

# What only SMAUG can see

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The logo of the University of Rennes 1, featuring a stylized red dragon head with a small 'web' icon to its right.

**iDR**  
PHYSIQUE

The logo for the iDR (Institut de Recherche en Dynamique) in Physics, consisting of the letters 'iDR' in blue with white circles above the 'i' and 'R', and the word 'PHYSIQUE' in white on a blue vertical bar to the left.

# e-PYTHEAS project

Astronomical  
observations

Experimental  
data

**EXOPLANET  
(HOT JUPITER)**

1000- 3000K

$\text{CH}_4$ ,  $\text{C}_2\text{H}_2$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_6$

Theoretical  
molecular  
model

Atmospheric  
modelling



# Establishing experimental data

Objective: record spectral data

- \* known molecules
- \* known conditions

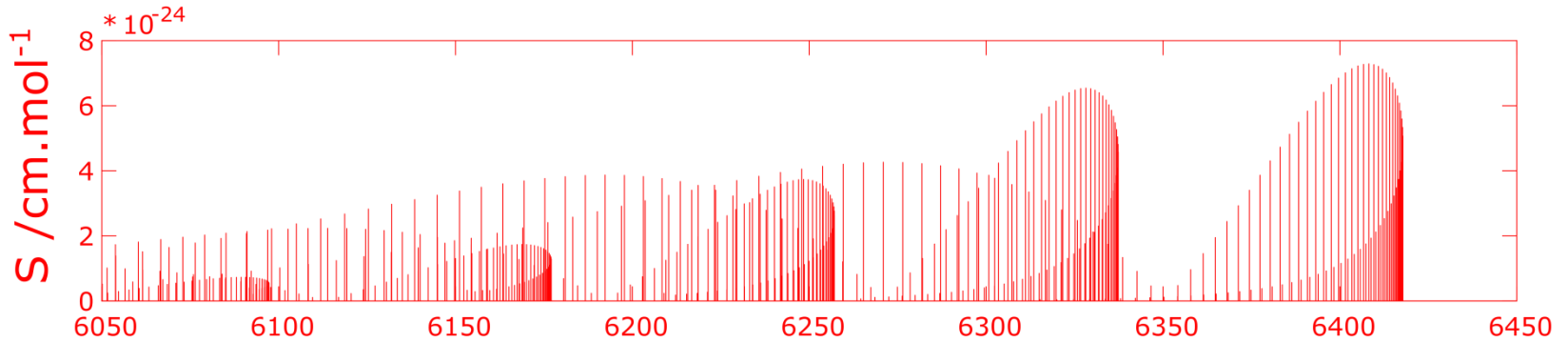


1. Heat-up the gas
2. Probe the gas
3. Analyse the recorded spectra

**SMAUG**

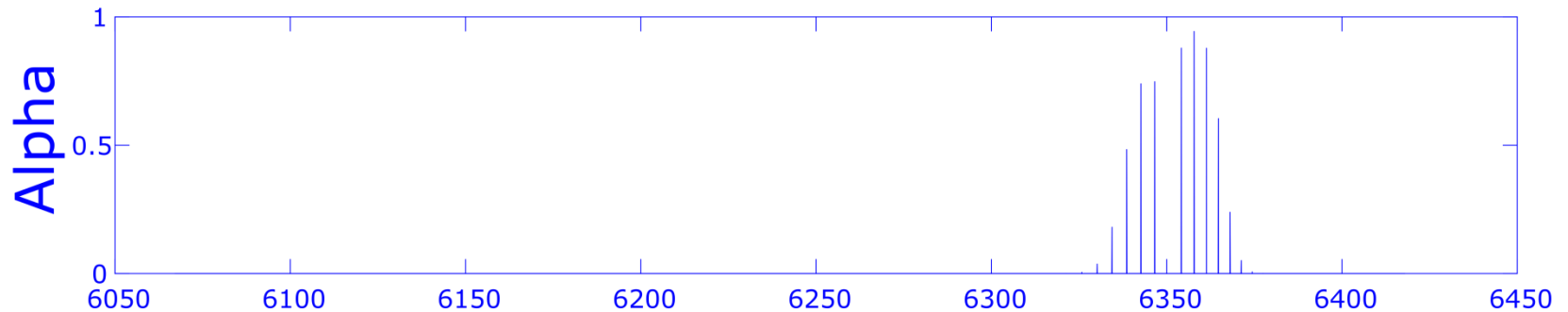
**Spectroscopy of Molecules Accelerated in  
Uniform Gas flows**

# 1. Hot gas – Cold gas



Simulated spectrum of CO @2000K

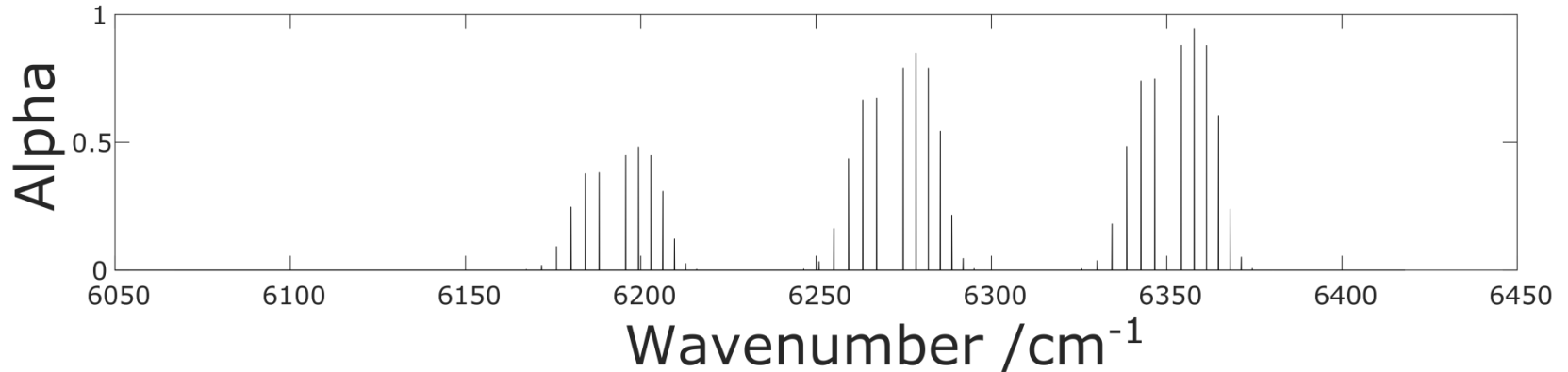
Overcrowded spectrum → difficult to identify lines



Simulated spectrum of CO @15K

Lack of information on hot bands

# Out-of-equilibrium state



Simulated spectrum of CO  $T_{\text{vib}} = 2000\text{K}$   $T_{\text{rot}} = 15\text{K}$

**Decoupling integral degrees of freedom of molecules**

- **high vibrational levels** thermally populated
- **high- $J$  rotational levels** thermally depopulated



simplified rotational structure



# Hypersonic expansion (theory)

$$Mach = \frac{\text{speed of gas}}{\text{speed of sound}} = \frac{u}{\sqrt{\gamma r T}} \propto \sqrt{\frac{E_{kinetic}}{E_{thermal}}}$$

Adiabatic expansion:

$$c_P T_0 = c_P T + \frac{1}{2} u^2$$

$$u = 0 \frac{m}{s} \quad \blacktriangleright \quad M = 0$$

$$T \rightarrow 0 \text{ K} \quad \blacktriangleright \quad M \rightarrow +\infty$$

Accelerate the gas → Laval nozzle

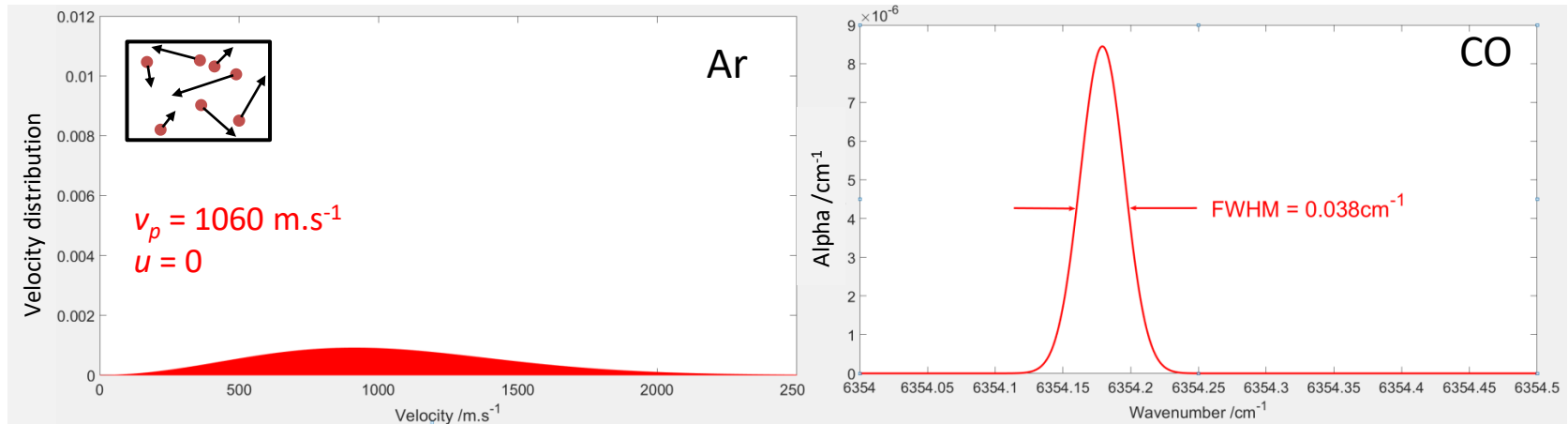
→ no molecular collision

→ no energy transfer

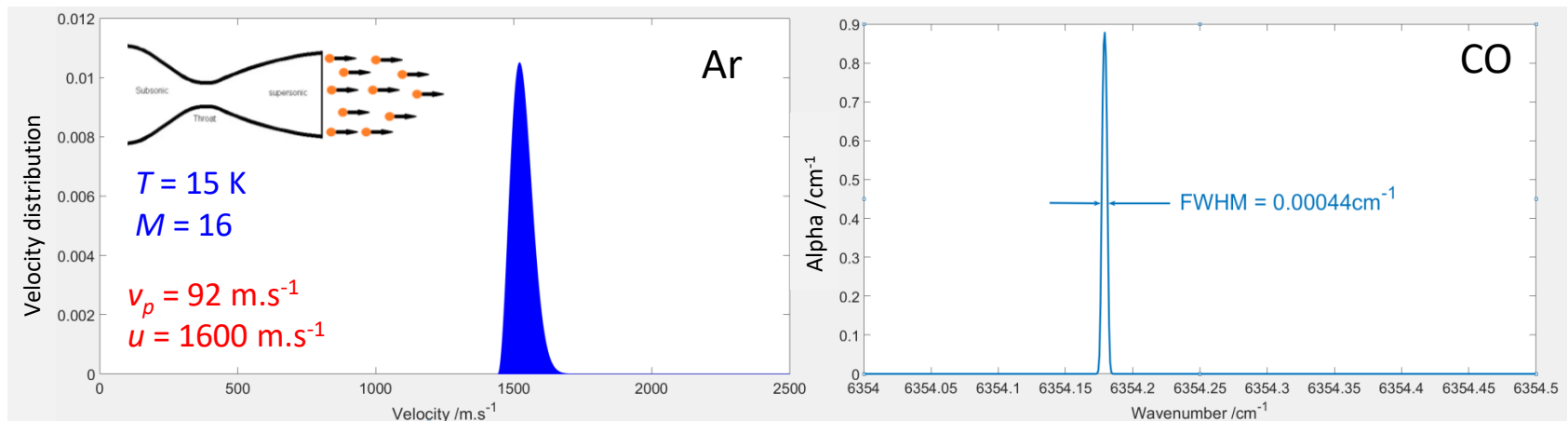
→ decoupled integral degrees of freedom

# Hypersonic expansion (theory)

**Static gas:**  $T = 2000$  K ; Flow velocity  $u = 0$  ; Mach number  $M = 0$

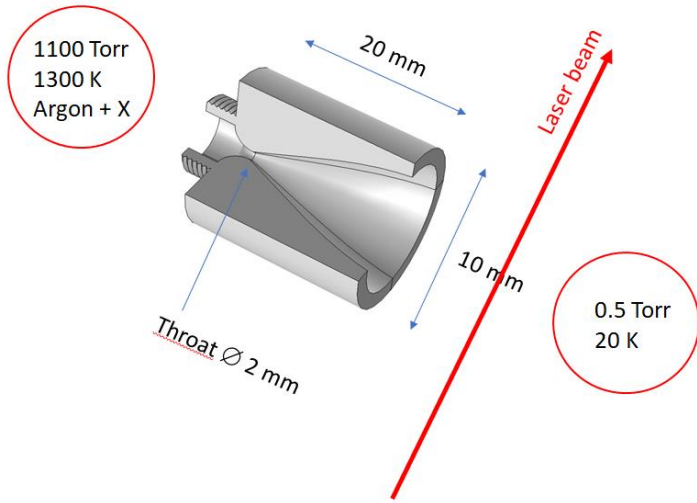


**Hypersonic expansion:**  $T_0 \rightarrow 2000$  K ;  $u \rightarrow u_{lim}$  ;  $M \gg 1$

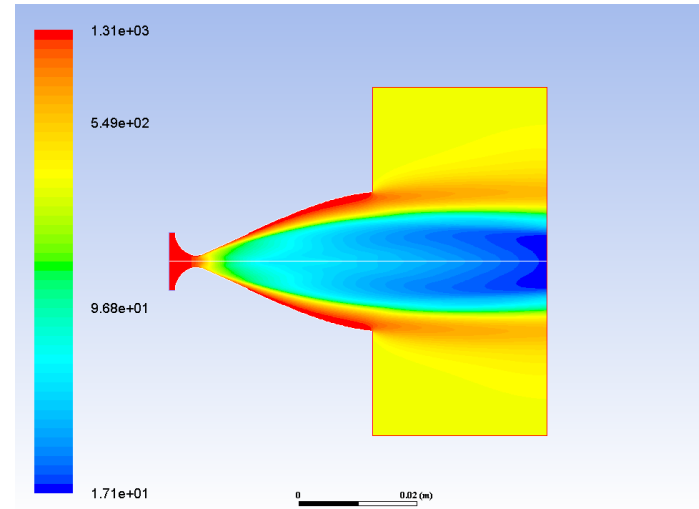


Reduced Doppler broadening  $\rightarrow$  resolved spectral lines

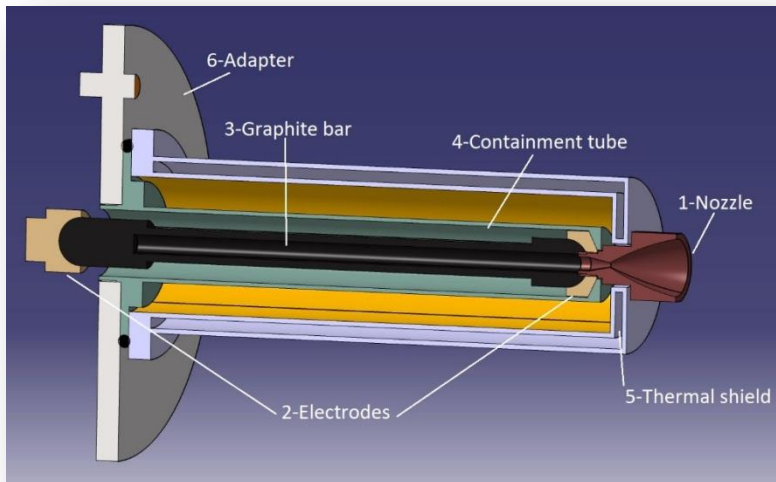
# Hypersonic expansion (practise)



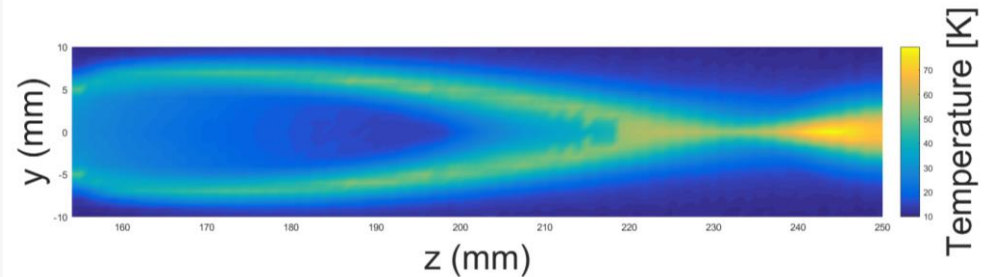
Laval nozzle



Simulated expansion  
flow temperature



High Entalpy Source

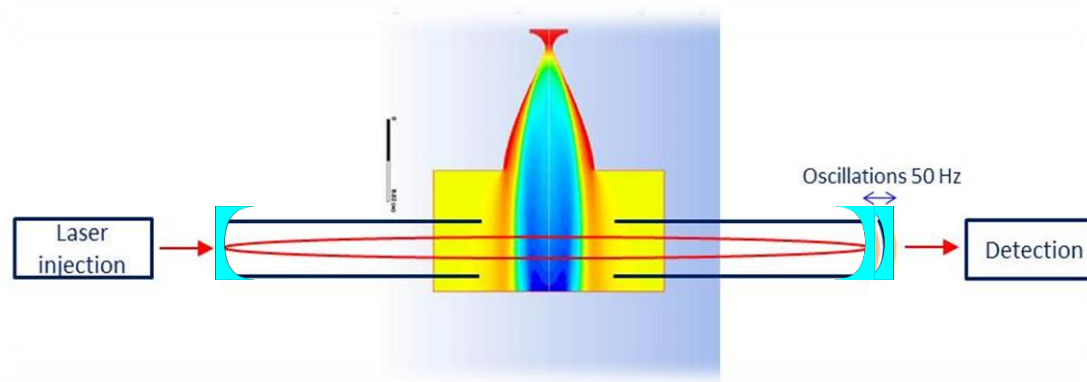


Temperature mapping (Pitot probe)



# 2. Probe the gas

## Cavity Ring-Down Spectroscopy

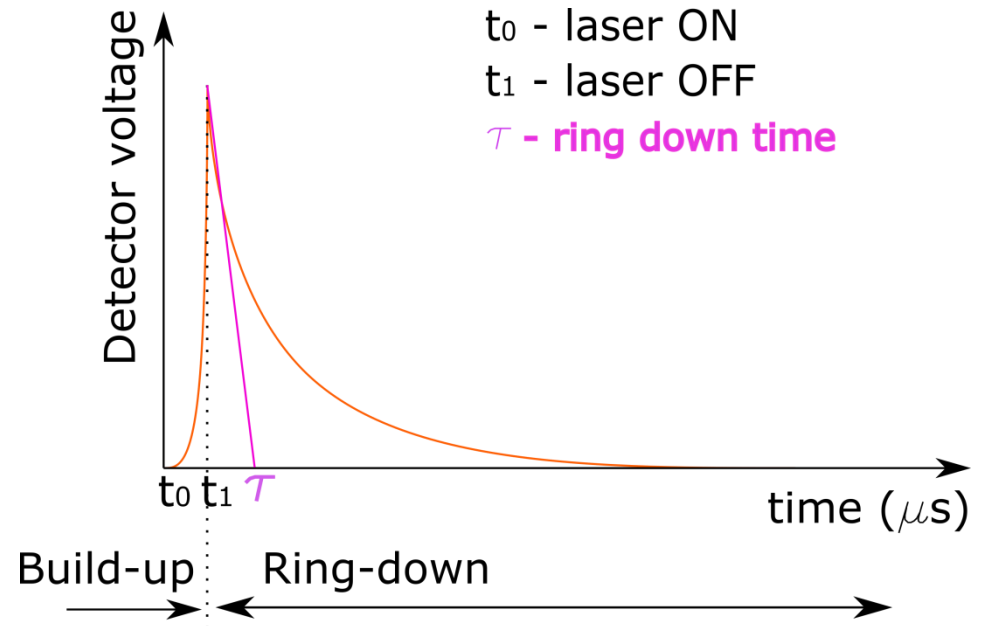


Isentropic core diameter = **1 cm**  
 Equivalent absorption length = **675 m**

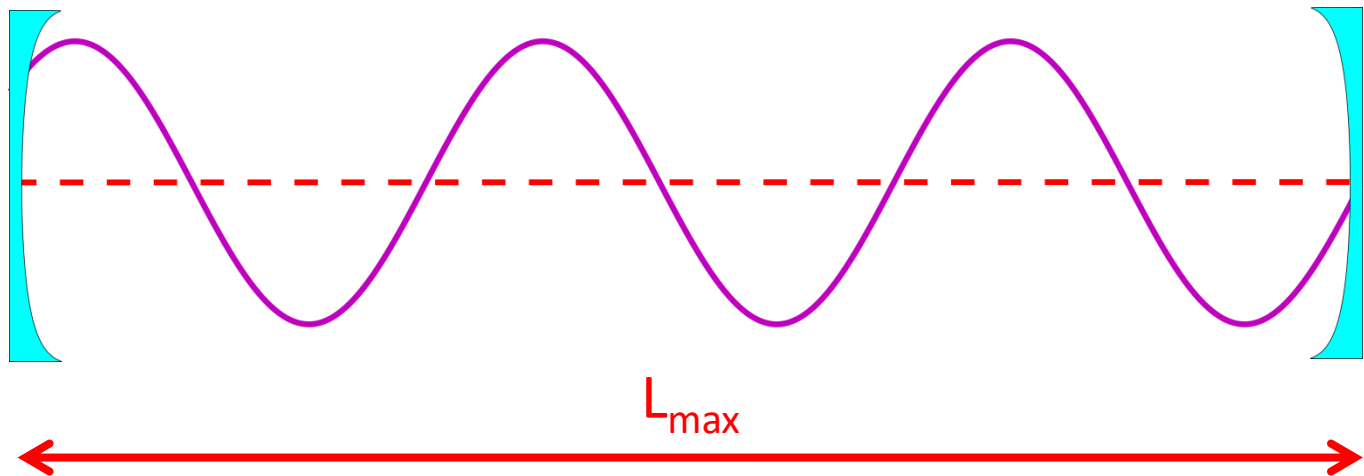
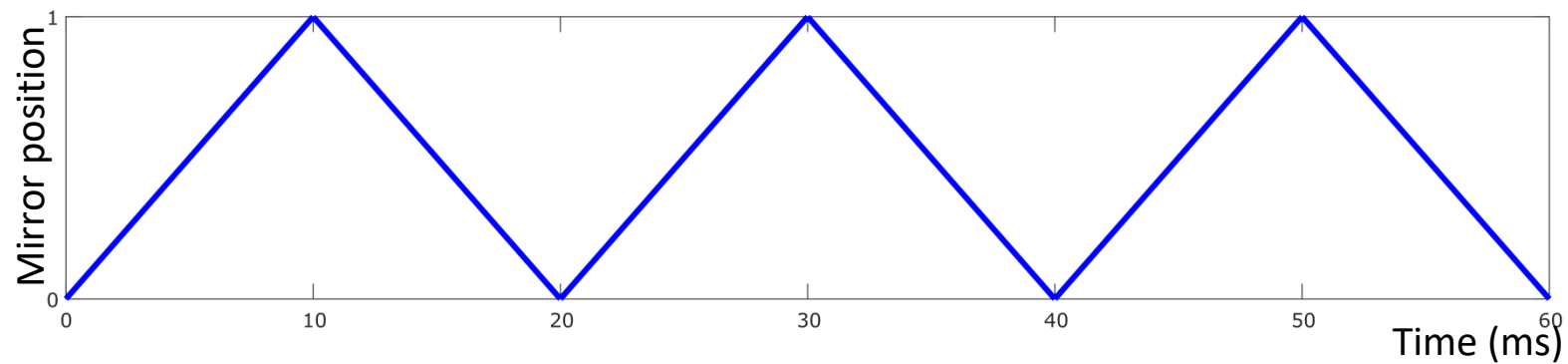
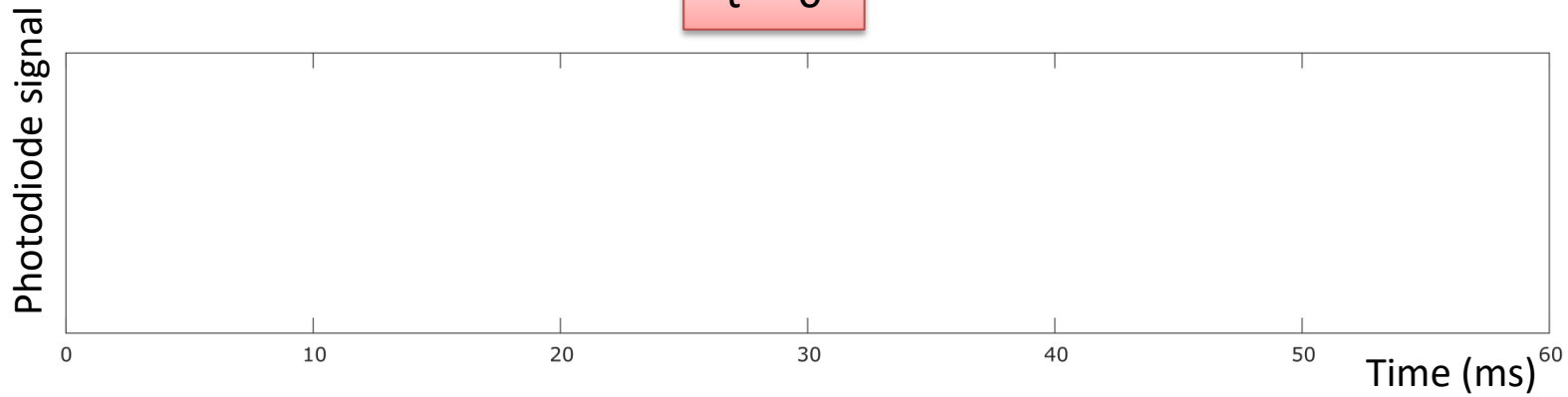
**Absorption coefficient:**

$$\alpha = \sigma \times n = \frac{1}{c \cdot \tau}$$

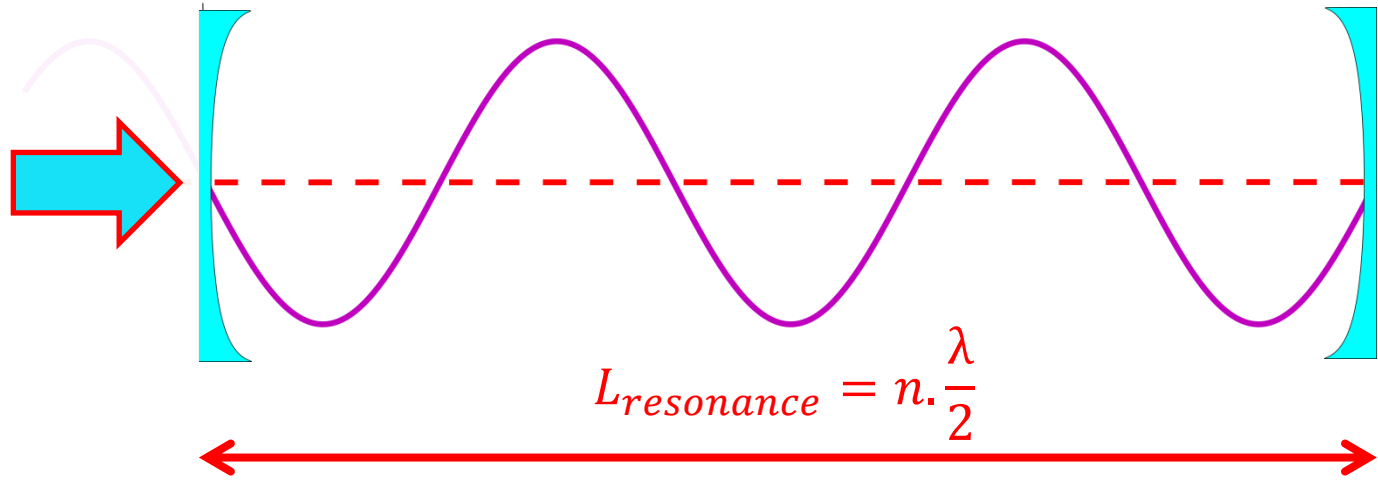
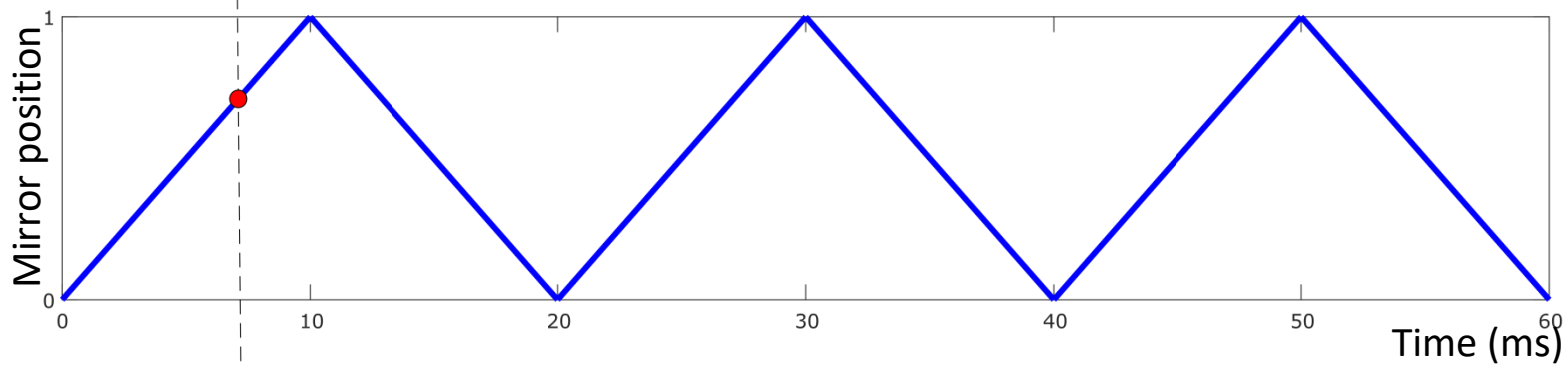
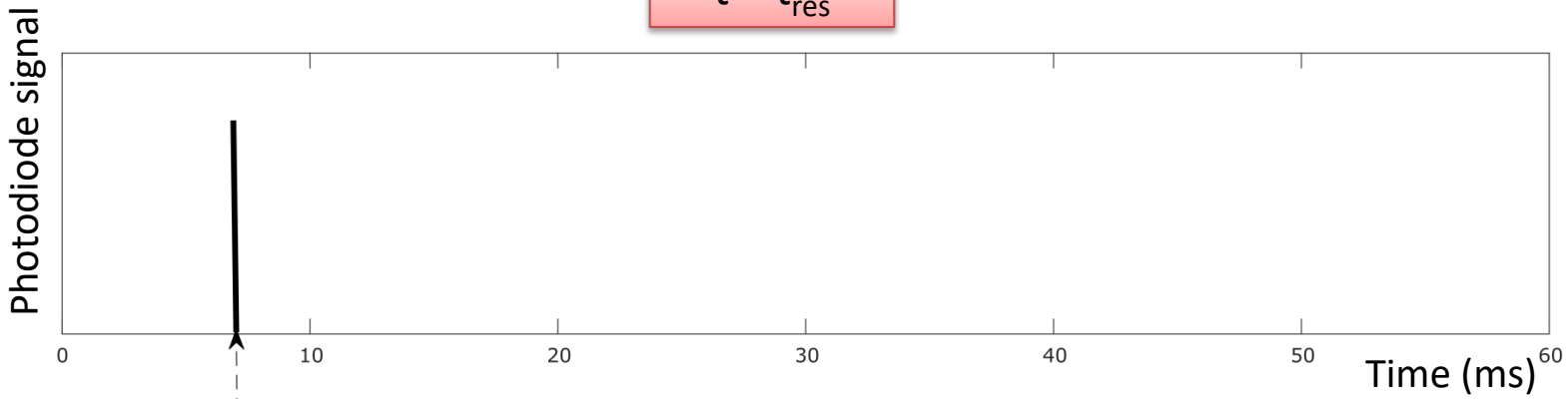
**Photodiode signal**

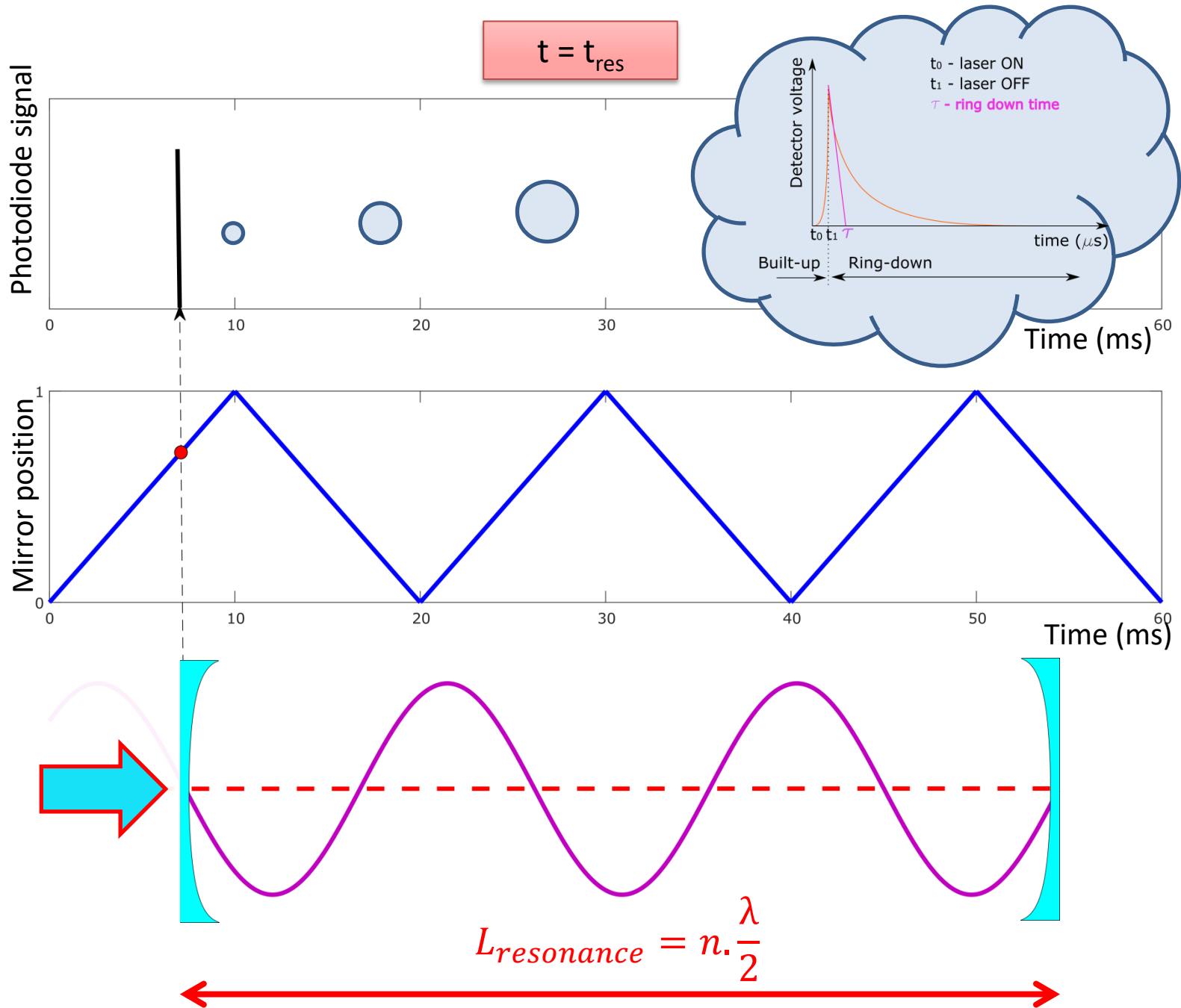


$t = 0$

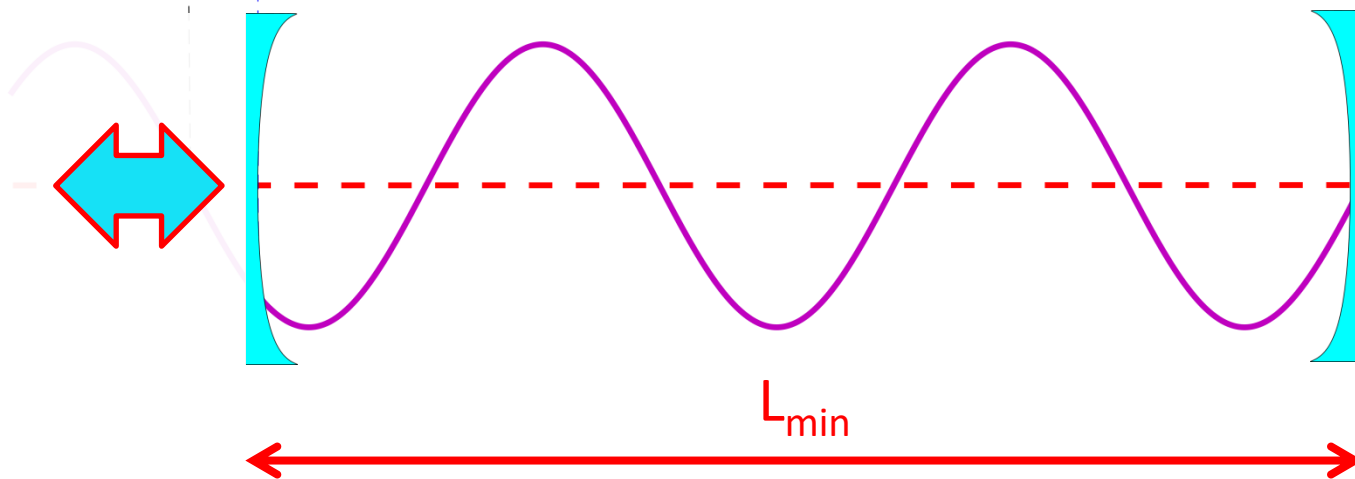
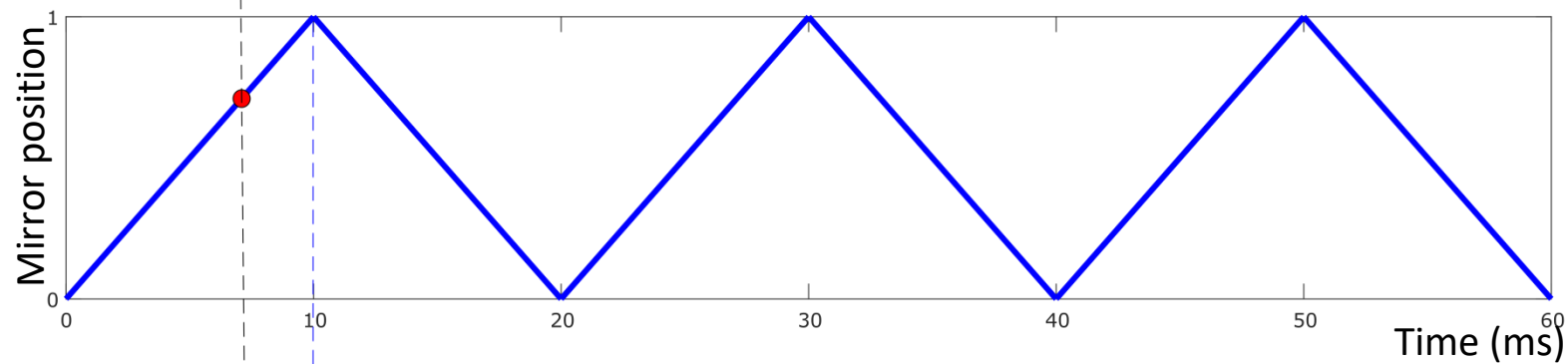
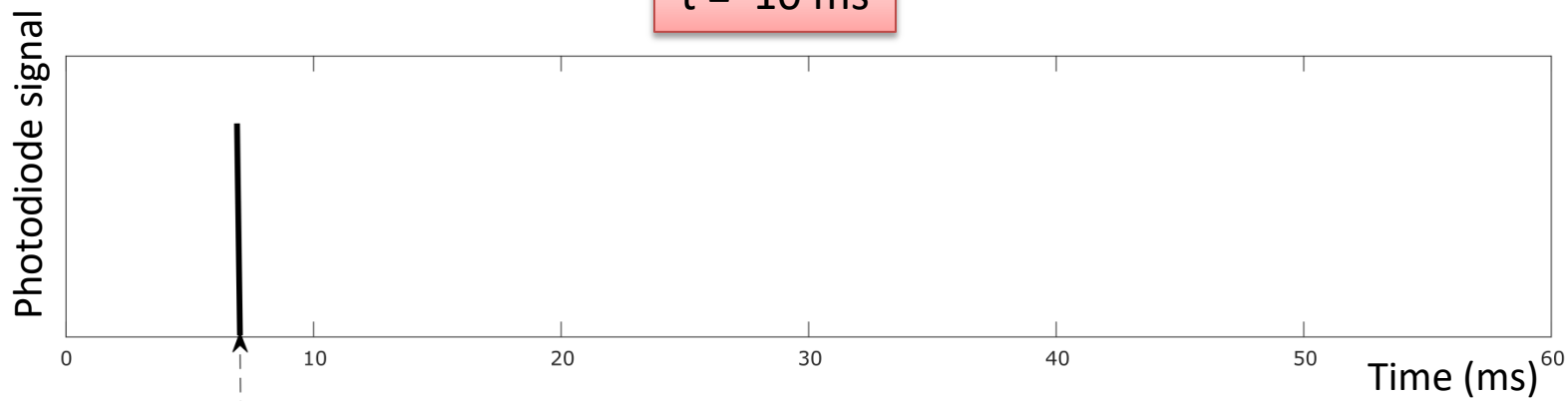


$$t = t_{res}$$

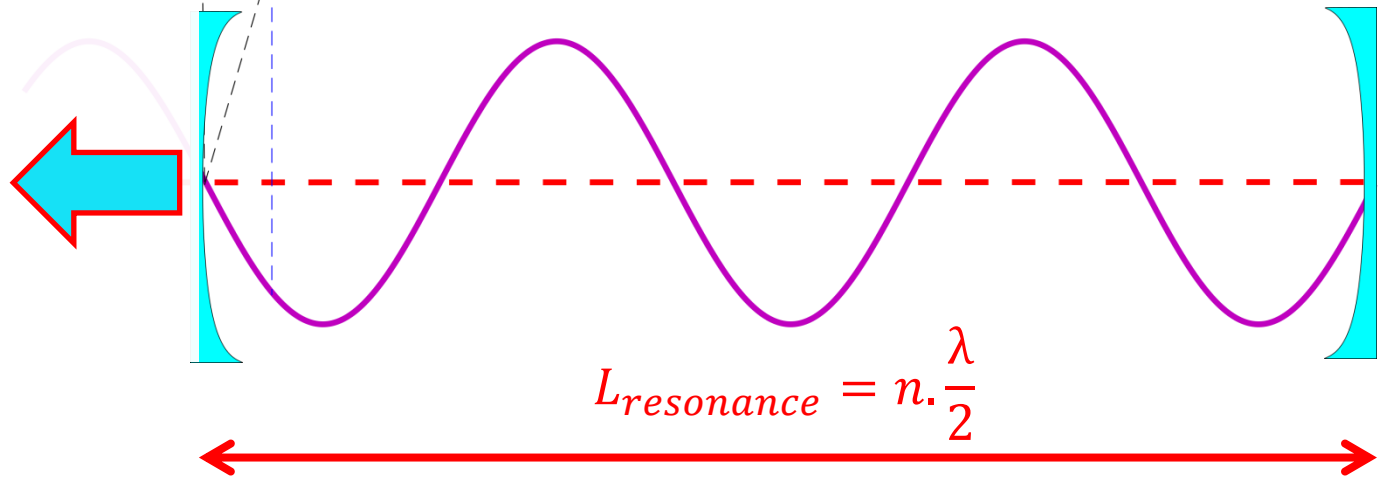
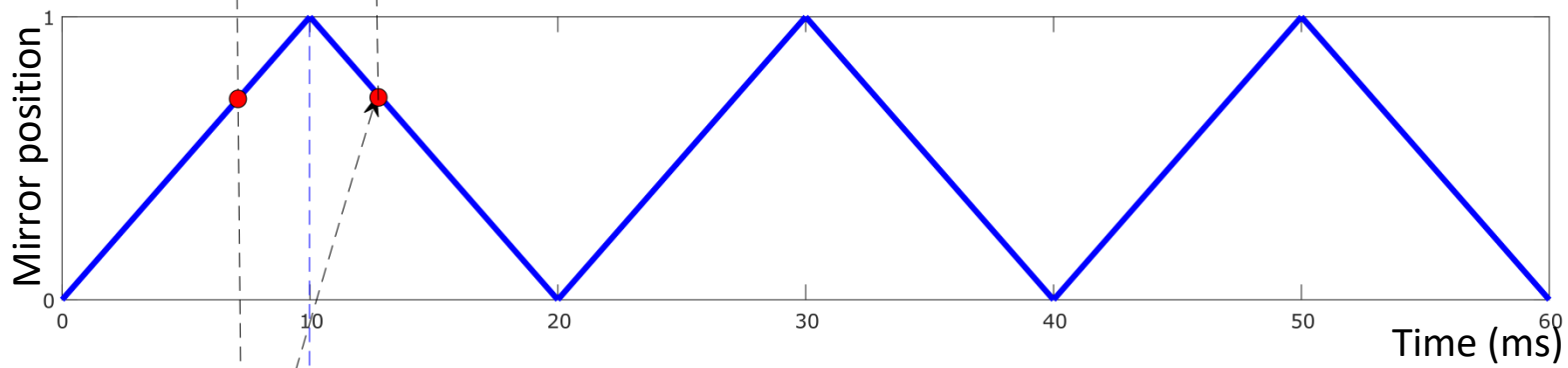
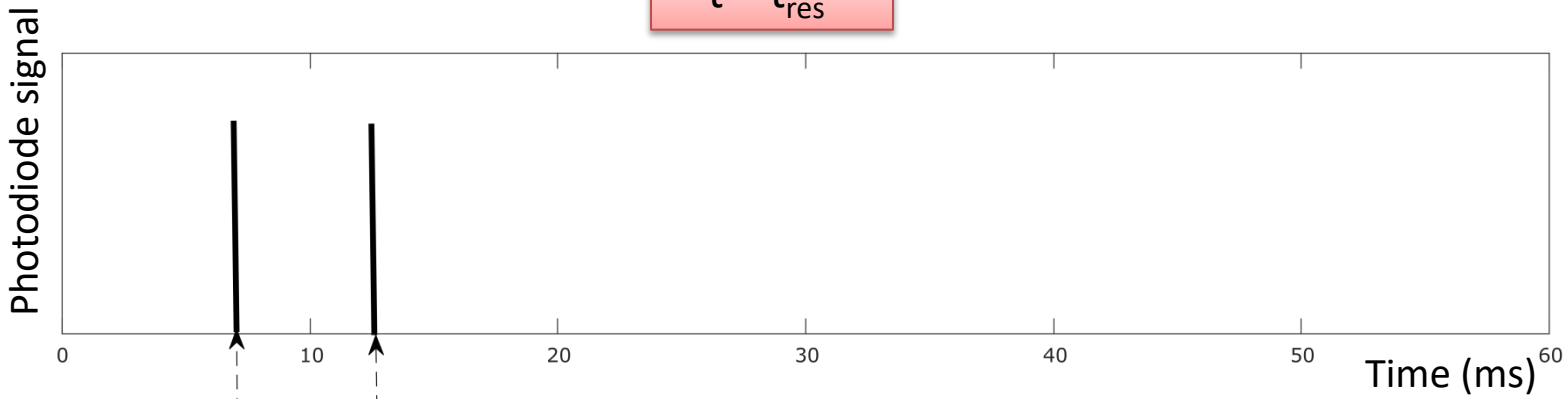




$t = 10 \text{ ms}$

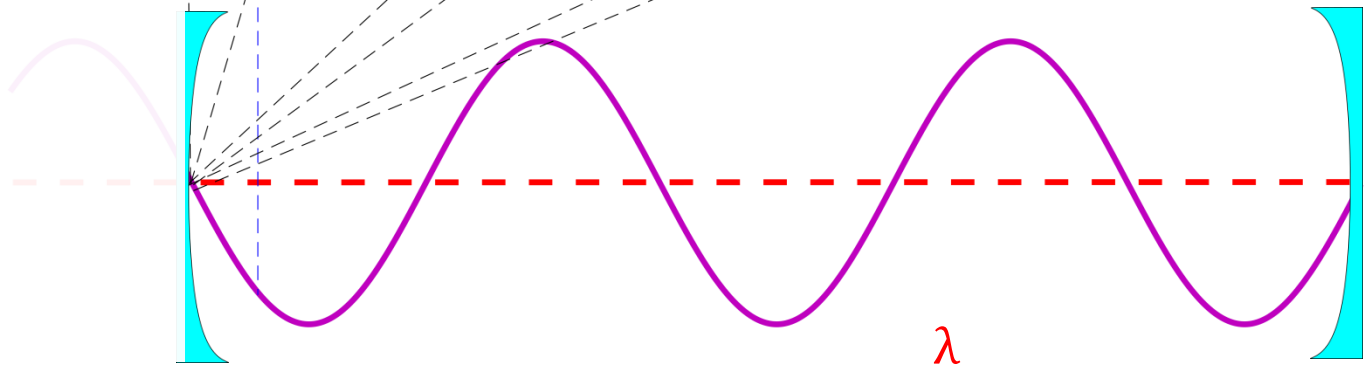
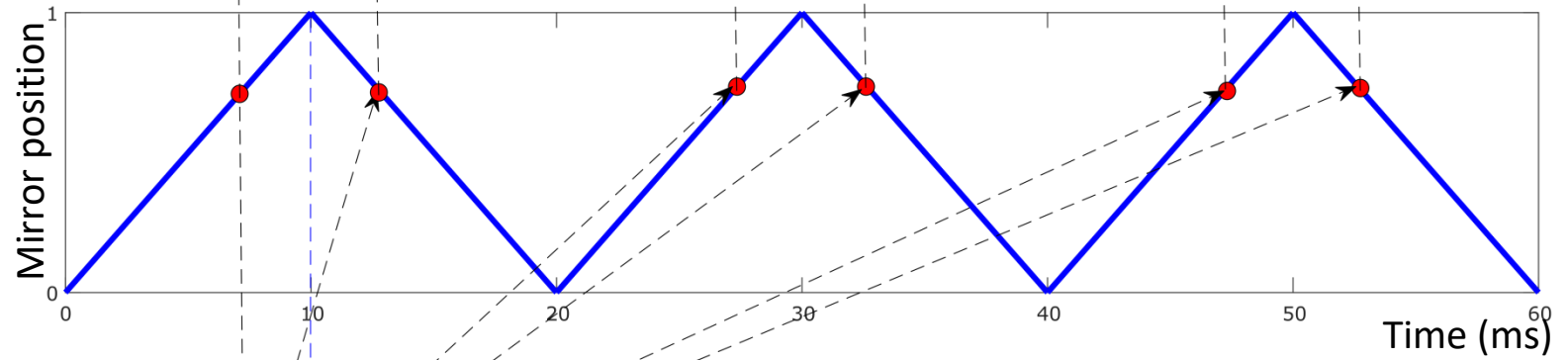
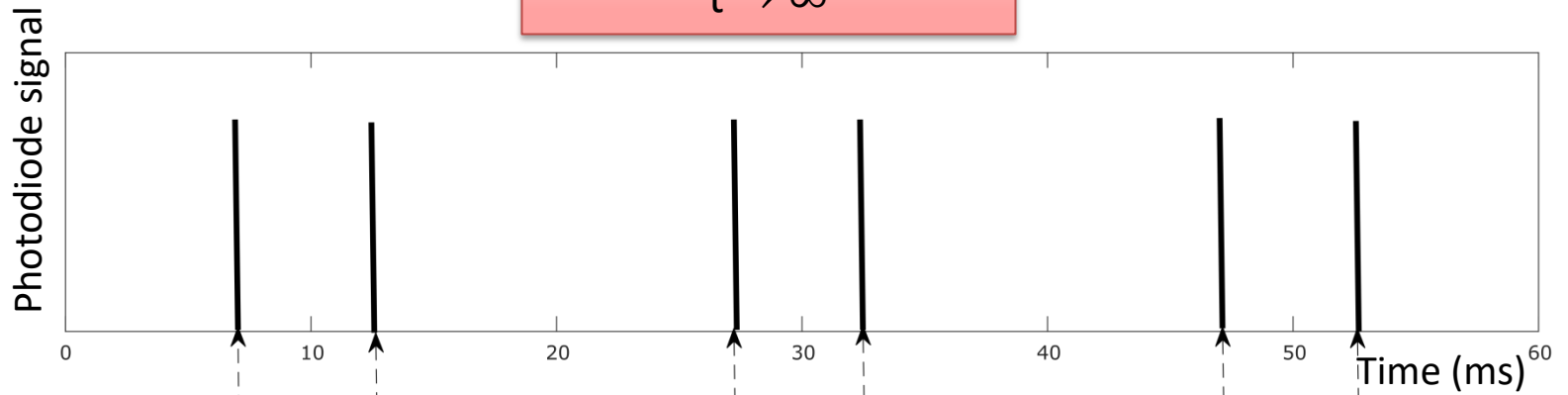


$$t = t_{res}'$$



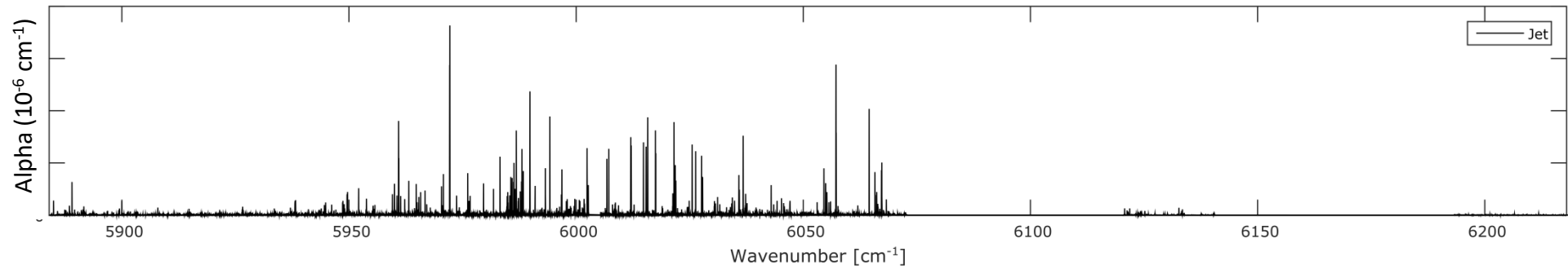


$t \rightarrow \infty$



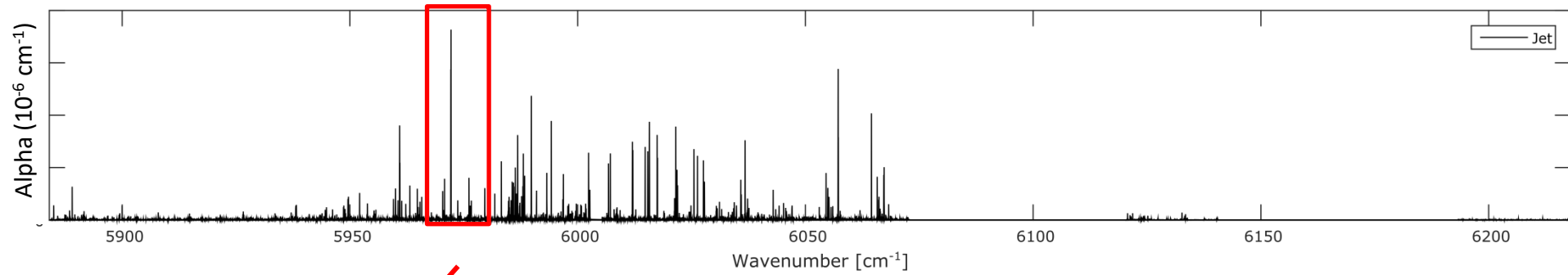
$$L_{resonance} = n \cdot \frac{\lambda}{2}$$

# 3. Analyse the recorded spectrum

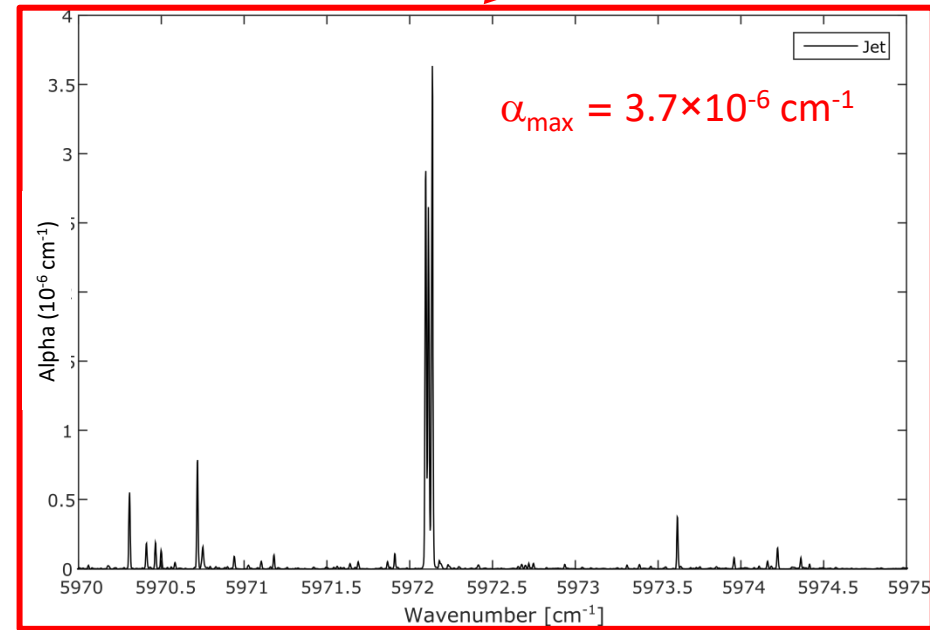


Recorded spectral data of CH<sub>4</sub>

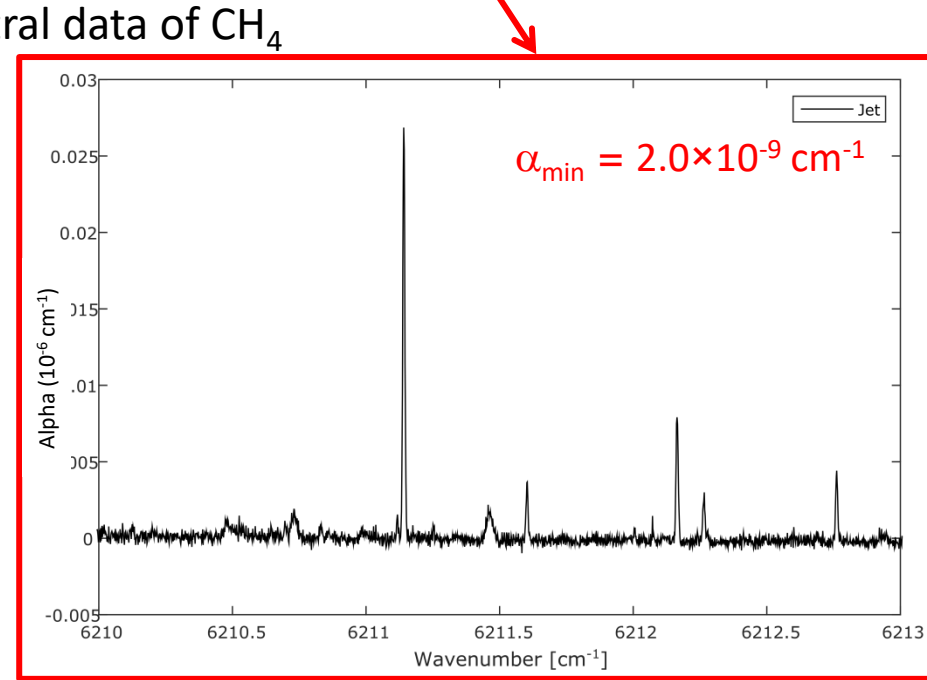
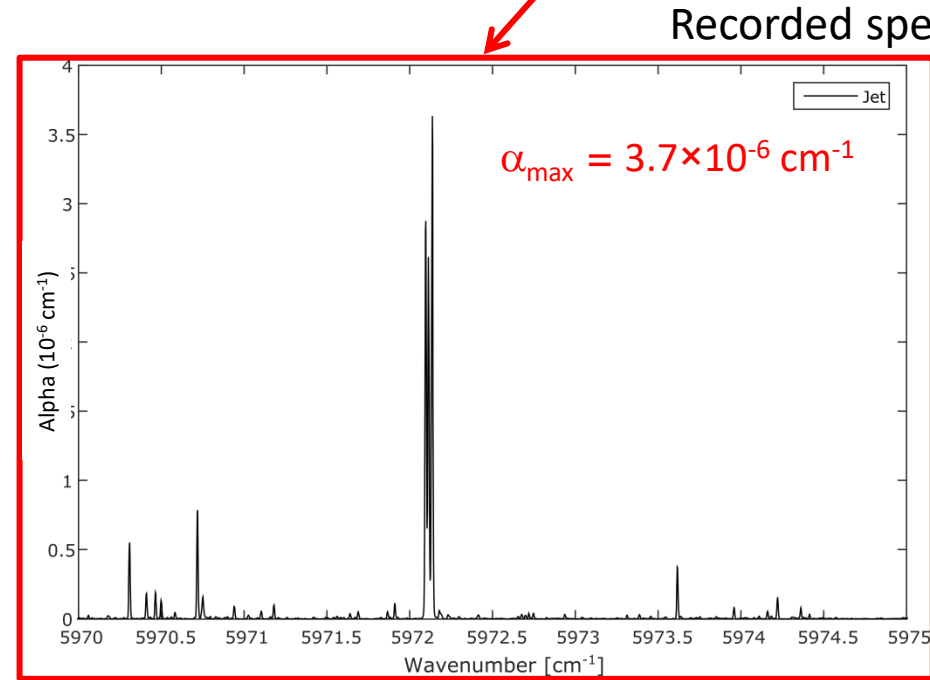
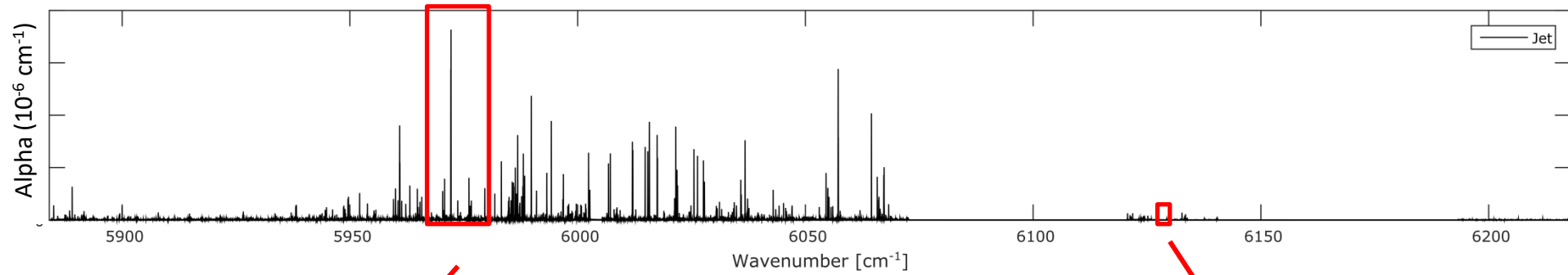
# 3. Analyse the recorded spectrum



Recorded spectral data of CH<sub>4</sub>

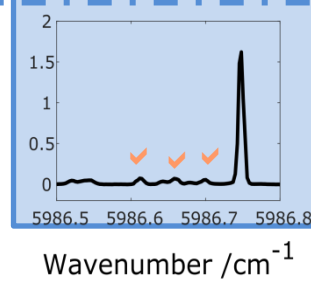
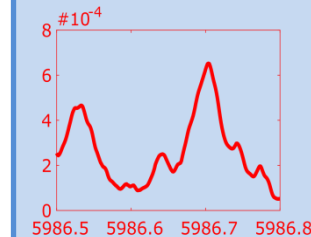
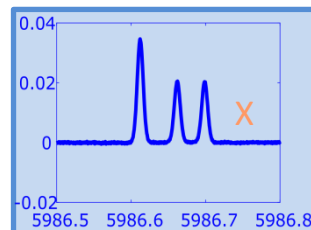
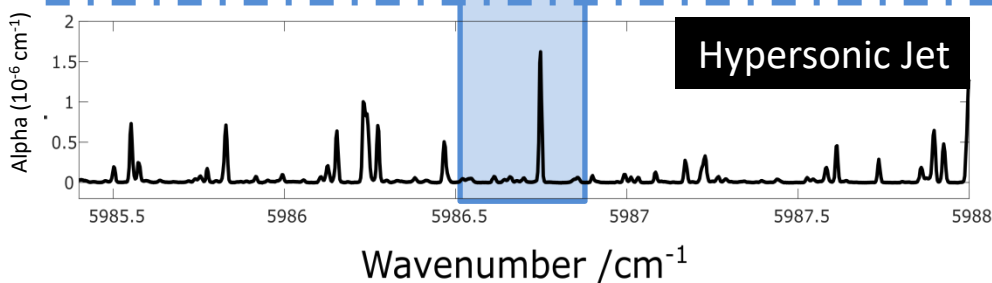
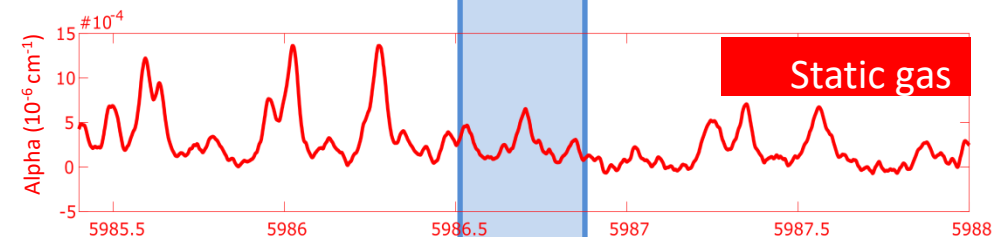
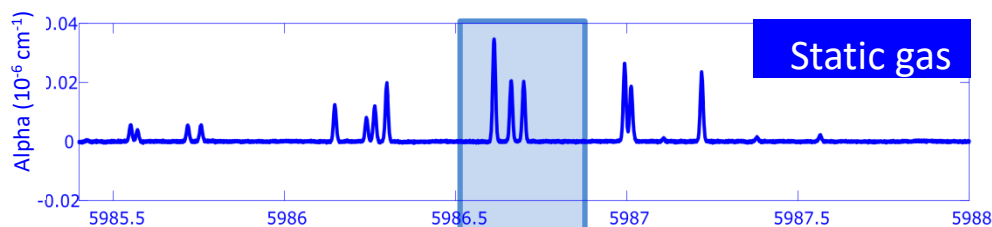


# 3. Analyse the gas



Ultra sensitive technique

# LTE vs Non-LTE



$T_{\text{vib}} = T_{\text{rot}} = T_{\text{trans}}$   
 Cold bands only  
 Molecular population is mainly on GS

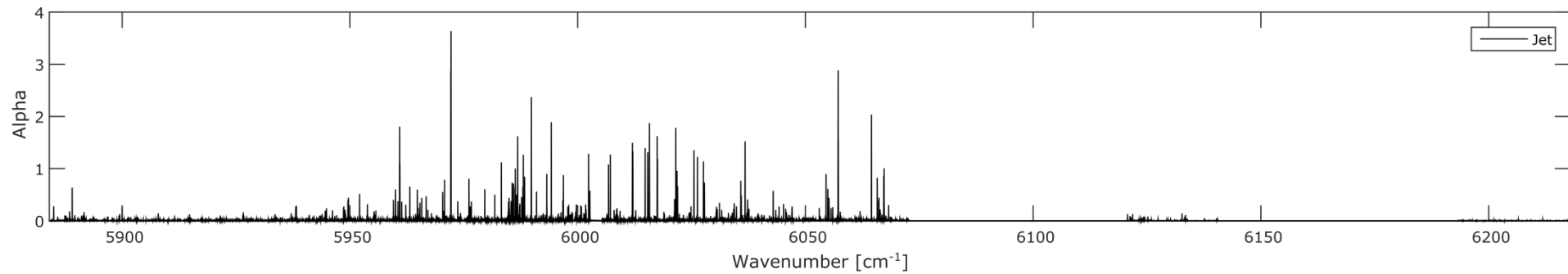
LTE  
(LIPhy)

$T_{\text{vib}} = T_{\text{rot}} = T_{\text{trans}}$   
 Overcrowded spectrum  
 (super lines)

$T_{\text{vib}} \gg T_{\text{rot}} \sim T_{\text{trans}}$   
 Intense hot bands  
 GS depopulated

Non-LTE  
(IPR)

CRD Spectrum of methane



### Line identification:

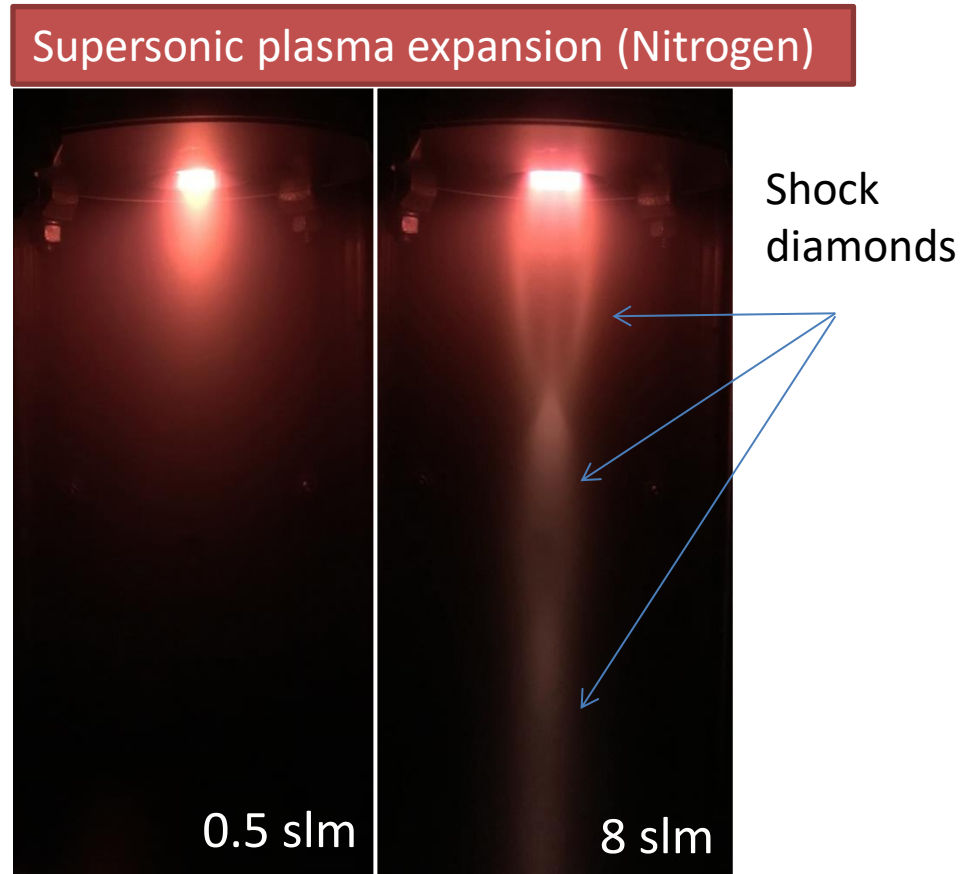
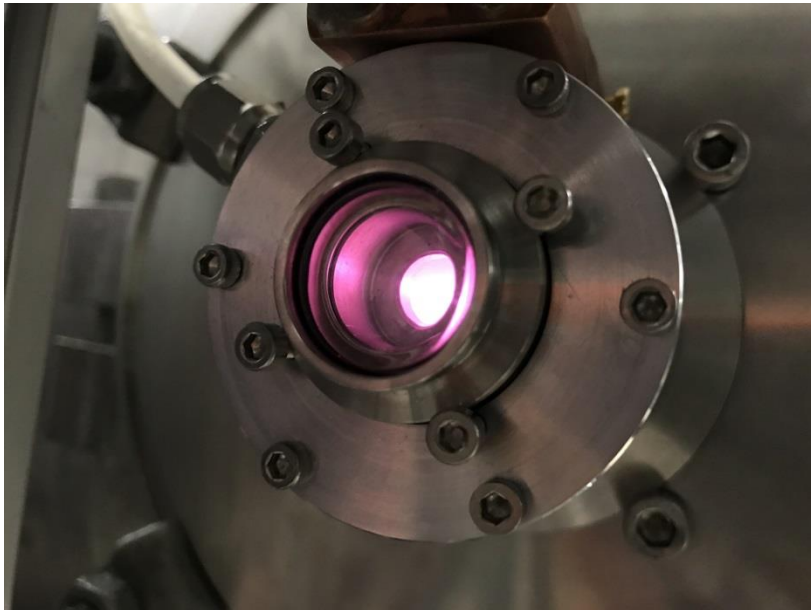
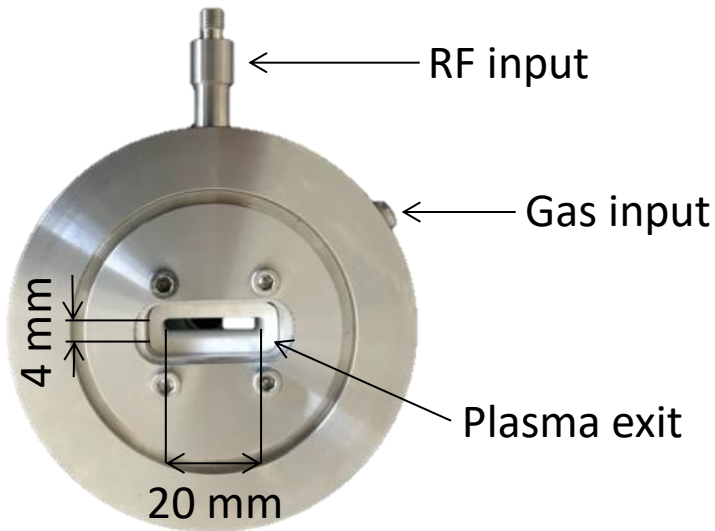
- compare recorded spectra with: **existing data bases** (ex: HITRAN, MeCasDa)
- compare recorded spectra with: ***ab initio* calculation**

### Limitations of the current experimental system:

- $(T_0)_{\max} \sim 2000\text{K}$
- graphite heating element → limited variety of molecules can be studied



# The PLATYPUS Project



In collaboration with **Christine Charles**,  
**Dimitrios Tsifakis**, **Rod Boswell**,  
Space Plasma, Power and Propulsion  
Laboratory (SP3), Australian National  
Laboratory