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Miniature Tunable Laser Spectrometers for Quantifying Atmospheric Trace Gases, Water Resources, Earth Back-Contamination, and In Situ Resource Utilization

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Jet Propulsion Laboratory, California Institute of Technology

Concepts and Approaches for Mars Exploration
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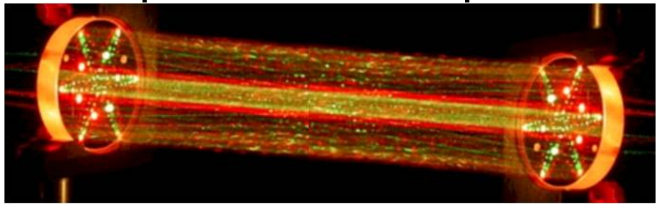
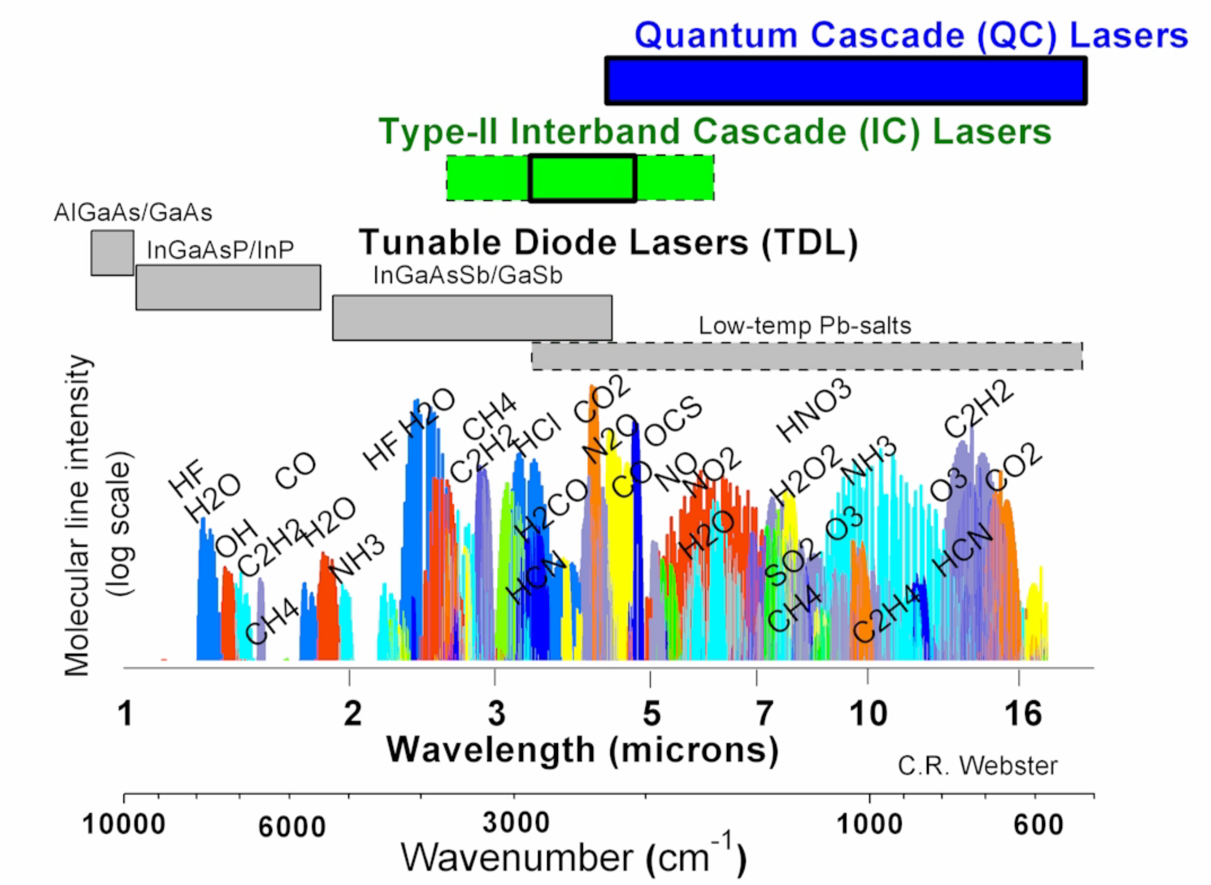
Tunable laser spectrometers

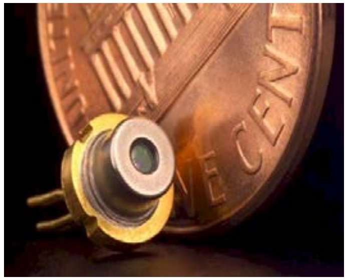
- The TLS technique has seen wide applicability in gas measurement and analysis for atmospheric analysis, industrial, commercial and health monitoring and space applications;
- In Earth science using balloons and aircraft over 2 decades, several groups (JPL, NASA Langley & Ames, NOAA, Harvard U., etc) have demonstrated the technique for ozone hole studies, lab kinetics measurements, cloud physics and transport, climate change in the ice record;
- The recent availability of high-power (mW) room temperature lasers (TDL, IC, QC) has enabled miniaturized, high-sensitivity spectrometers for industry and space
  - Mars, Titan, Venus, Saturn, Moon
  - Commercial isotope ratio spectrometers (e.g. Picarro) are replacing bulkier, complex isotope ratio mass spectrometer (IRMS)

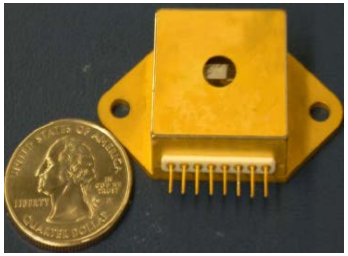


Lasers and Detectors for a TLS

Solid-state miniature devices available at room temperature (TEC stabilized)

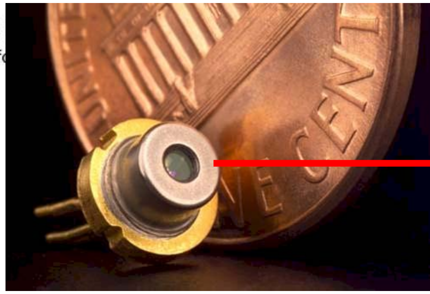






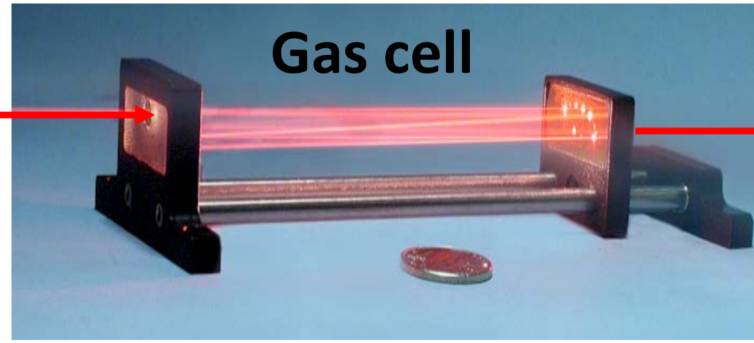
TLS laser – 100 g

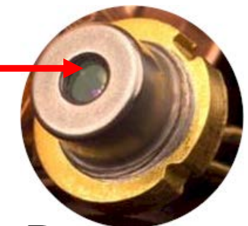
Tunable Laser Absorption Spectroscopy



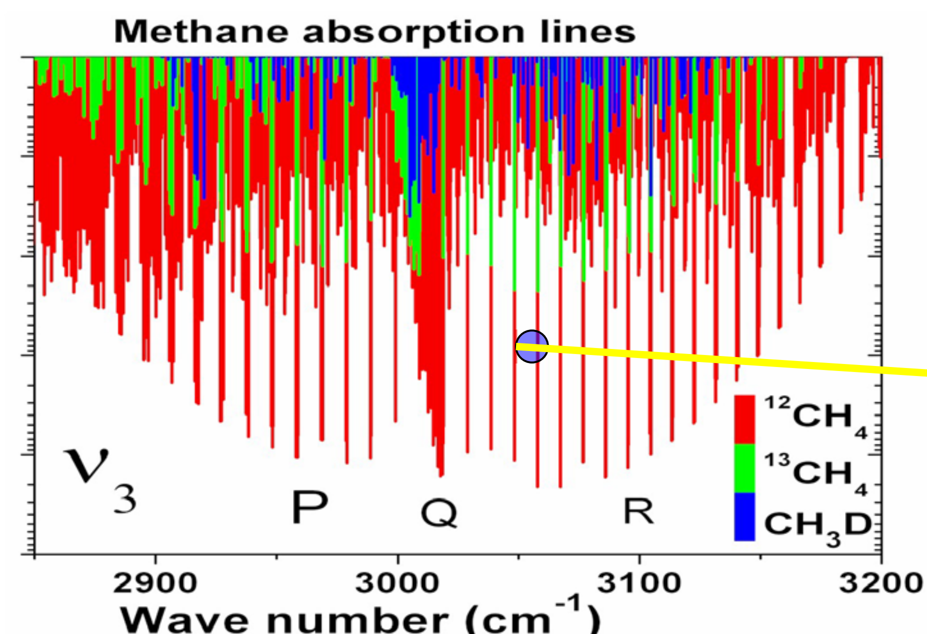
Tunable laser

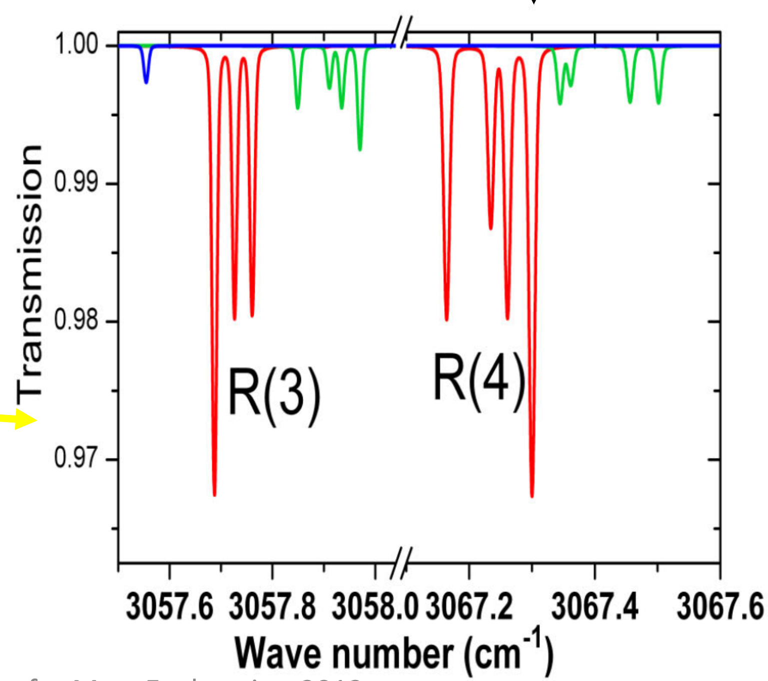
1-12 µm





Detector





Comparing the Mass Spec. and TLS

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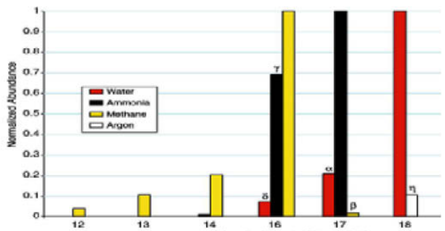
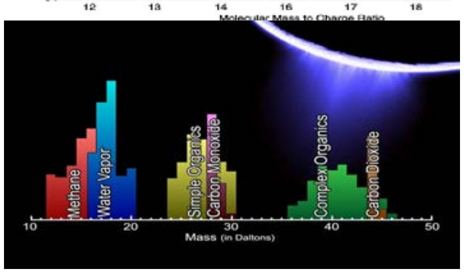
Mass Spectrometer:

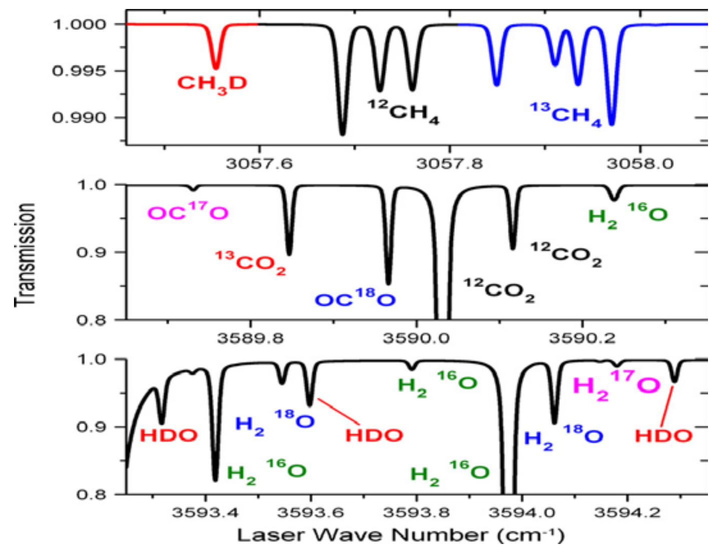
- Surveys all gases;
- Essential for noble gases & complex organics;
- High vacuum instrument needing pumps, bakeout
- Mass interferences in D/H, CO/N_2, $^{13}CO_2$ (Phoenix), methane, ammonia and water.





Tunable Laser Spectrometer:

- Targets specific gases- no interference;
- Direct, non-invasive, with high sensitivity to water, methane, other gases;
- Carbonates, hydrates to 10^{-9} wt%
- High precision ~0.1% CHNOS isotope ratios without interferences
- "High" pressure (0.1-100 mbar) instrument
- All solid-state with no moving parts.



Cell configurations for TLS

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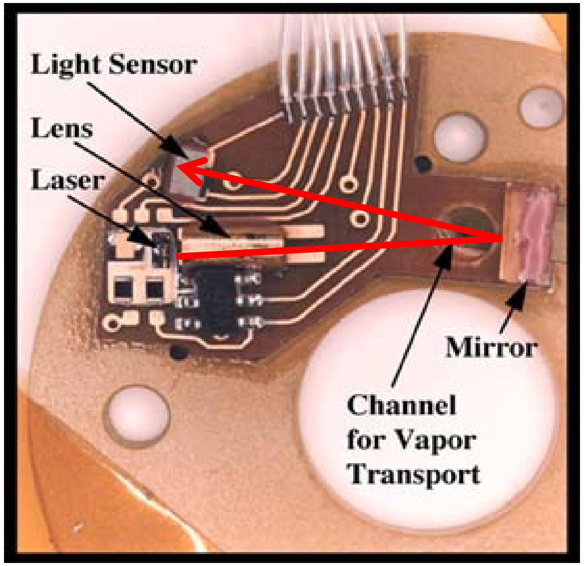
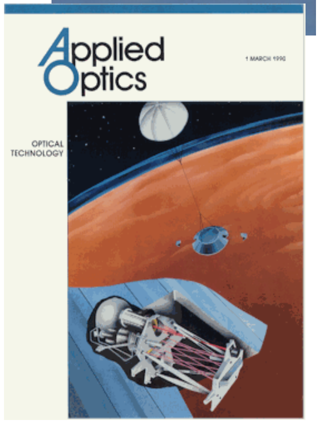
- Open path Herriott cell or to reflector
  - DS-2 penetrator, Cassini Huygens, Mars 98 MVACS, atmospheric probes, Mars balloon



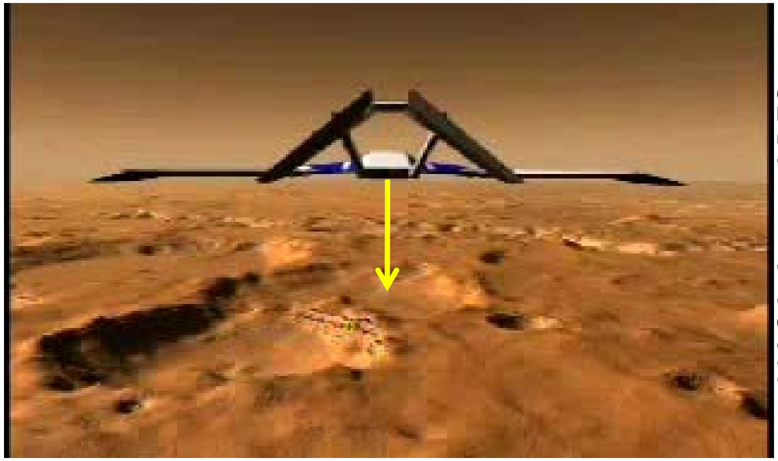
DS-2 penetrator TLS for H_2O- 3cm path

Mars Probe Hygrometer

Earth balloon TLS



- Open path to surface (topographic)
  Mars airplane (Joel Levine, Wendy Calvin)



NASA Ames ARES

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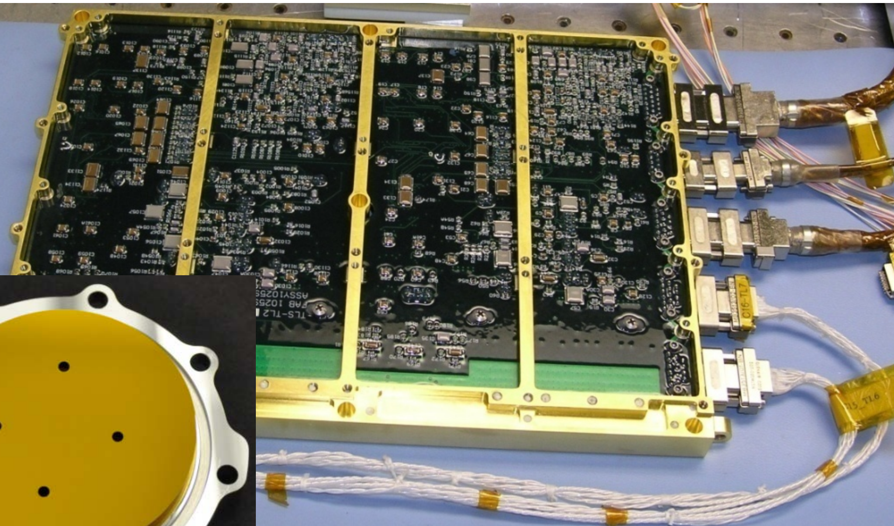
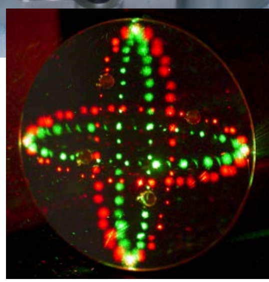
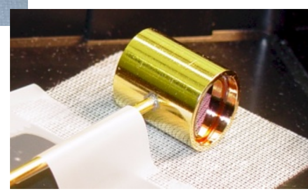
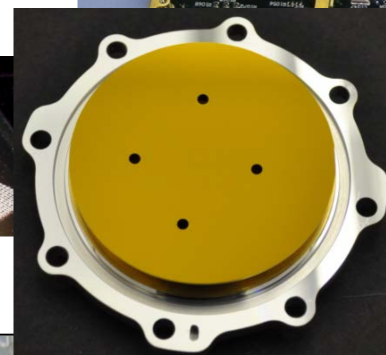
Surface Landers & Rovers

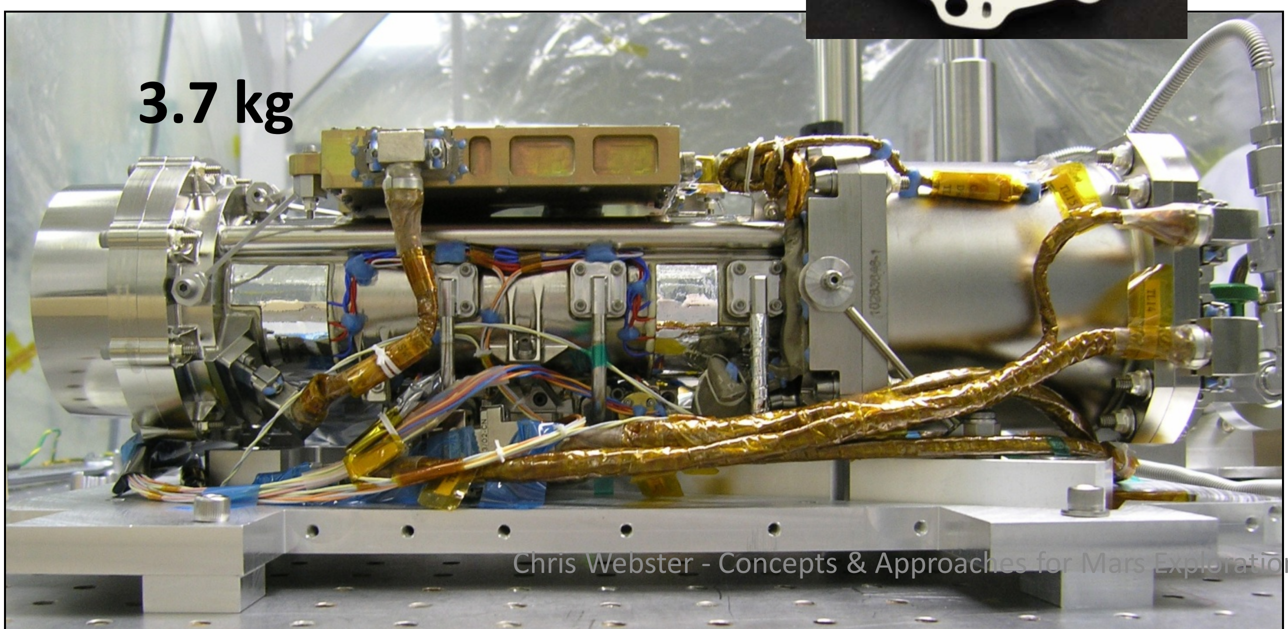
TLS flight hardware

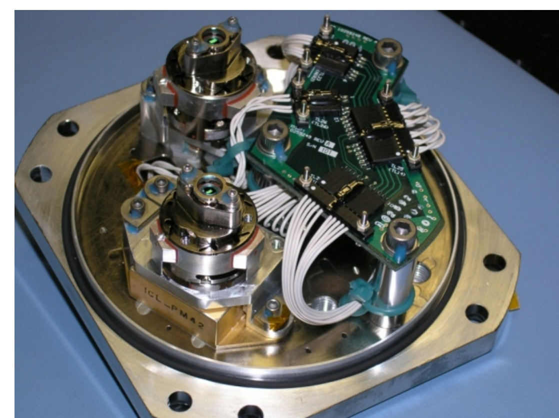




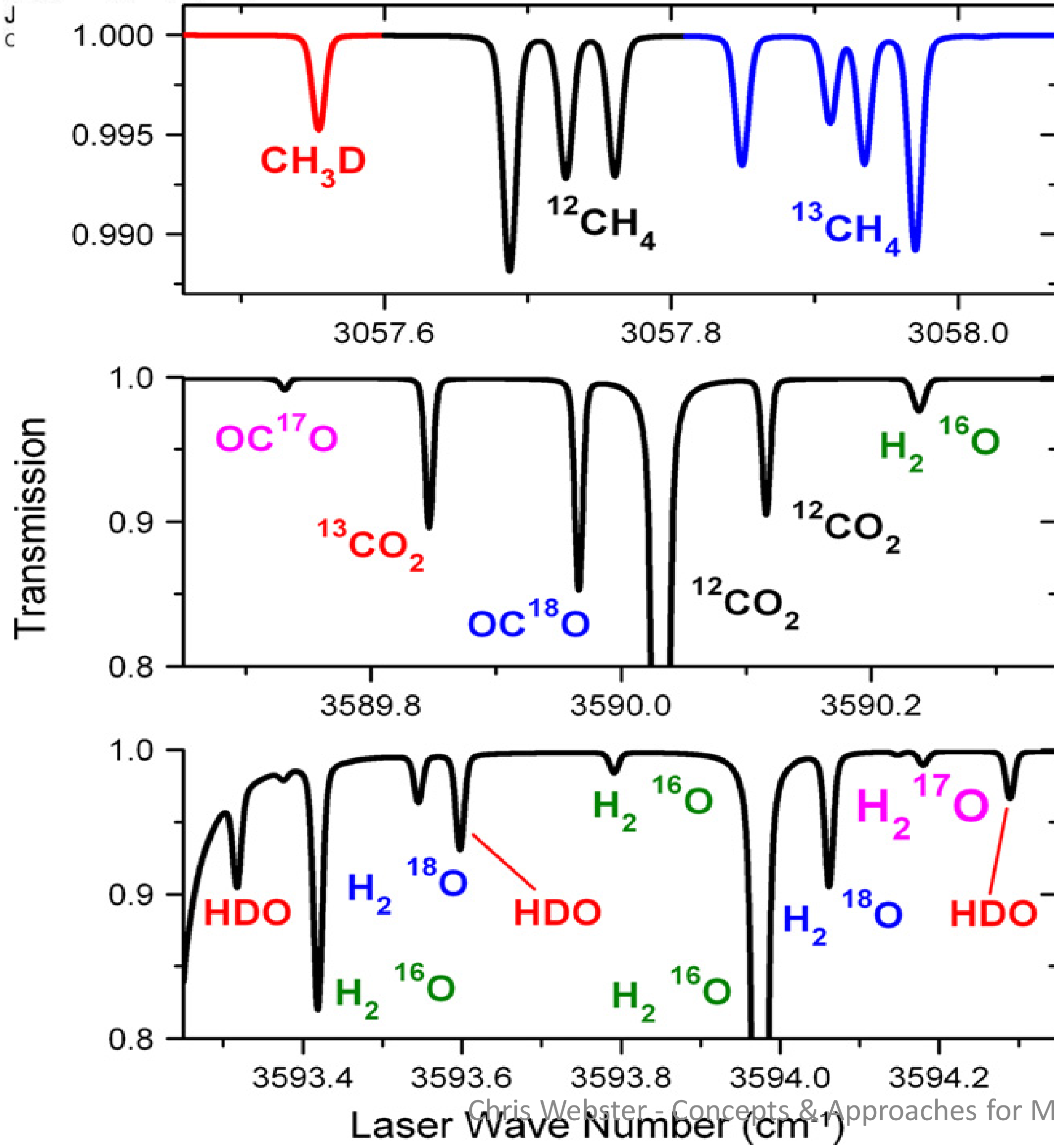




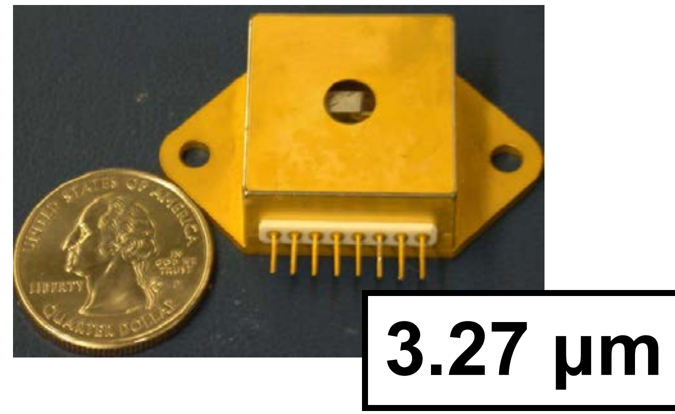




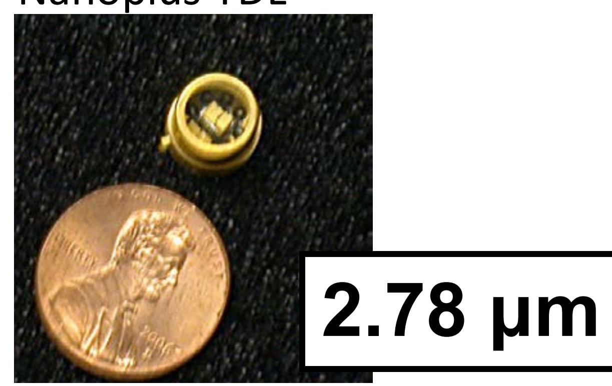
TLS target spectral regions



JPL IC laser



Nanoplus TDL



Gas abundances

- High spectral resolution provides high sensitivities (ppb or less) for numerous gases:
  - HCl, HF, NO, NO2, CO, CO2, H2O, CH4, O3, SO2, H2S, NH3
- Rocks, solids, liquids are made to produce gases through pyrolysis, laser ablation, combustion, reaction;

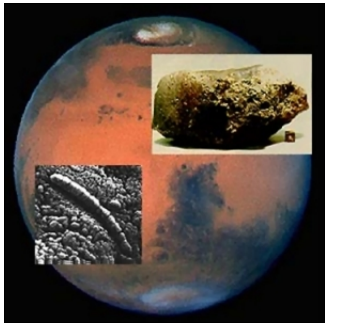
Stable isotope ratios

- Carbon $^{13}C/^{12}C$ identifies biological & chemical processing:
  - Plants deplete ^{13}C by 2-4% and bacteria can produce 12% depletion;
  - C isotopes in carbonates reveal formation temperatures
- Oxygen-18 identifies rock and meteorite types, and is an indicator of solar system origin and evolution
- D/H reveals planetary origin and outgassing (escape)
- S and N isotopes detail biological and dynamical processing

High Science Return Isotope Ratio Measurements for Mars

Carbonates in the Martian meteorite Allan Hills 84001 formed at 18 ±4 °C in a near-surface aqueous environment

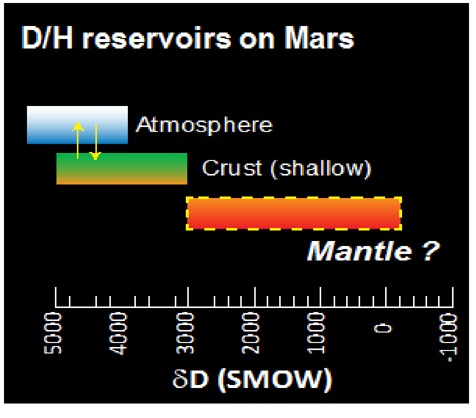
- Itay Halevy, Woodward Fischer, John Eiler, 2011



• K-Ar dating says meteorite is 4 billion years old;

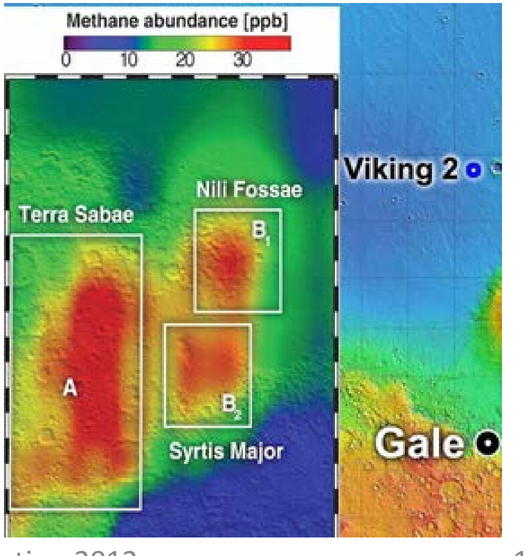
• Isotope ratios in ^{3}He, ^{21}Ne and ^{38}Ar say it was in space (cosmic ray exposure) for 10-20 million years!

•^{14}C dating says that it sat in Antarctica for 13,000 years;



•What will MSL-SAM reveal about Mars?

• Is Mars CH_4 biogenic?



ISRU resources

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- ISRU for Mars- use of resources found or manufactured for habitation- building materials, water, oxygen for breathing, fuel, energy sources, shielding materials;
- The availability and detection of water is critical for exploration
  - Frozen surface ice, subsurface water within a meter
- A miniature TLS can be extremely sensitive to water and other volatile gases evolved from clays, hydrates, carbonates
  - TLS detection limit for evolved H_2O, CO_2 is 10^{-9} weight% carbonate, hydrates in rocks
  - For CH_4 fuel production through Sabatier process, TLS can monitor both reactants (CO, CO_2) and product (CH_4, H_2O)

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ or the reaction $CO_2 + H_2 \rightarrow CO + H_2O$

Space station, on-surface cabins, astronaut health diagnostics

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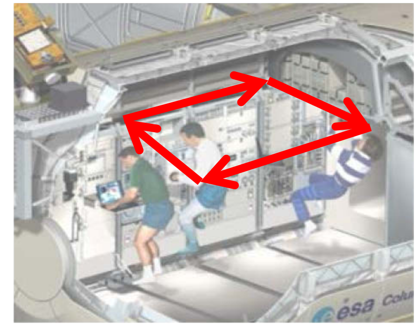
- Laser beam around top perimeter of cabins and on-surface structures monitor
  - Respiratory and waste gases CO_2, O_2, H_2O (humidity) CH_4, H_2S, NH_3;
  - Contaminants like HCl, HF, CO, H_2S, N_2H_2 (hydrazine);
- Earth back-contamination
  - Across-capsule monitor of ppb CH_4, H_2S, NH_3 for microbial activity during sample return back to Earth;
- Astronaut health
  - In-suit or in-helmet monitor of respiratory gases CO, CO_2, H_2O, O_2 and of key isotope ratios for breath analysis
  - e.g. $^{13}CO_2/^{12}CO_2$ for human breath diagnosis of vital organs, stomach ulcers



Genesis sample return capsule