Hot Jupiter in a Tube

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Laboratory emission spectroscopy of simulated hot Jupiters

- Hypothesis: Mimic exoplanet physical conditions to obtain lab spectra for interpreting observations.
- Alternative to modeling based on lab/theory line parameters and assumptions about composition and equilibrium.

Approach

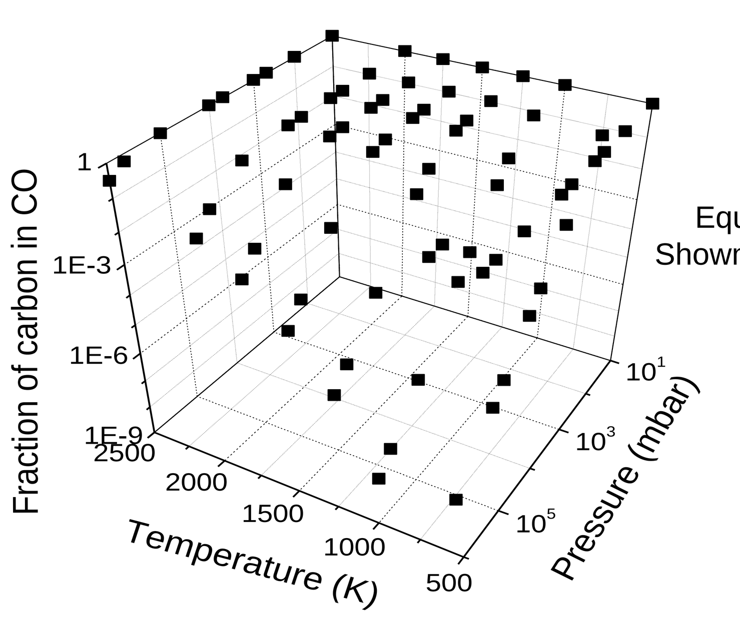
- Emission spectra from equilibrium and non-equilibrium mixtures
- Pressure and temperature gradients.
- Furnace and microwave discharge
- Fourier transform spectrometer (UV to far-IR)

Significance

- Emission spectra of exoplanets are known from emergent flux method.
- Exoplanet molecular bands can appear as *emission*, in contrast to usual absorption for stars.
- Non-equilibrium chemistry likely for hot Jupiters

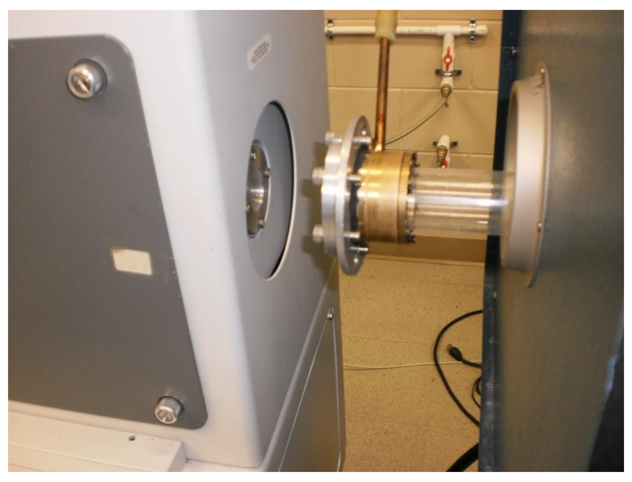
Particular case

$CH_4 \leftrightarrow CO$ in mixtures with water vapor and carrier gases H_2 and He
Relevance: hot Neptune GJ 436b with 7000-fold methane deficiency [Stevenson, Harrington et al 2010].



Equilibrium case [Cooper and Showman 2006]. Assumes specific reaction pathway.

Equilibrium, in furnace
- Isobaric (1 mbar – 10 bar)
- Isothermal (600 – 1800 K)

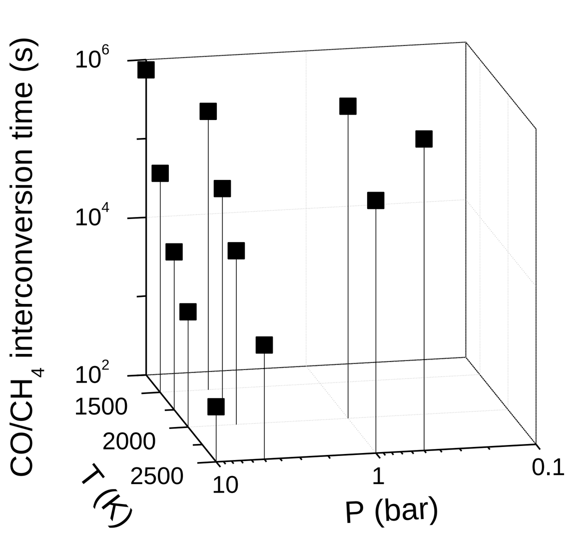


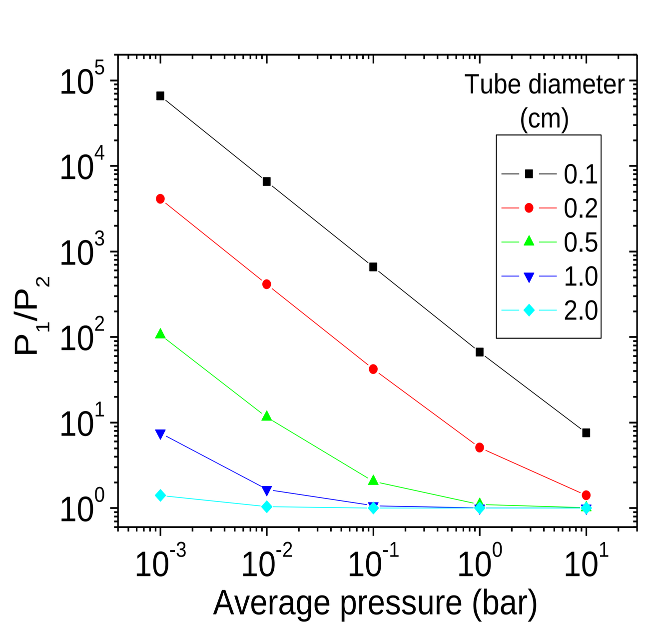
Reasons for chemical dis-equilibrium in exoplanets

- Dynamic mixing may be faster than chemical reactions;
- Photo-dissociation elevates photochemical products above equilibrium levels;
- No chemical equilibrium for HD 209458b in 1-1000 mbar range [Copper and Showman 2006]

Disequilibrium chemistry in a furnace

- For pressures relevant to observations, CO/CH_4 interconversion is slow [Cooper and Showman 2006]
- Assumes particular reaction pathway
- Possible to observe interconversion and non-equilibrium spectra on convenient laboratory time scales.





Observations along column with pressure and temperature gradients

GJ436b Hot Neptune (Stevenson, Harrington et al. 2010)

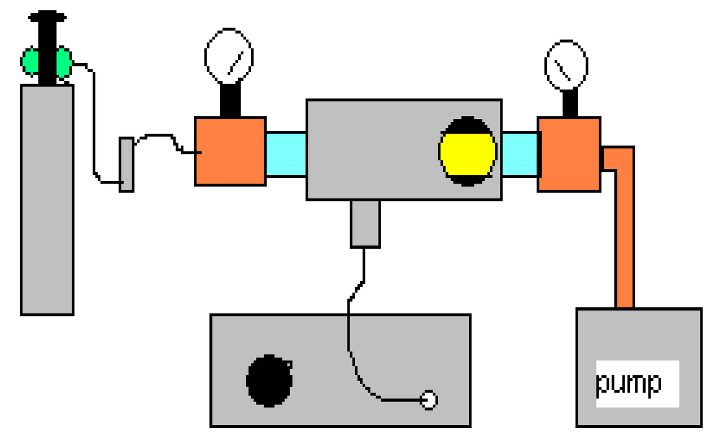
Observational facts	**Interpretation**
No 1.4 micron water absorption	low water?
Strong 3.6 micron emission	low CH4 absorption
Weak 4.5 micron emission	high absorption by CO/CO2
Modest 5.8 micron emission	Little hot H2O emission
Modest 8.0 micron emission	Little hot CH4 emission
Strong 16 micron emission	weak CO2 absorption

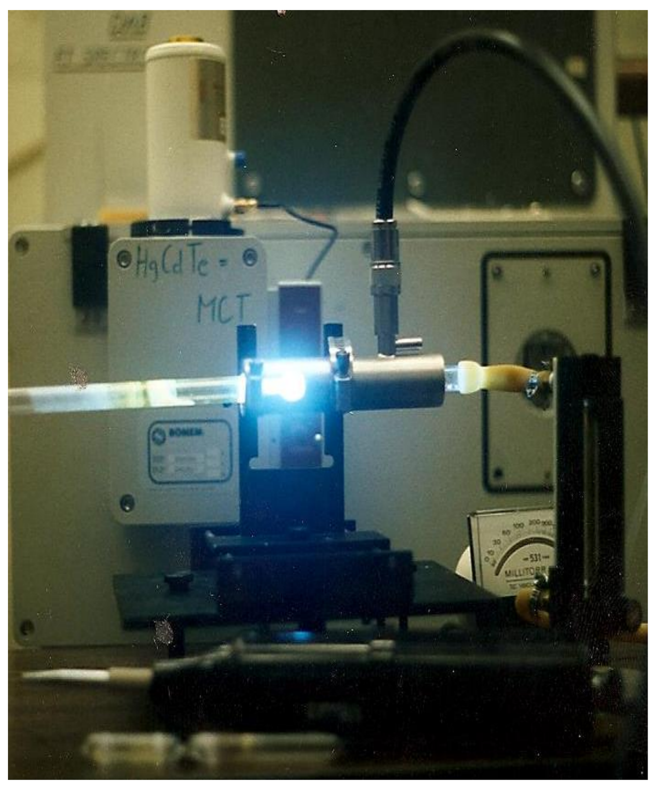
Conclusions

CO dominates IR active molecules
Much less CH4 than expected from equilibrium model
- Strong vertical mixing to give non-equilibrium distribution
- CH4 polymerization -> (e.g.) C2H2

Disequilibrium, in microwave discharge

- Ionization
- Reactive fragments
- High temperatures



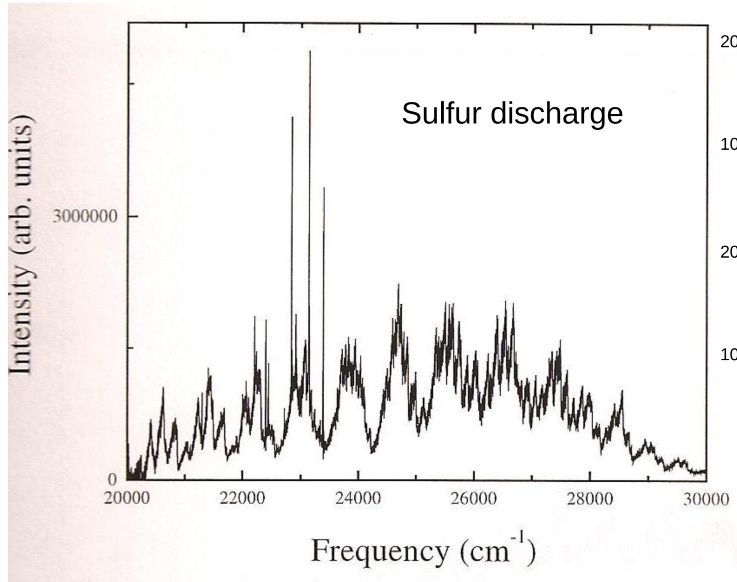


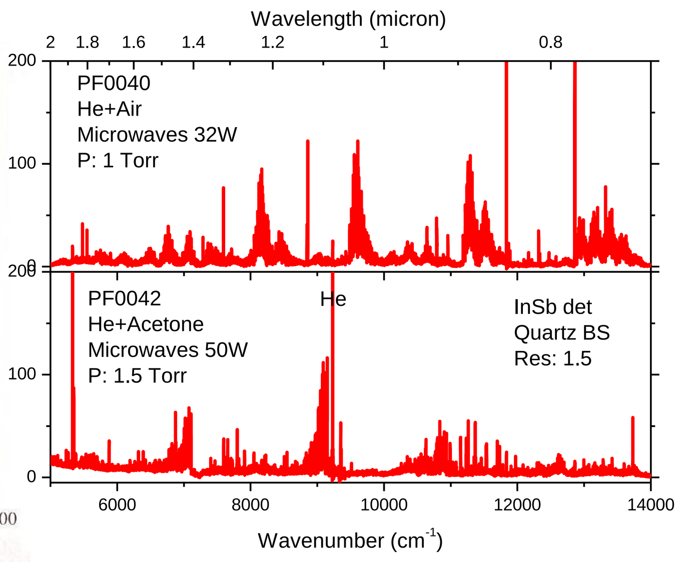
Common assumptions in modeling exo-atmospheres

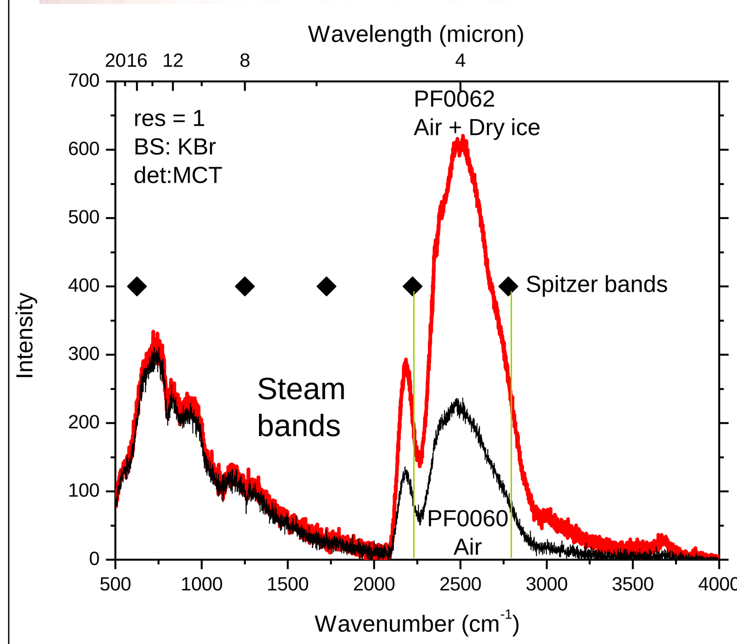
- Solar abundances
- Amount of O sequestered in rock
- Metals and other compounds contributed by meteorites and comets

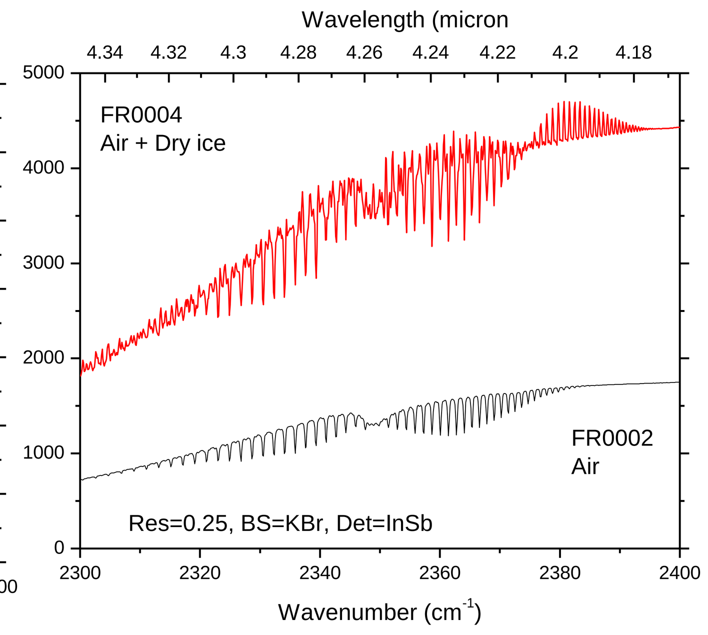
Possible sources of spectral interferences

- Opacity from photochemical haze or silicate clouds
- TiO, VO, and sulfur
- silicate minerals such as perovskiite and enstatite
- Hydrogen and its ions
- alkali metals Na and K
- Fe, Mg, Ca, Al
- metal hydrides FeH
- Water, N2, CO2, NH3
- ethylene (C2H4), acetylene (C2H2), and hydrogen cyanide (HCN)









Hyperdog: Planetary sniffer

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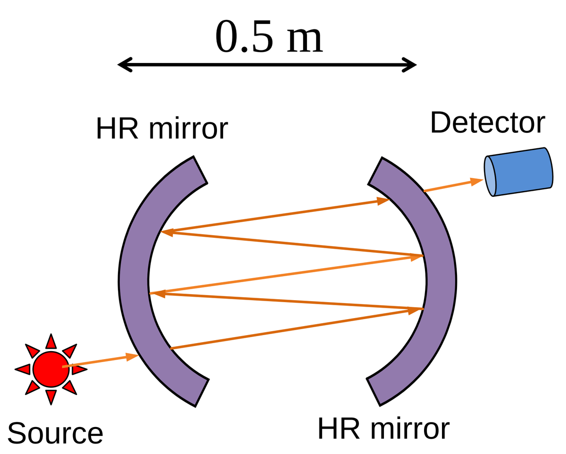
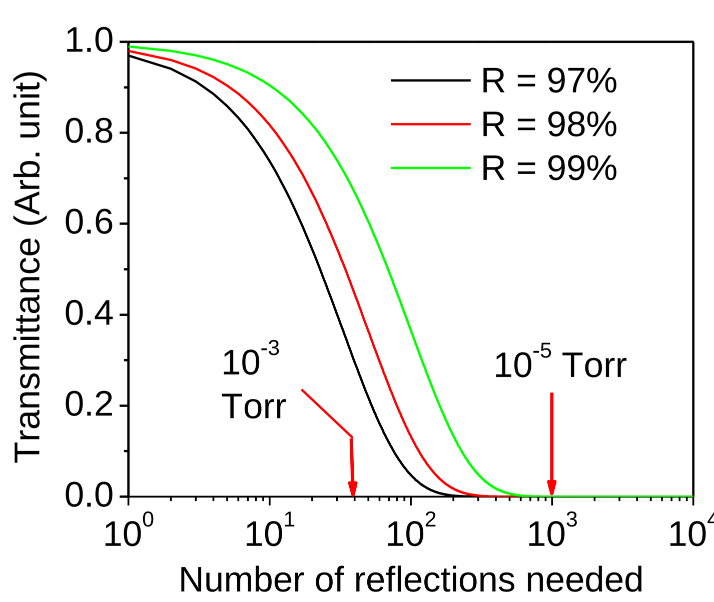
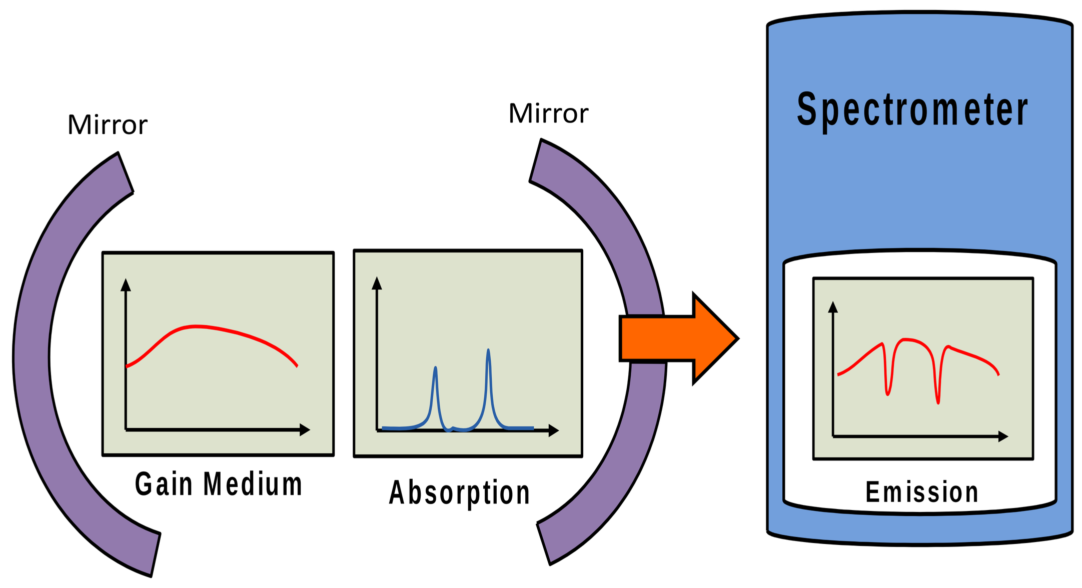
Ultratrace gas detection requires long folded path
Passive cavity: Effective pathlength <100m



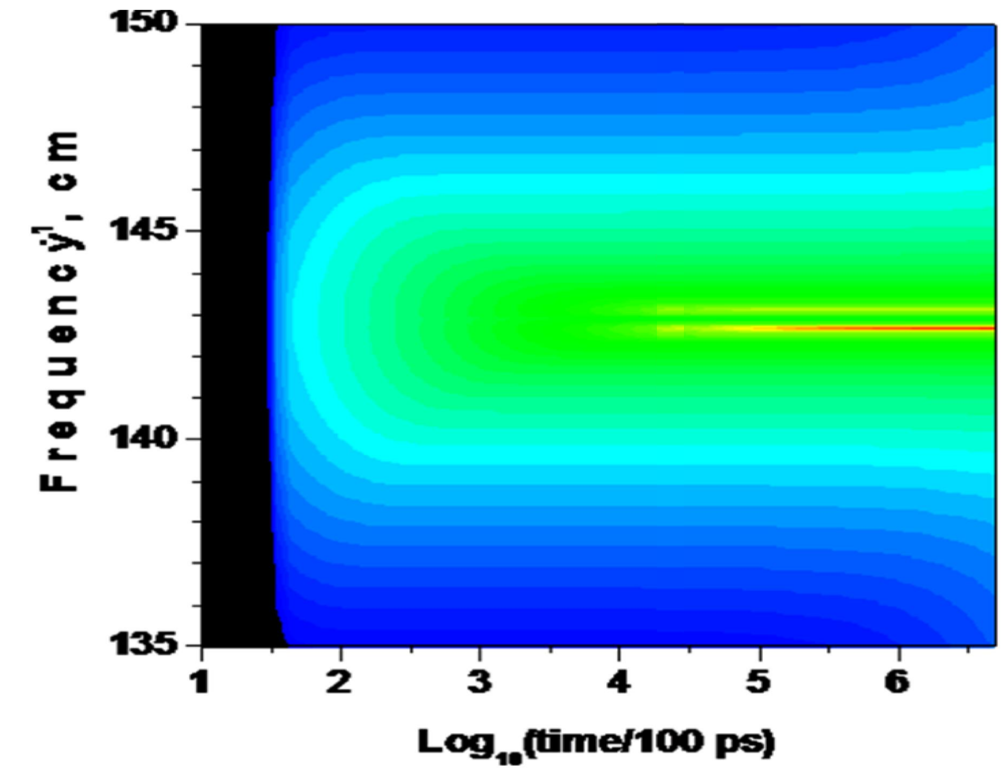
Ultra long paths impossible due to reflection losses



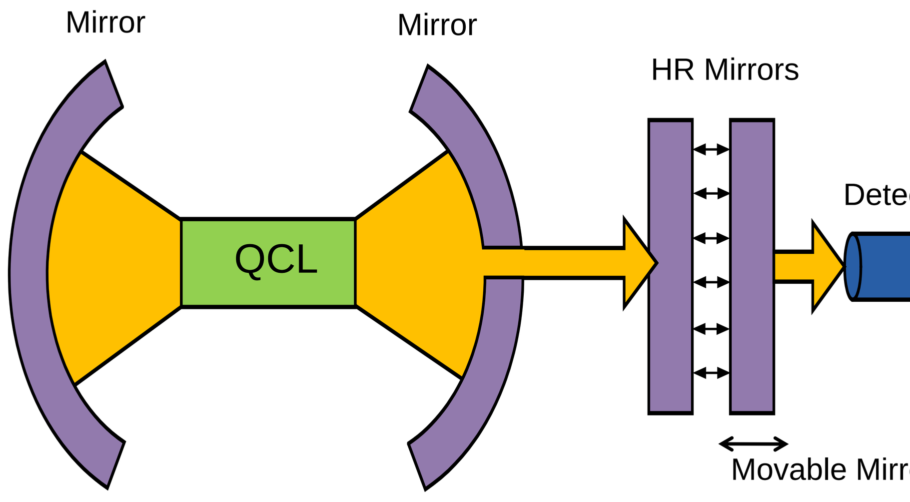
Active cavity can achieve
Effective Path length > 1km



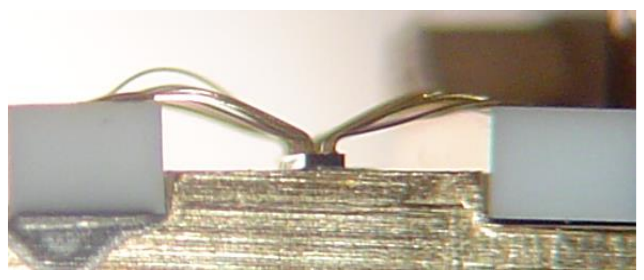
Numerical solution of laser rate equations for quantum cascade laser with weak intracavity absorption line shows feasibility of detecting molecular absorption at level of 10^{-6} Torr

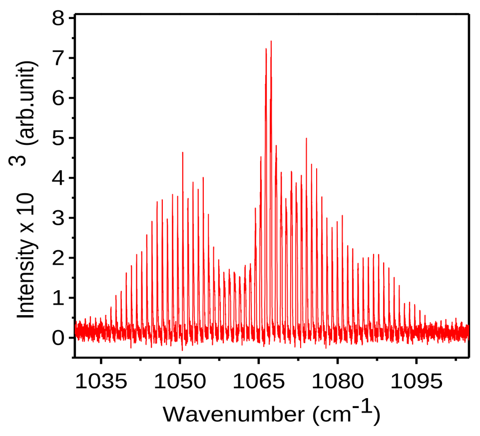


Enabling technologies
- External Cavity Quantum Cascade Laser
- Scanning Fabry-Perot spectrometer

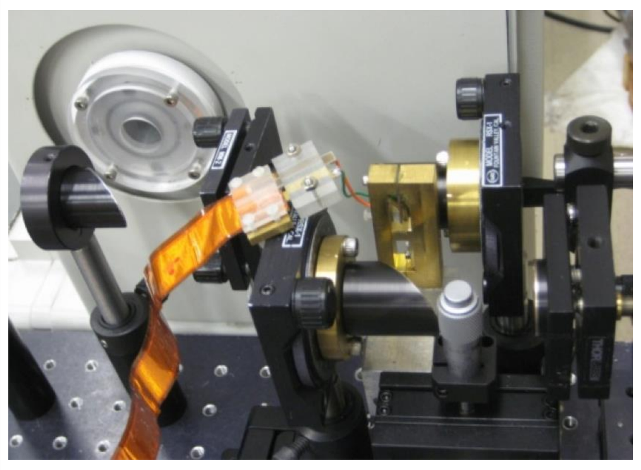


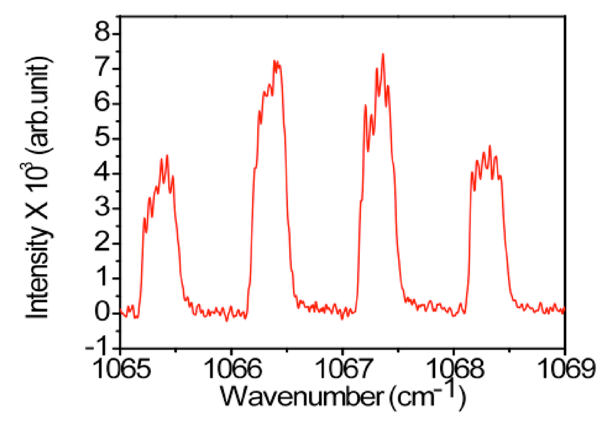
QCL with broad multimode emission



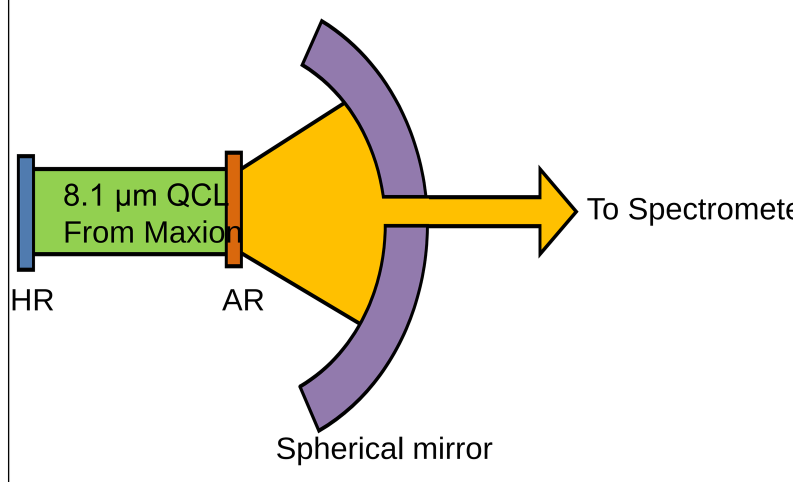


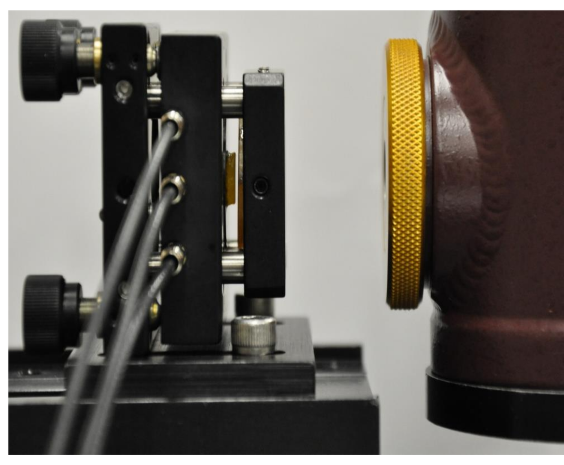
External cavity with dense mode spectrum

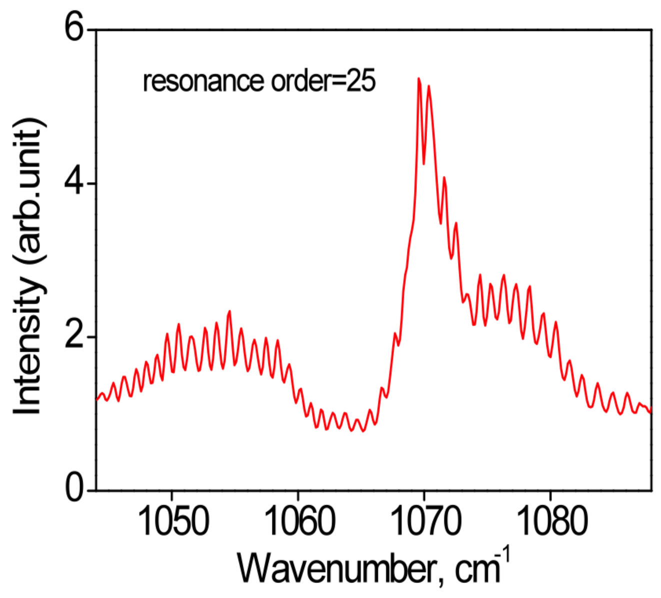




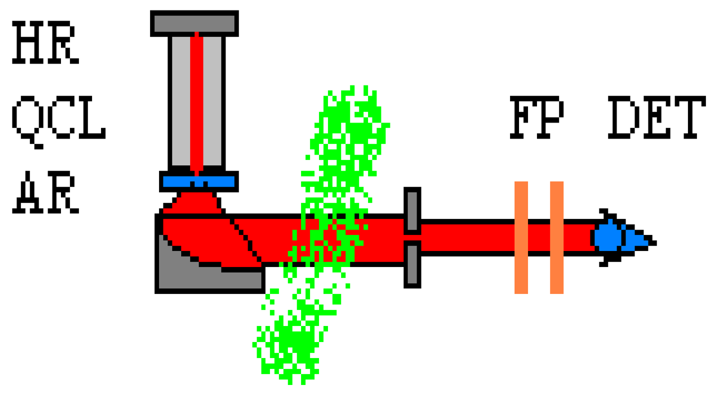
High resolution Fabry Perot spectrometer







Application to solar system exploration
Detection of trace gases and vapors
- Water
- Hydrocarbons



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