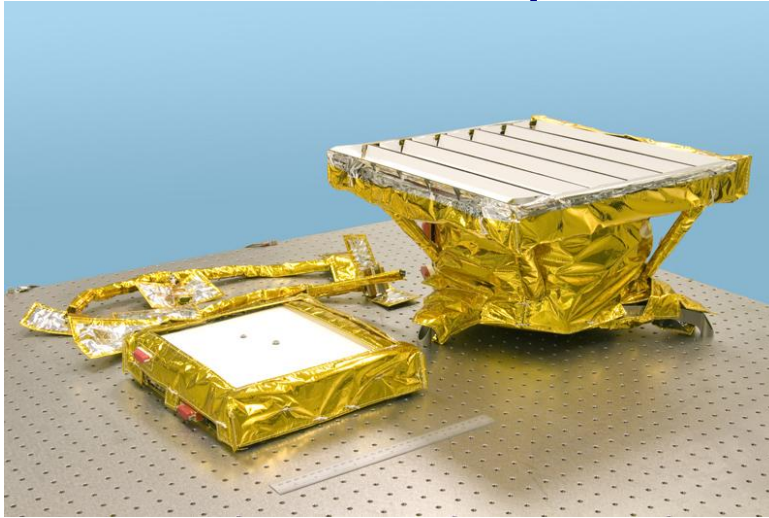
- Focus and zoom capability
- Use of Scientific CMOS focal plane arrays
- Advanced lenses (aspheric and graded-index elements)
- Miniaturization and power reduction



MSL MastCam (Malin Space Science Systems):
Color Medium and Narrow-Angle Imager

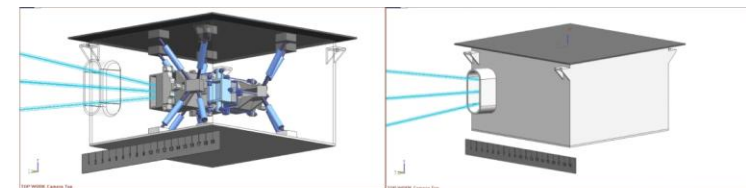
*Stereo-capable Bayer-color +12 filter panoramic imaging
5° and 15° FOV Cameras
Video capability*

Exciting technology trend: Miniature Reflectance Imaging Spectrometers compatible with mast-mounting



Current state-of-the-art:
Moon Mineralogy Mapper
8 kg, <15 W

Under development:
Ultra Compact Imaging Spectrometer (“Mini-M3”)
2 kg, ~5 W (mid-TRL)
(targets beyond Mars may require active illumination)



MINI-M3 Instrument with radiator & a 19 cm scale

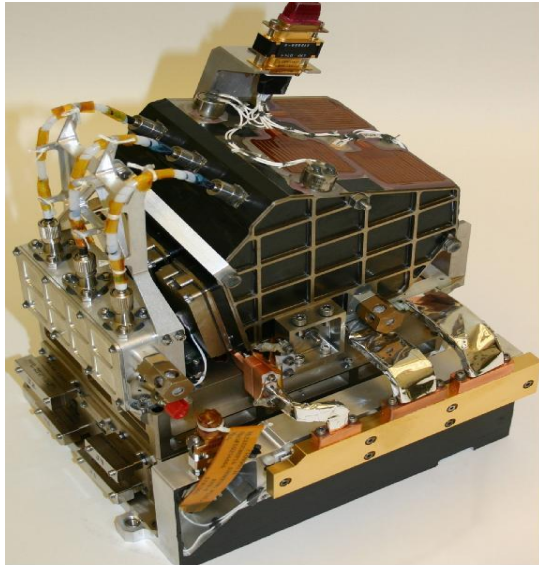


MINI-M3 Optical Bench Assembly and Ray trace diagrams

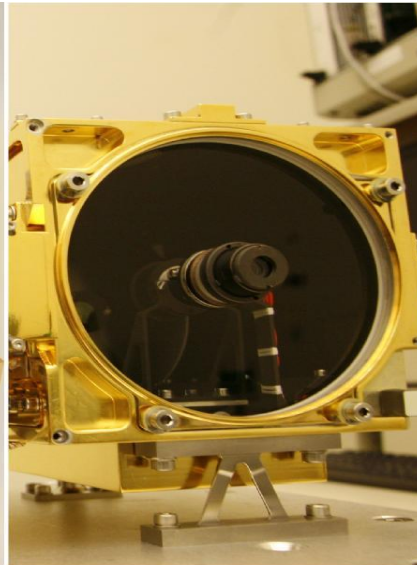
Mast-mounted laser spectroscopy instruments

Trends:

- Extension of laser-induced breakdown spectroscopy (LIBS) from Earth to other planetary bodies
- High power pulsed lasers for stand-off Raman (< 1.5 m) and LIBS (< 9 m)
- Combined Raman/LIBS
- Time-gated detectors, detectors with gain (Scientific CMOS, ICCDs, EMCCDs)



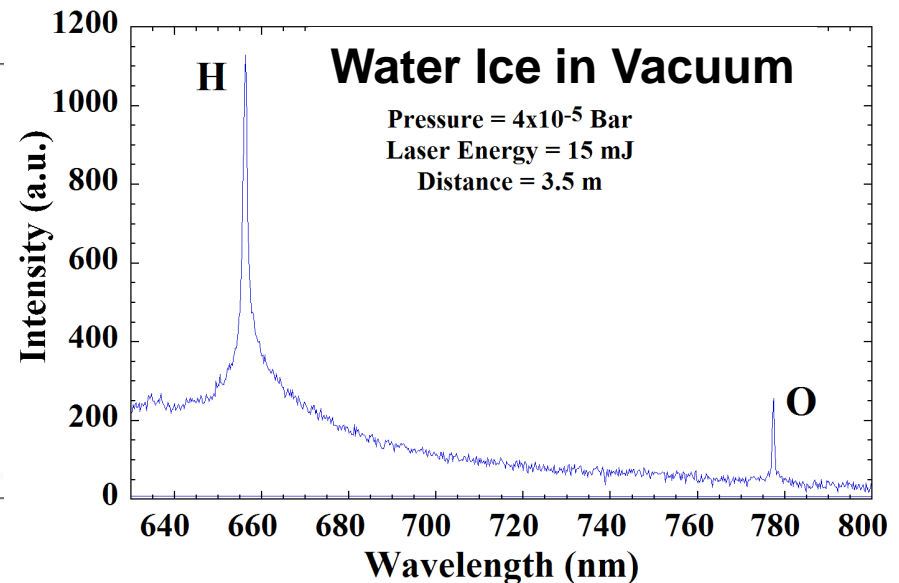
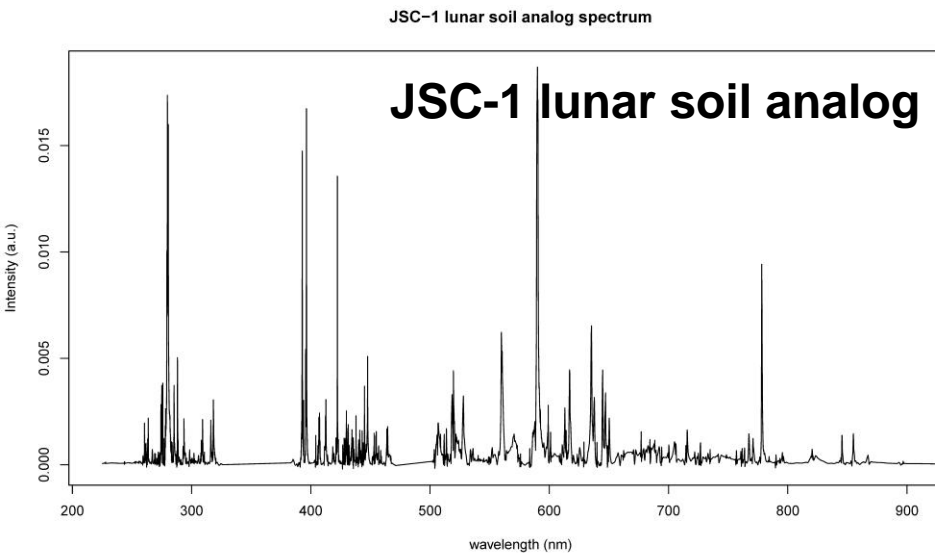
Elemental chemistry of a 0.5 mm spot from 1 to 9 m distance, 80 μ rad imaging @ 20 mrad FOV



MSL ChemCam (LANL):
Laser Induced Breakdown
Spectrometer & Remote Micro
Imager

LIBS is capable of producing high quality spectra under vacuum (as needed for primitive body surface missions)

- Plasma behavior is pressure-dependent, so LIBS spectral library must be acquired under vacuum (predictive capability improves with size of library)
- Investigations of mixtures of rock, carbonaceous material, and ices underway by LANL ChemCam team



LPSC 2011 abstract, “Applicability of LIBS on the moon: elemental analysis of lunar simulants under vacuum.” J. Lasue, R.C. Wiens, S.M. Clegg, D.T. Vaniman, K.H. Joy, S. Humphries. (Spectra courtesy of Sam Clegg, LANL.)

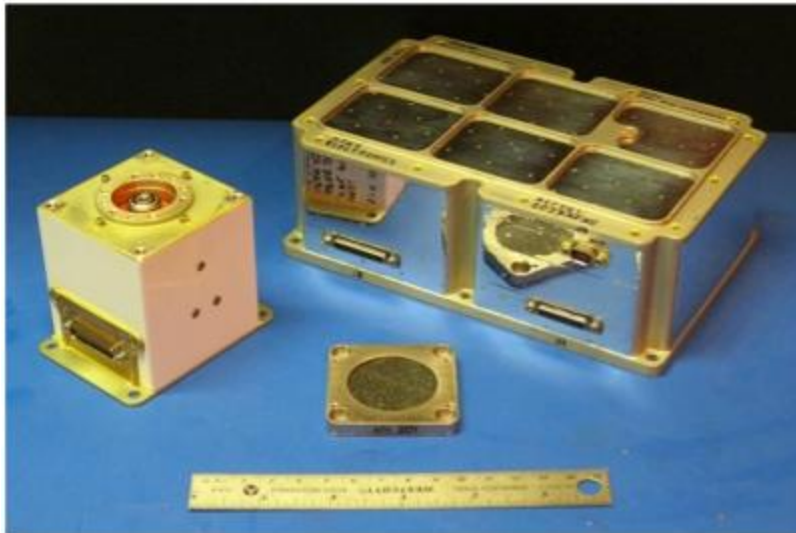
Trends for Arm-Mounted Instruments

(Examples)

Arm-mounted elemental analysis

Trends (mid TRL):

- Micro-scale mapping rather than bulk averaging
- Active X-ray excitation with miniature X-ray tubes
- Use of capillary focusing optics
- High performance X-ray detectors with improved spectral range and resolution



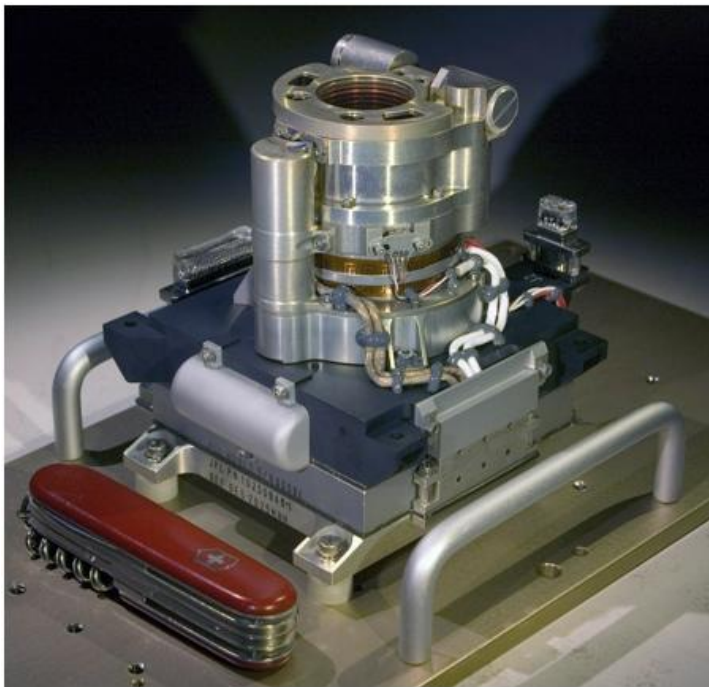
MSL APXS (CSA):
Alpha Proton X-ray
Spectrometer

Rock/soil elemental chemistry of a
1.5 cm spot in 15 min to 3 hrs.

Arm-mounted Imaging

Trends:

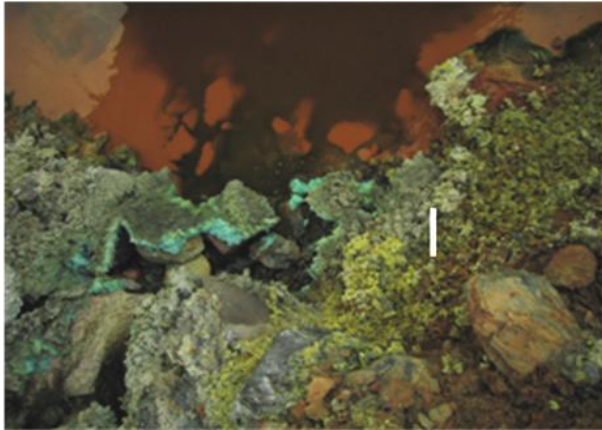
- Use of diode arrays to increase # of spectral bands
- Imaging over a wider spectral range (to near-IR) with InGaAs focal plane arrays
- Autofocusing
- UV fluorescence imaging



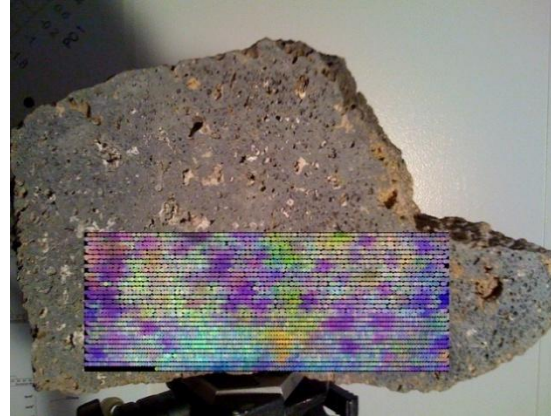
MSL MAHLI (Malin Space Science Systems):
Hand-Lens Imager

Bayer-color, 15 $\mu\text{m}/\text{pix}$, 1600x1200,
LED lighting, autofocus

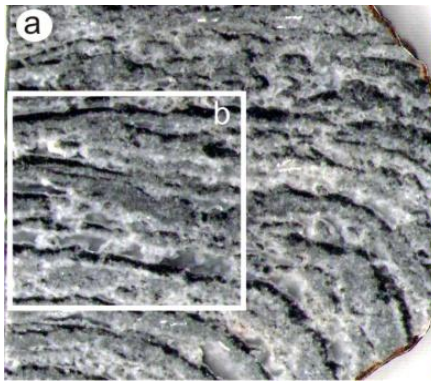
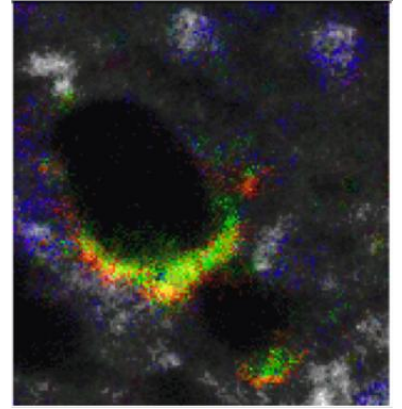
Future directions for in situ instruments: Integrating spectroscopy and imaging



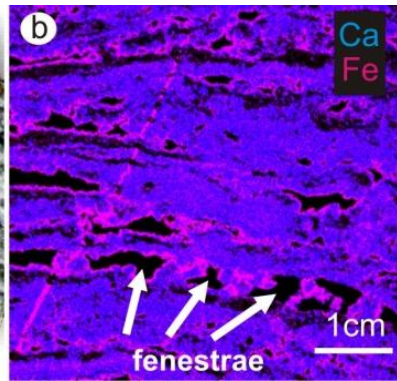
Near-IR mapping – mineralogy



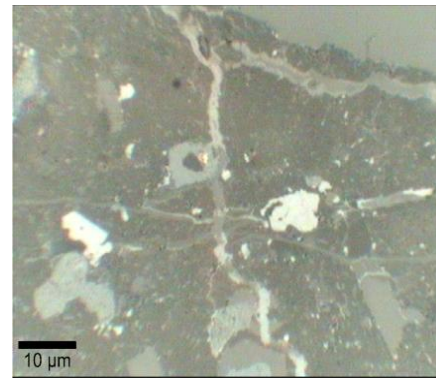
Deep UV Fluorescence mapping – sub-ppm organics



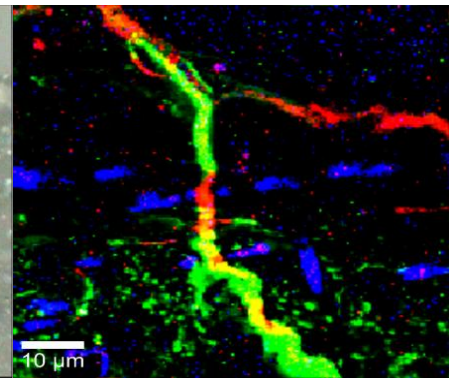
Visible



XRF mapping –
elemental composition



Visible



Raman mapping –
mineralogy

Mapping instruments could be used to relate mineralogy / chemistry / elemental composition / organics to textures, fabrics, and small scale structures.

How much small-scale variation is expected on small bodies?

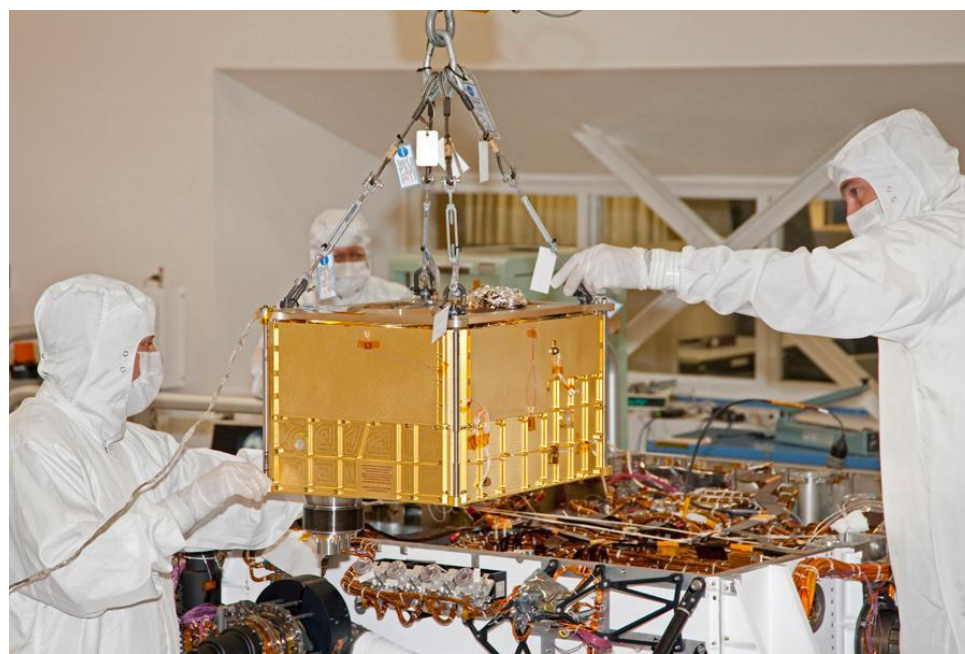
Trends for Platform-Mounted Instruments

(Examples)

Mass Spectrometers for Sample Analysis

Trends:

- Various approaches to sample introduction (e.g. Matrix-Assisted Laser Desorption Ionization)
- Various MS types: QMS, Paul trap, TOF, multi-bounce TOF; improved mass resolution, higher sensitivity, and extended mass range are desired
- MEMS-based GC columns
- Gas processing subsystems to improve measurement quality
- Power supply miniaturization



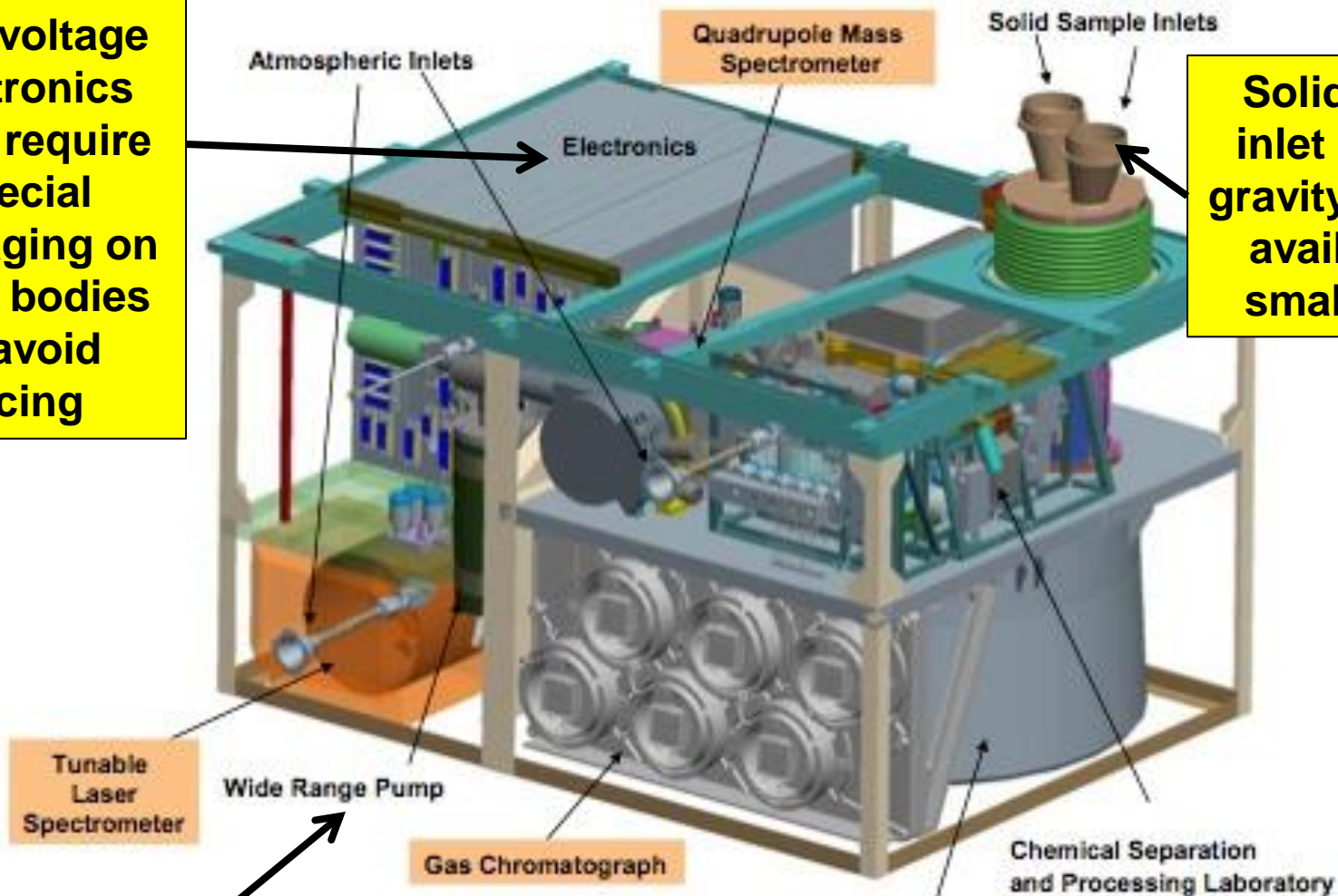
MSL Sample Analysis at Mars (SAM) (GSFC):

Gas Chromatograph/Mass Spectrometer
And Tunable Laser Spectrometer
~40 kg, up to 1 kW

Molecular & isotopic composition,
2-535 Dalton mass range for
atmosphere and evolved gas.
Continuous oven heating to
1000°C.

SAM design tailored for Mars surface applications, not for small body surface missions

High voltage electronics don't require special packaging on small bodies to avoid arcing



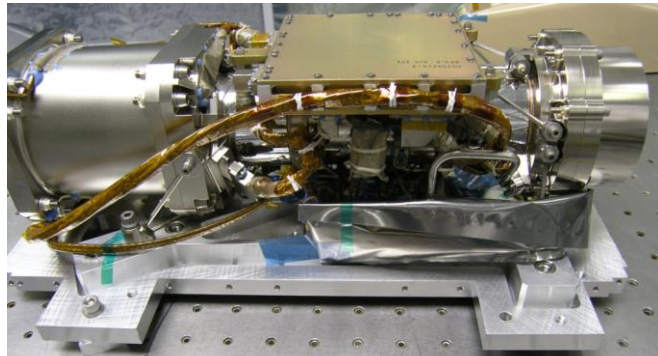
Solid sample inlet relies on gravity feed, not available for small bodies

Vacuum pumps not required on small airless bodies

Tunable Laser Spectrometers for Trace Gas and Isotopic Analysis

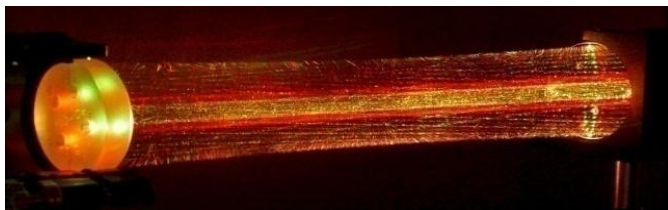
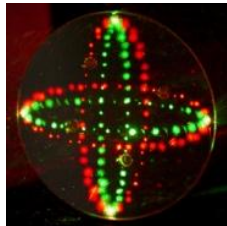
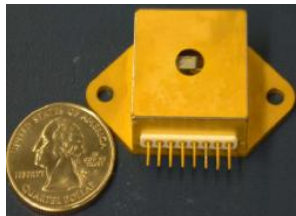
Trends:

- Early conversion from analog to digital electronics
- Room temperature IR lasers packaged with TECs, especially at 3-5 μm for hydrocarbons
- Reference gas cells with cte-matched window seals



MSL Tunable Laser Spectrometer (TLS)
in SAM (JPL)

TLS uses long pathlength IR laser absorption within a multipass Herriott cell to record ultrahigh-resolution (0.0005 cm^{-1}) direct and second-harmonic spectra of selected IR rotational and vibrational absorption lines of targeted gases. Depending on laser selection, TLS delivers ultra-high-accuracy, unambiguous measurements of gases such as H_2O , CH_4 , CO_2 , OCS , and CO (not all measured on MSL). TLS can precisely measure isotope ratios such as $^{13}\text{C}/^{12}\text{C}$ in both CO and CO_2 ; $^{18}\text{O}/^{17}\text{O}/^{16}\text{O}$ in CO_2 ; $^{34}\text{S}/^{33}\text{S}/^{32}\text{S}$ in OCS ; both D/H and $^{18}\text{O}/^{16}\text{O}$ in H_2O .

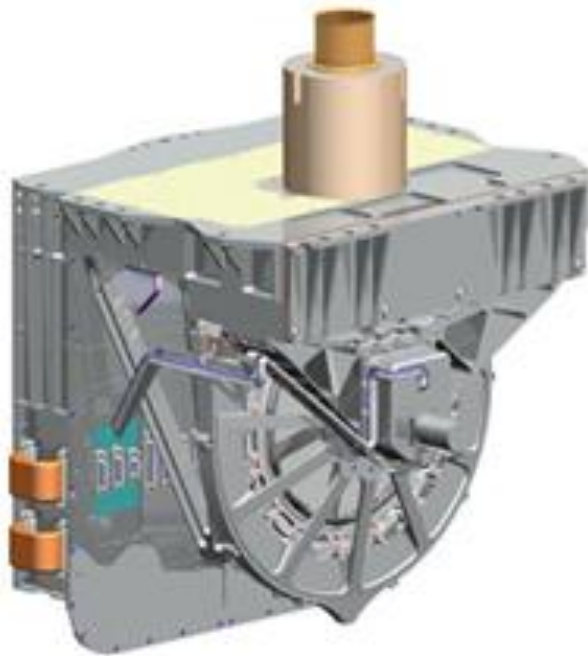


X-ray Diffraction Instruments for Mineralogy

Trends:

- X-ray microfocus tube & power supply miniaturization
- Reflection as well as transmission geometries
- Deep-depleted CCDs with integral TECs
- Design modifications for improved simultaneous XRD/XRF quantitative analysis capability

MSL CheMin (ARC PI Dave Blake / JPL build)



Identification of a wide range of minerals at
> 3 wt% abundance

Miniature X-ray tube (5W)

600x600 40um pixel CCD

Sample wheel with 36 vibrated cells

Gravity-fed Sample delivery funnel

Mass = ~10 kg

Power = ~40 W

Size = ~30X30X30 cm.

XRD Range = 5 - 55° 2 θ

XRD resolution = 0.30° 2 θ FWHM

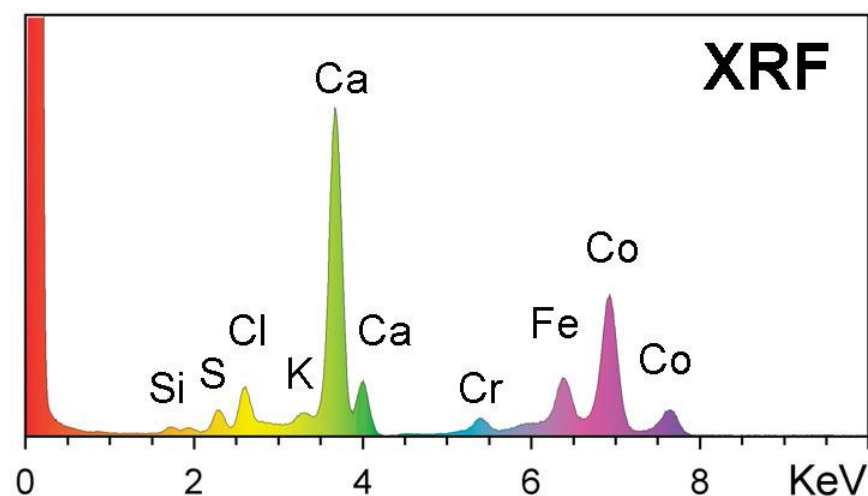
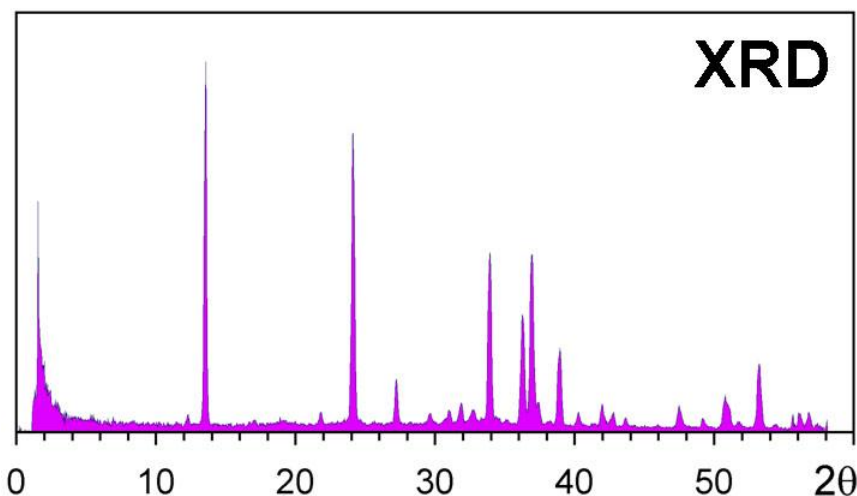
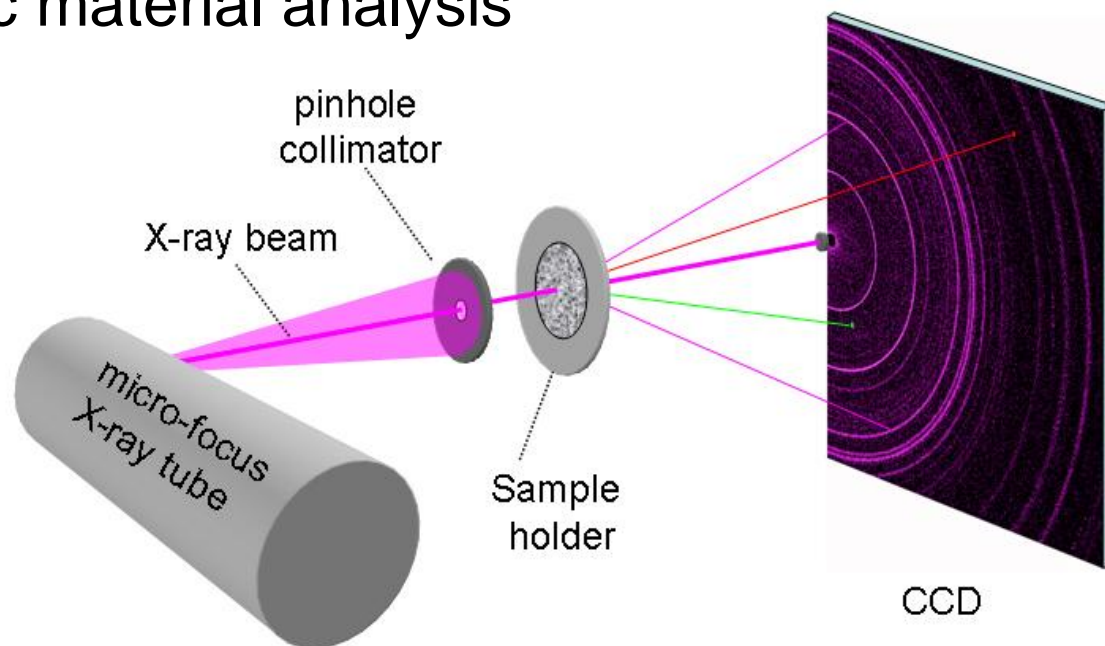
XRF range = 1.5 – 10 KeV

XRF resolution = <220 eV @MnK α (temp.
dependent)

CheMin – MSL 2011

Suitable for rock and regolith analysis, not for icy/carbonaceous/organic material analysis

- Transmission geometry
 - CCD detector for simultaneous XRD & XRF
 - Sample motion to handle coarse particles ($<150\mu\text{m}$)



Instruments similar to SAM, TLS, and CheMin require solid sample ingestion on landed small body missions

Challenges to collecting solid samples during a small body surface mission (not touch-and-go):

- Low gravity:
 - Anchoring required?
 - Sample delivery can't rely on gravity assistance
- Low pressure (vacuum):
 - Triboelectric, pyroelectric charging may cause powders to stick
 - Quantification of sample size not trivial
 - Liquid extraction requires gas management & sealing
- Other issues:
 - Low temperature operation – need to avoid sample heating that could compromise science
 - Strict contamination control for organic analysis
 - Samples may contain mixtures of rocky, icy, and carbonaceous materials



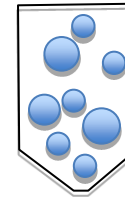
Challenges to collecting liquid samples



- In typical planetary environments, gravity overcomes surface tension and condenses liquids into continuous pools.
- In low gravity, surface tension dominates and you must separate liquids from gases because bubbles or air pockets interfere with or even stop fluid flow in microfluidic devices.
- Thus, you must separate liquids from gases (techniques include capillary forces into a porous hydrophilic media, cyclone pneumatics).



Fluid collection, high gravity



Fluid collection, low gravity

Active neutron spectroscopy; Neutron-activated gamma-ray spectroscopy

Trends:

- In situ active neutron pulsing with measurement of both returned neutrons and gamma-rays
- Neutron sensors with improved energy resolution
- Gamma-ray detectors with improved energy resolution



MSL Dynamic Albedo of Neutrons, or DAN (IKI): Neutron Backscatter Subsurface Hydrogen Detection



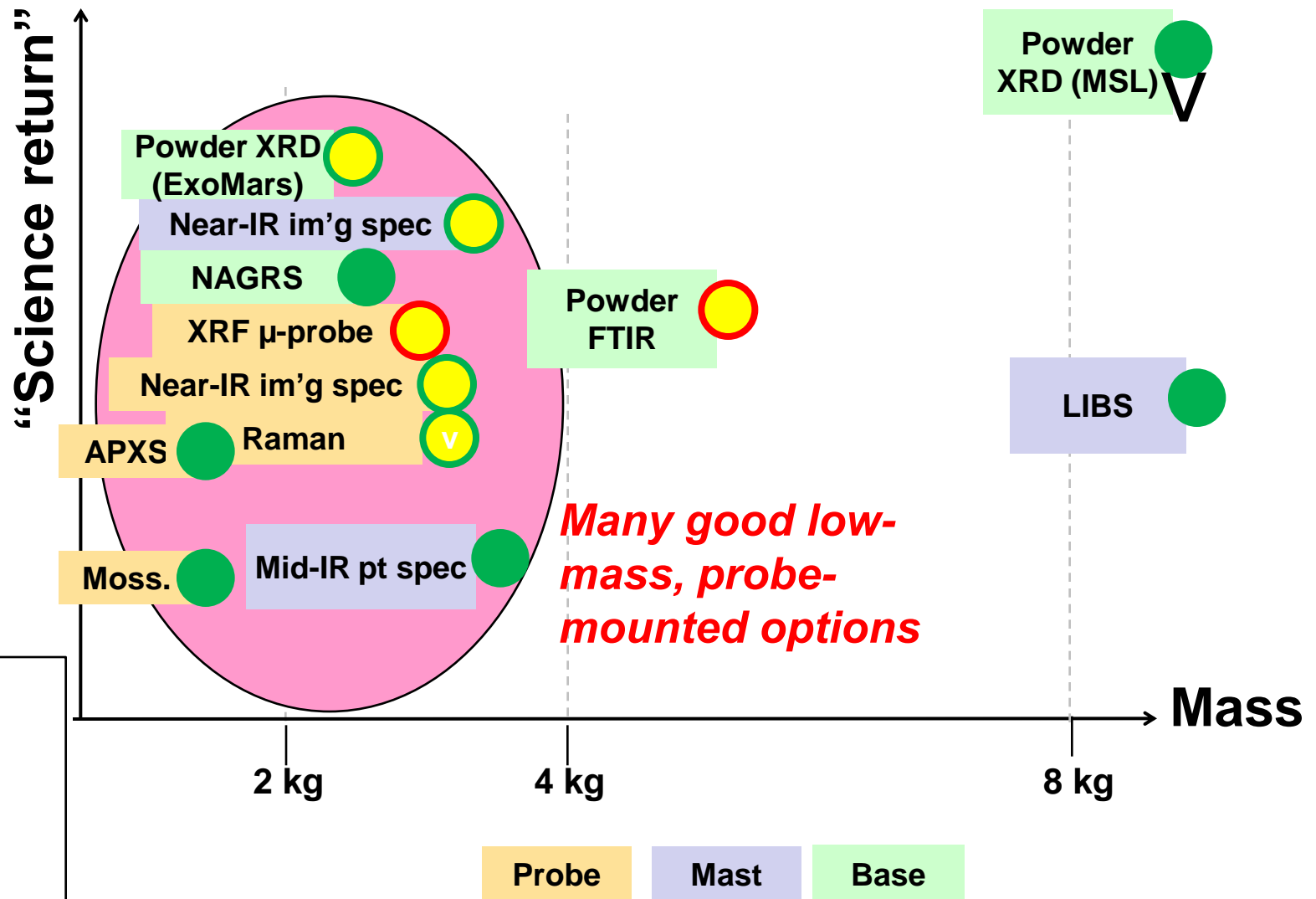
Active and passive neutron spectroscopy in-situ: H in upper 1 m

Active neutron pulsing can be coupled with gamma-ray spectroscopy to probe bulk elemental composition in upper ~1 m (not included on MSL, but option for future planetary missions)

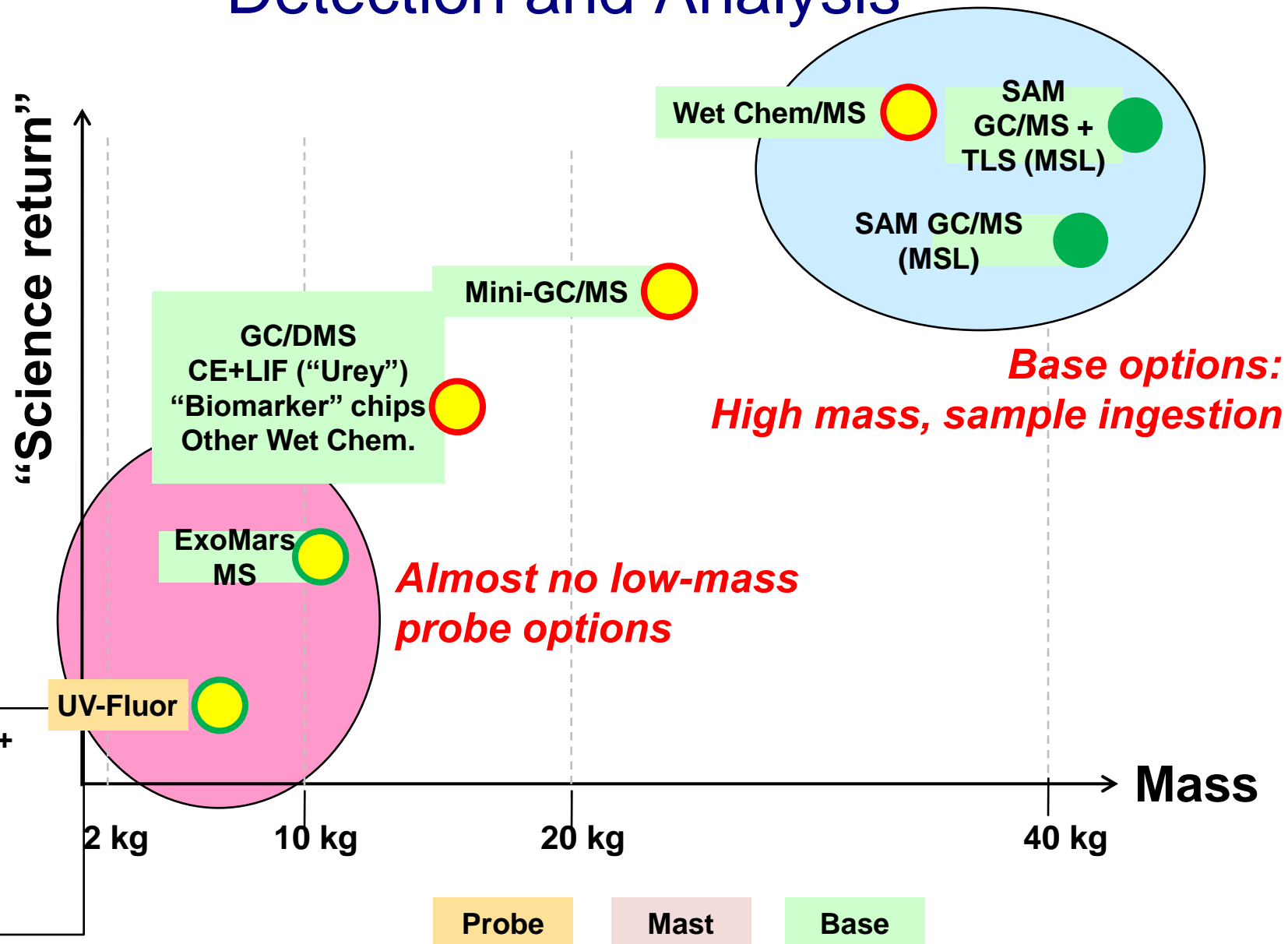
An Approach to Instrument Classification for Mineralogy and Organic Compound Detection

*(Preliminary, not comprehensive –
relative “science value” depends on mission goals
& instrument implementation.)*

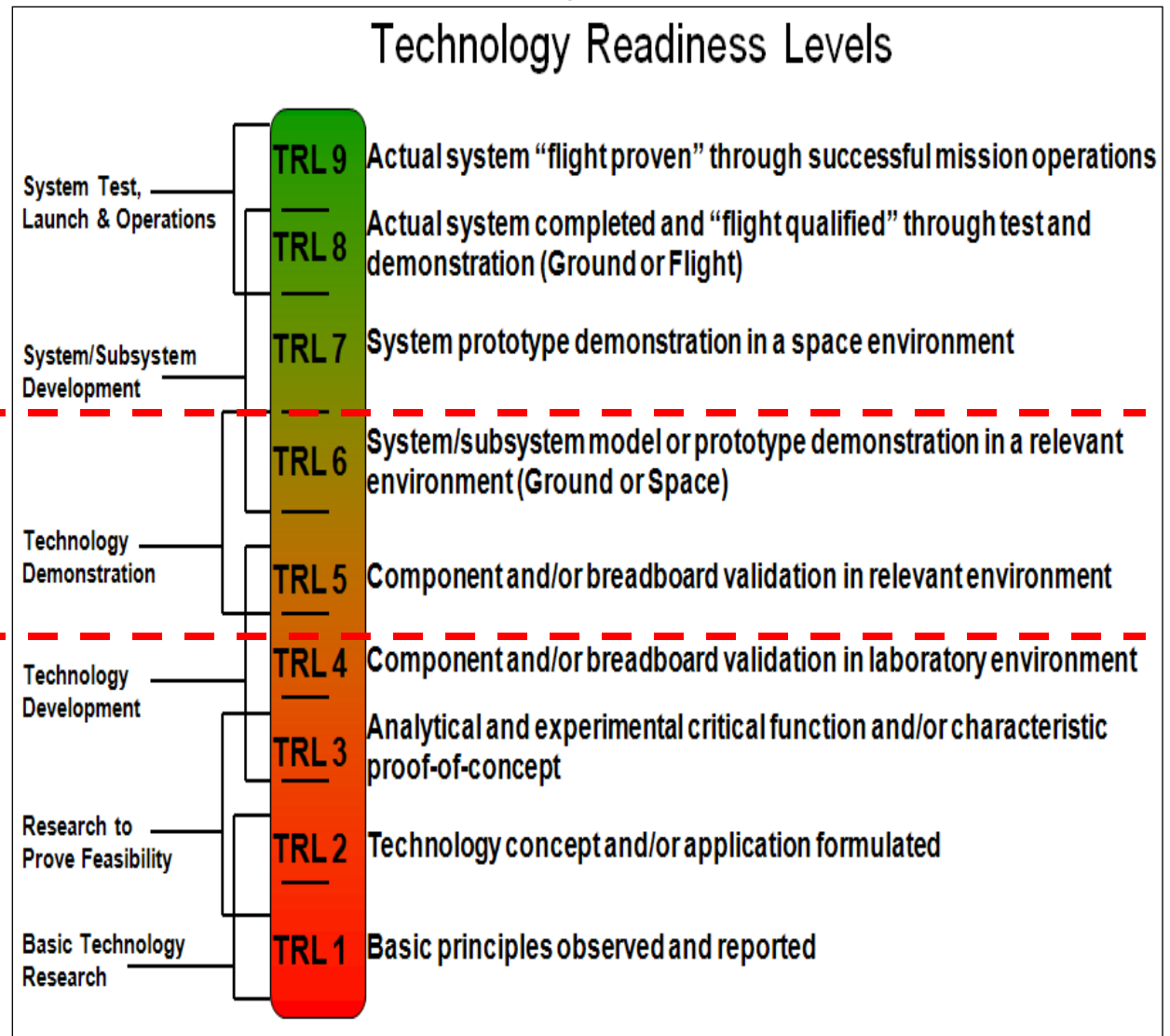
In Situ Mineralogy Instruments: Crystal structure, inorganic chemistry



In Situ Instruments for Organic Detection and Analysis



Assessing In Situ Instrument Readiness for Small Body Missions



**Critical
development need
and funding gap**

Summary

- The sheer diversity of small bodies makes in situ instrument development for these targets challenging
- In situ instruments for small bodies must provide compelling science return for a given mission cost; the option of sample return is very attractive
- The last decade of Mars exploration can provide:
 - A framework for analysis
 - State of the art in situ instrument concepts for small body exploration
- The vacuum, low gravity environment on small bodies presents unusual challenges for sample acquisition and handling, particularly if liquid handling is required
- Some low-mass options exist for mineralogy conducted on a mast or robot arm, but high quality organic compound analyses currently require sample acquisition
- There are many exciting technology trends – but new technologies will require adequate funding to cross the “Mid-TRL desert”!