

Inductively-coupled plasmas of Cl_2 , O_2 and mixtures : measurement of atoms, Cl_xO_y and electron densities



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Motivations



- $\text{Cl}_2 \rightarrow \text{Cl}, \text{Cl}^*, \text{Cl}^-, \dots$
- $\text{O}_2 \rightarrow \text{O}_3, \text{O}^*, \text{O}^-, \dots$?
- $\text{Cl}_2/\text{O}_2 \rightarrow \text{Cl}_x\text{O}_y, \text{Cl}, \text{O} \dots$

To understand the dynamic of these plasmas numerous simulations have been developed but...



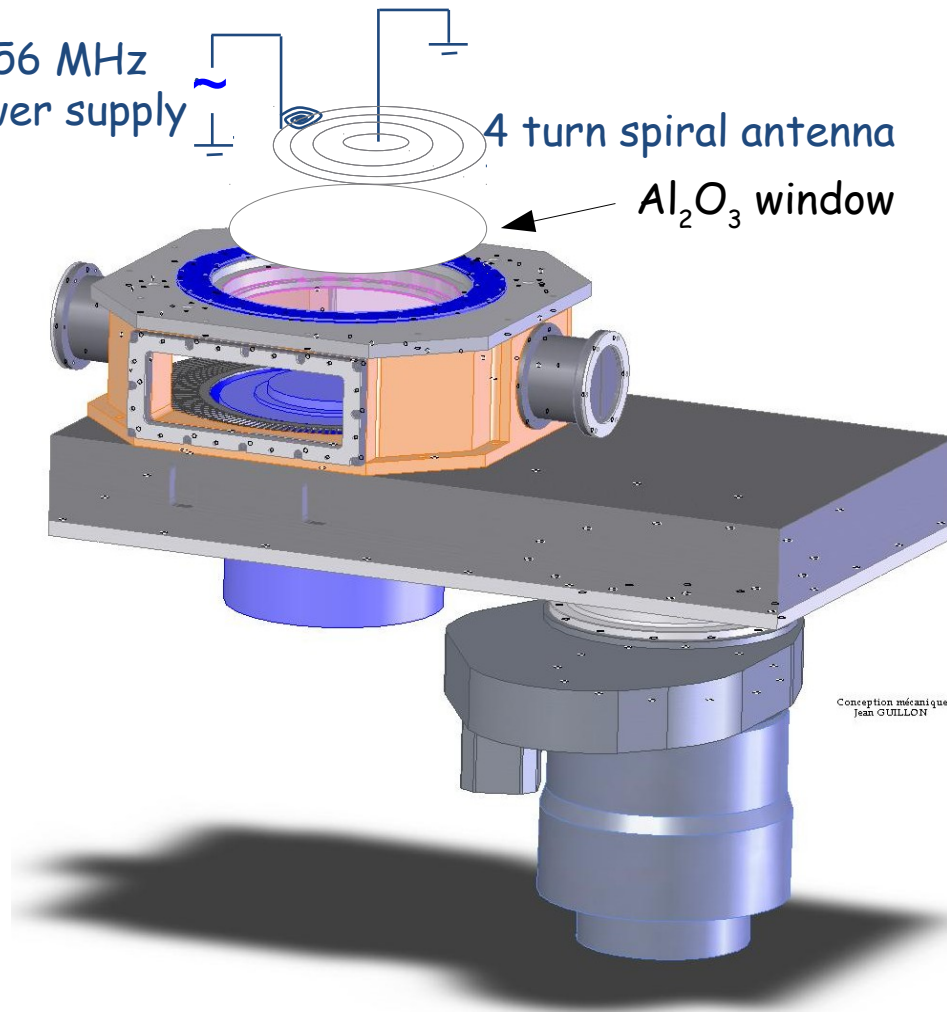
...experimental comparisons remain sparse.

Objectives



Make a complete set of experimental results on ICP of Cl_2 , O_2 and mixtures of these gases

ICP etching reactor



Diametre : 55 cm

Height : 10 cm

**RF powers : [50-550]
W**

**Pressures : [5-100]
mTorr**

Absorption spectroscopy : experimental setup



Broad-band
light source
(Energetiq LDSL)

Shutter

ICP reactor

Window

Detector NMOS
(Hamamatsu
S3904)

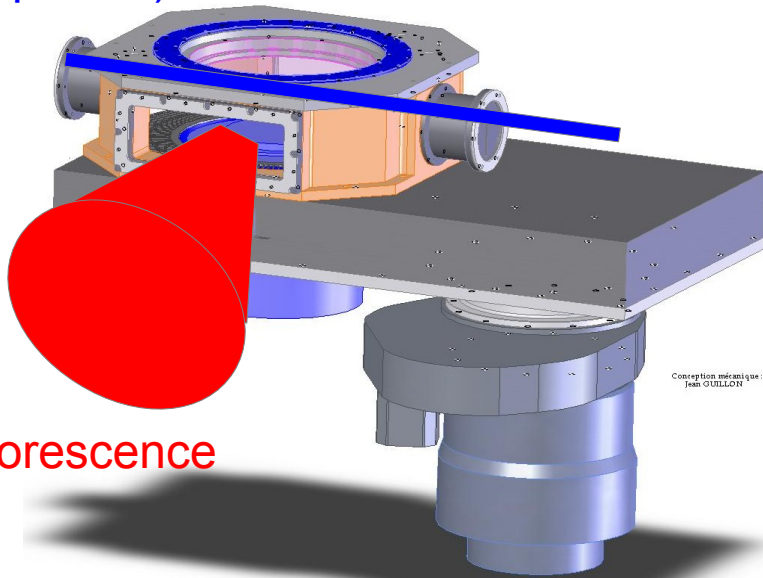
Spectrograph
(Acton SCT
320)

- A broad-band, intense and stable light source that solves usual problems with absorption spectroscopy.
- Measurements of densities of atoms and molecules and gas temperatures
- Absorbances upto 10^{-4} are visible.

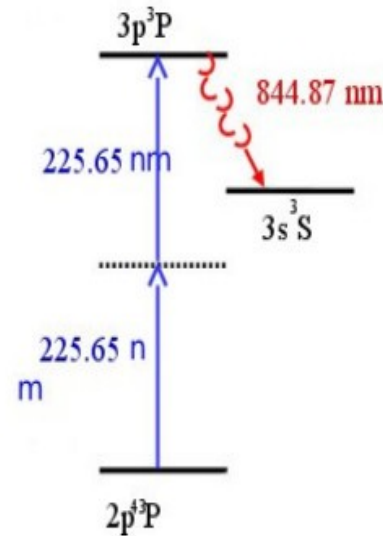
TALIF (Two-Photon Absorption Laser-Induced Fluorescence) : experimental setup



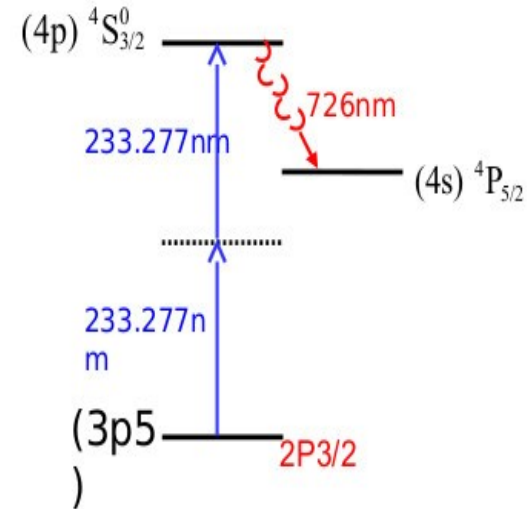
Dye laser
(pulsed)



O atoms excitation
scheme



Chlorine atoms
excitation scheme
(Ono JVSTA 1992)



- High spatial and temporal resolution measurements
- Relative densities of ground-state Cl and O atoms
- Absolute calibration requires additional setups



Booth et al : *J. Phys. D. : Appl. Phys.* **45**(2012)
Niemi et al : *PSST* **14**(2005) 375-386

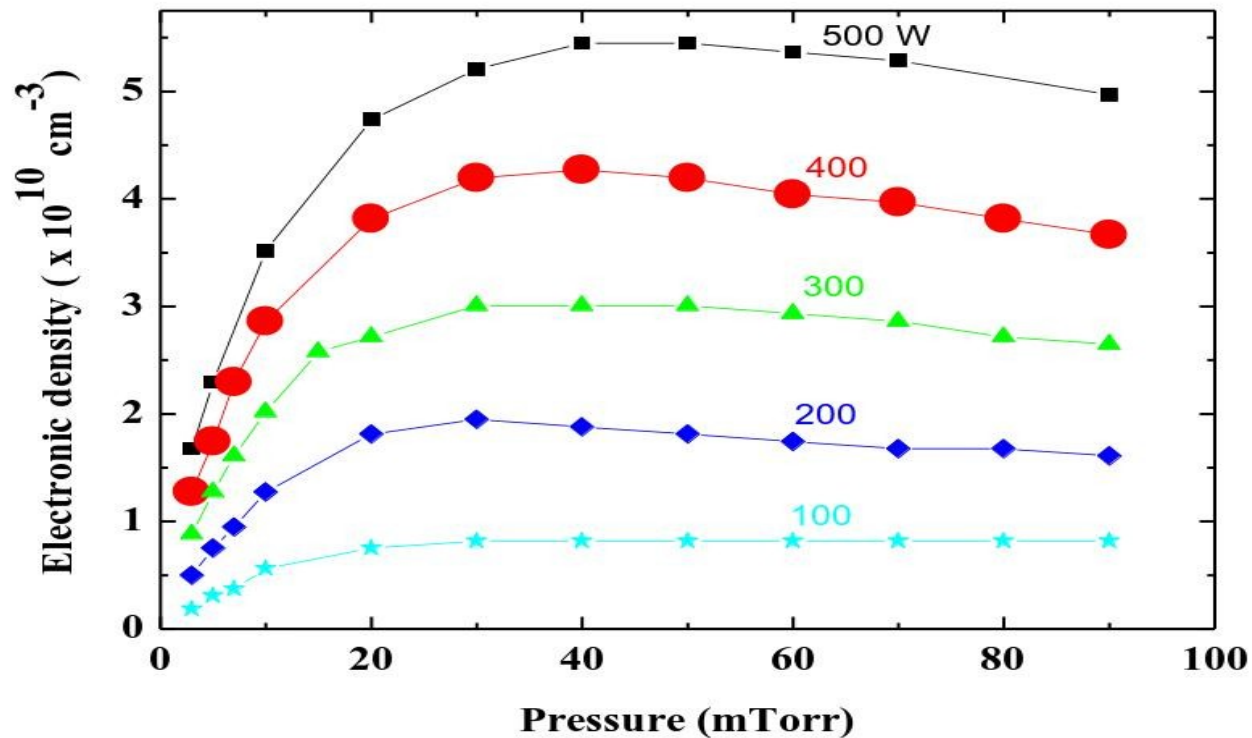
Electron density : Hairpin probe



- $\frac{1}{4}$ wave resonator : ~ 3 GHz : measure plasma permittivity
- The permittivity is simply related to the electron density
- Avoids many of the problems of Langmuir probes

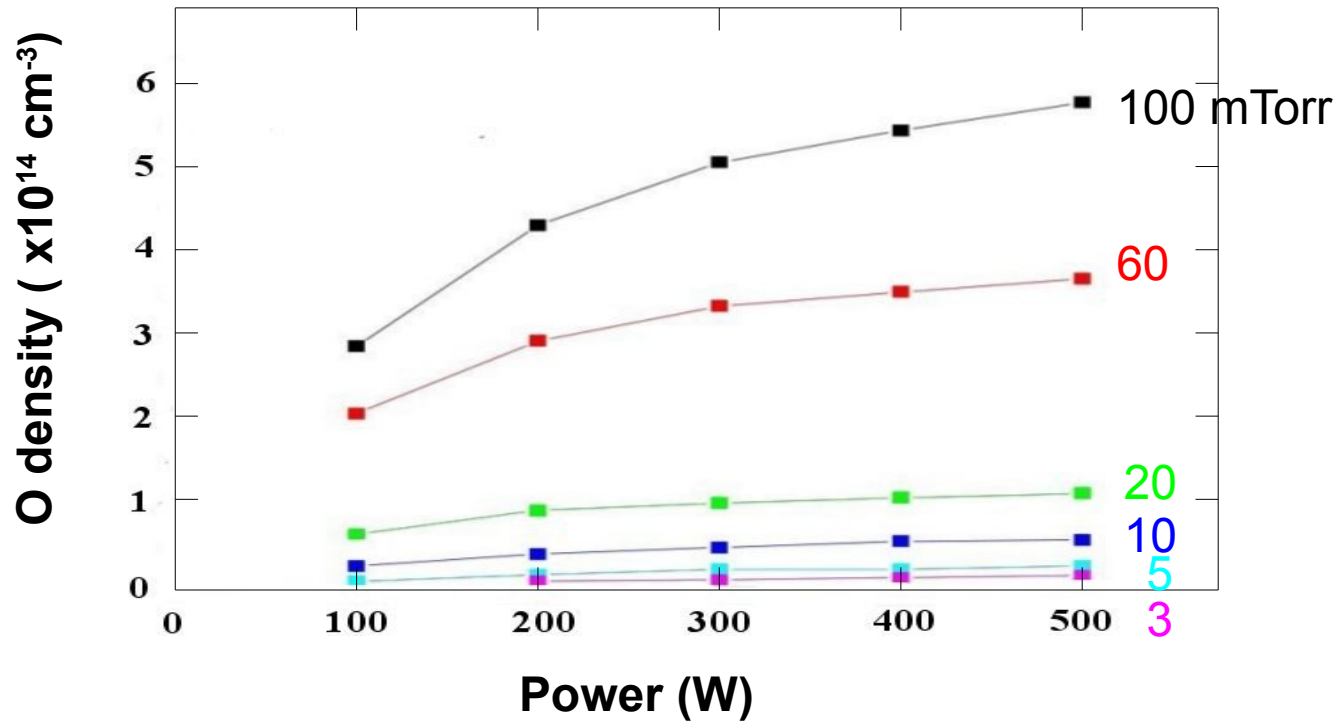
Results in pure O₂

Pure O₂ : Electron density



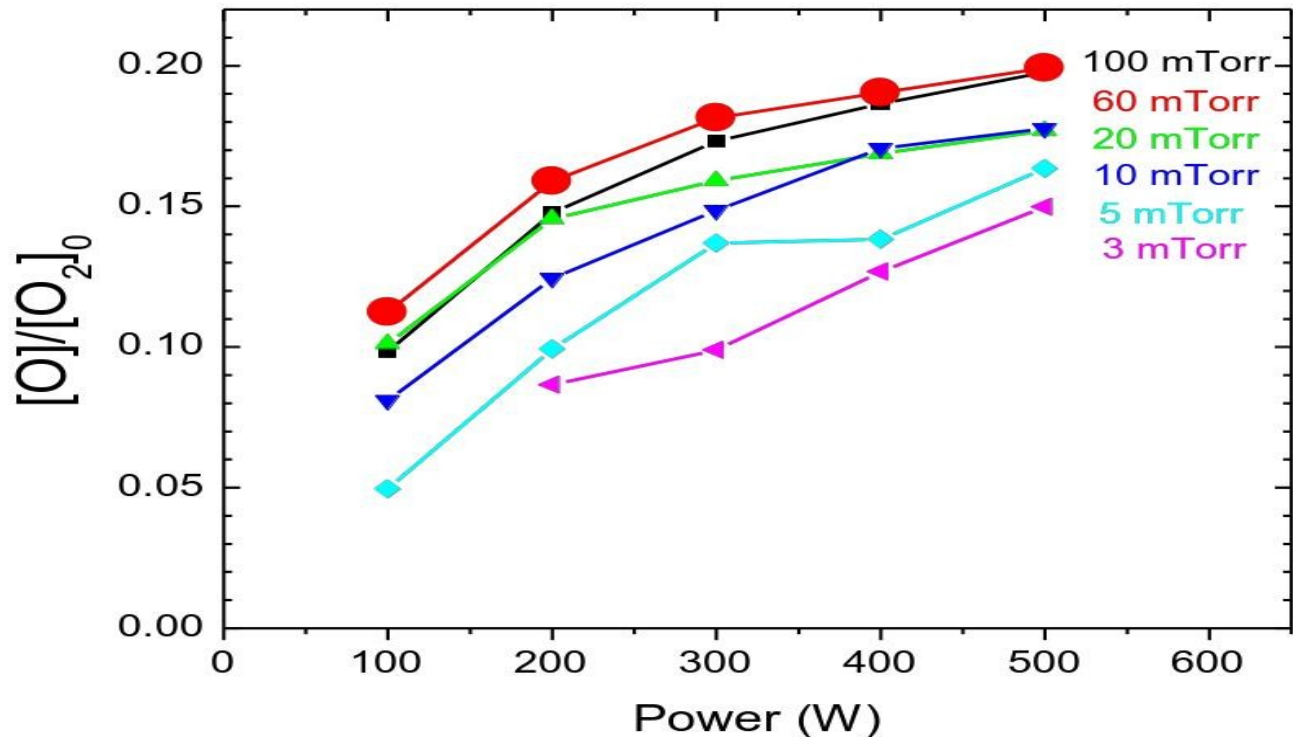
- Electron density broad max. for ~ 40 mTorr
- Competition between ionization and electron attachment

Pure O₂ : Atom density



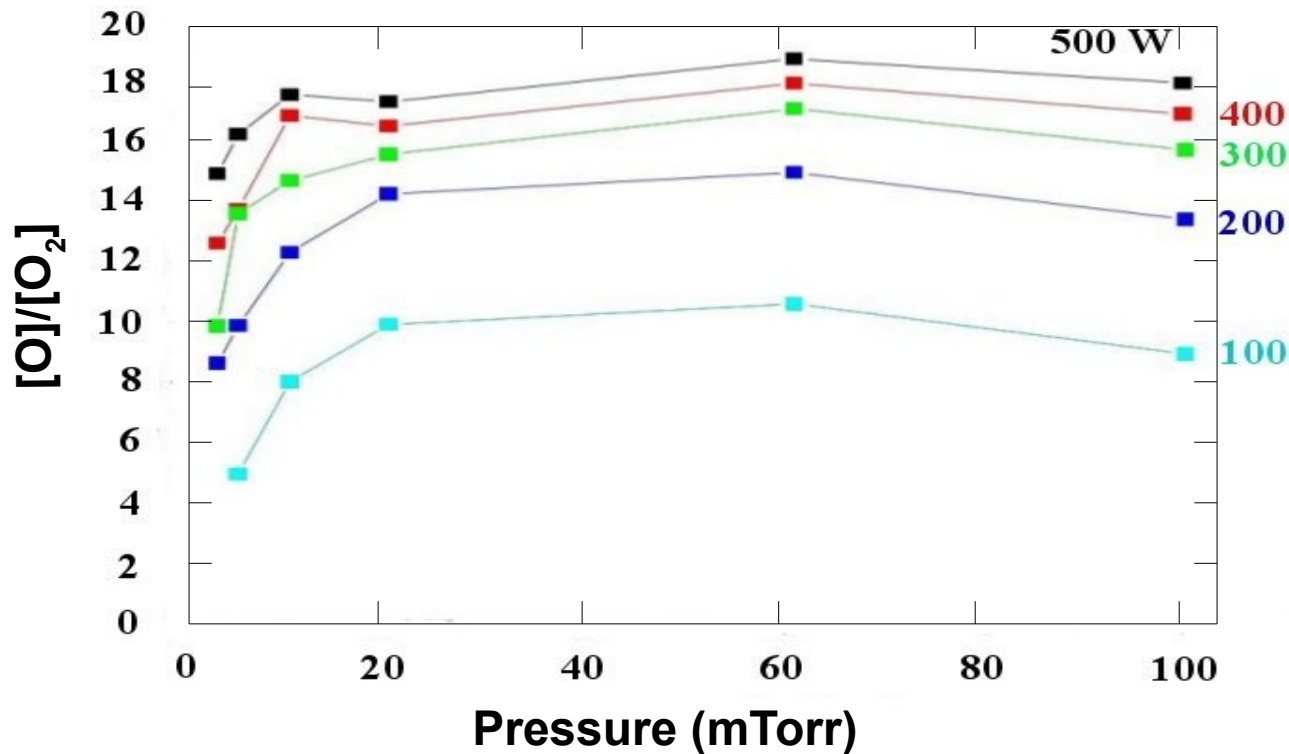
- Increase with power and pressure
- Saturation occurring → plasma heating ?

Pure O₂ : Atom density (dissociation)



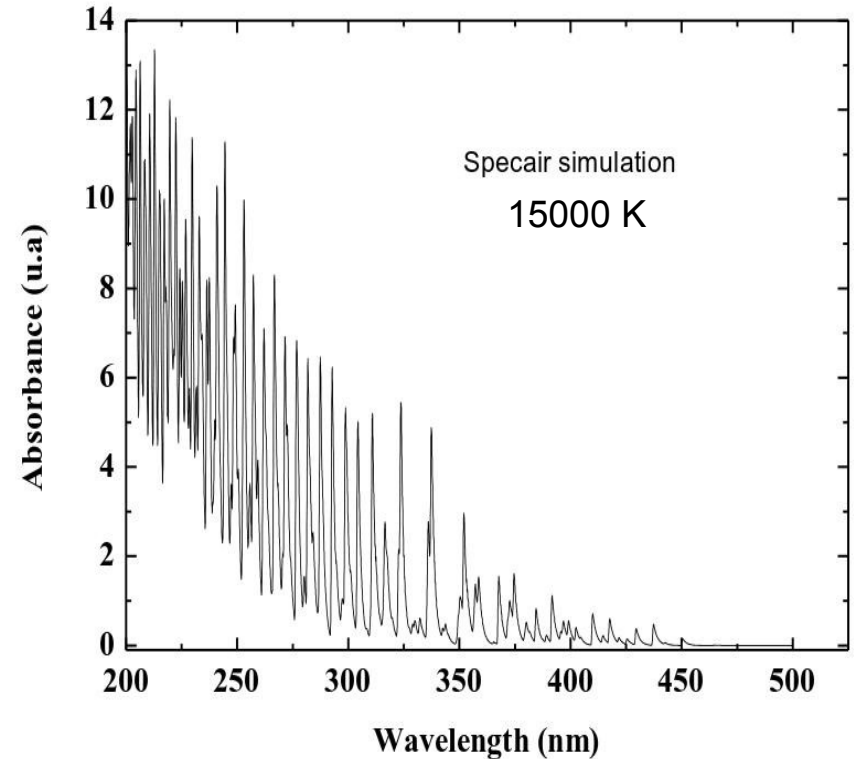
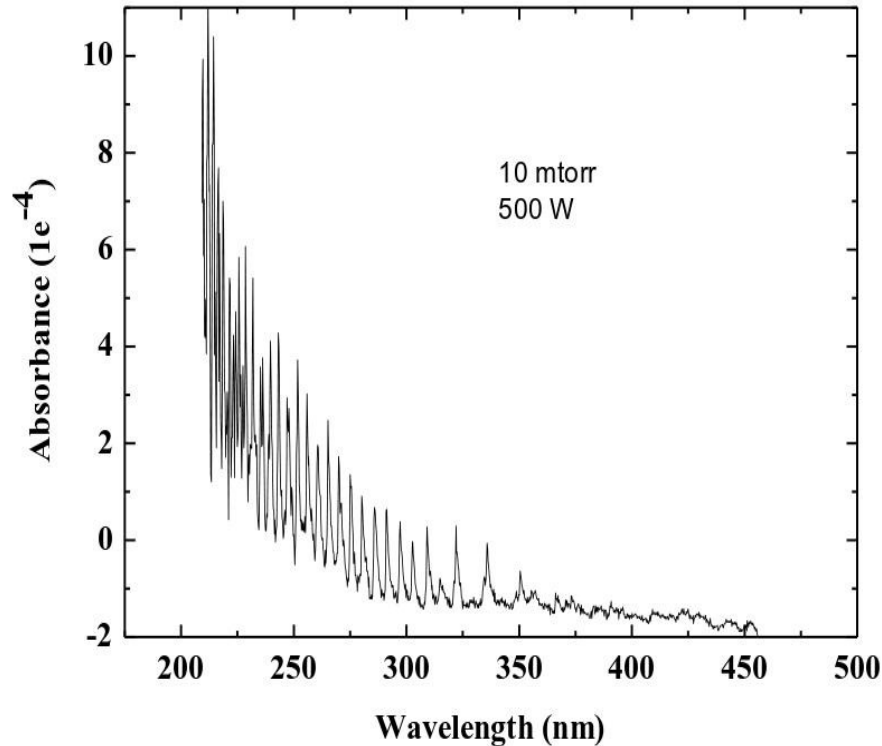
- The dissociation increases with power but seem to saturate
→ plasma heating ?

Pure O₂ : Atom density (dissociation)



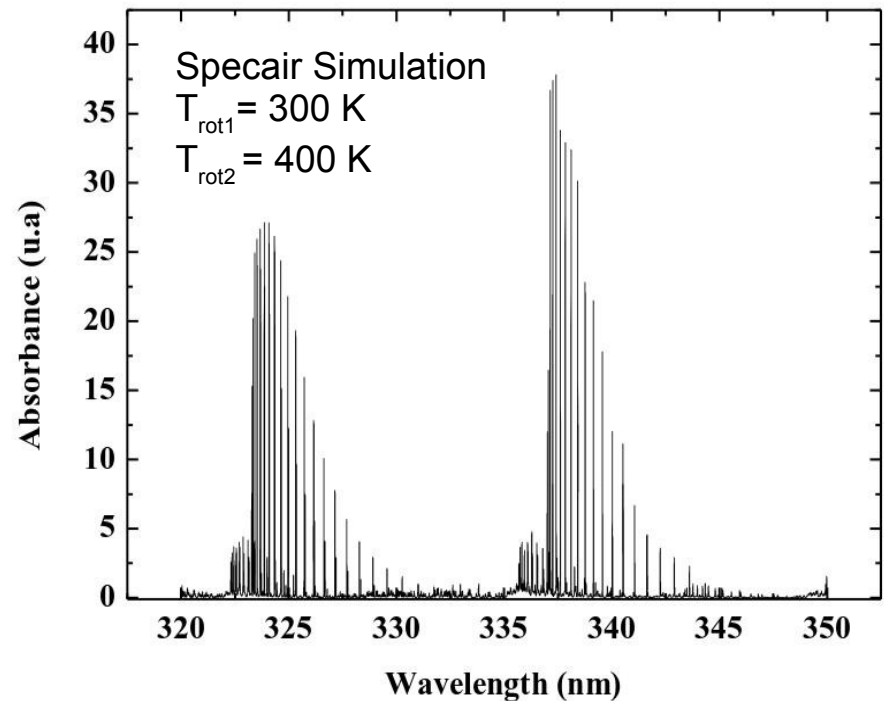
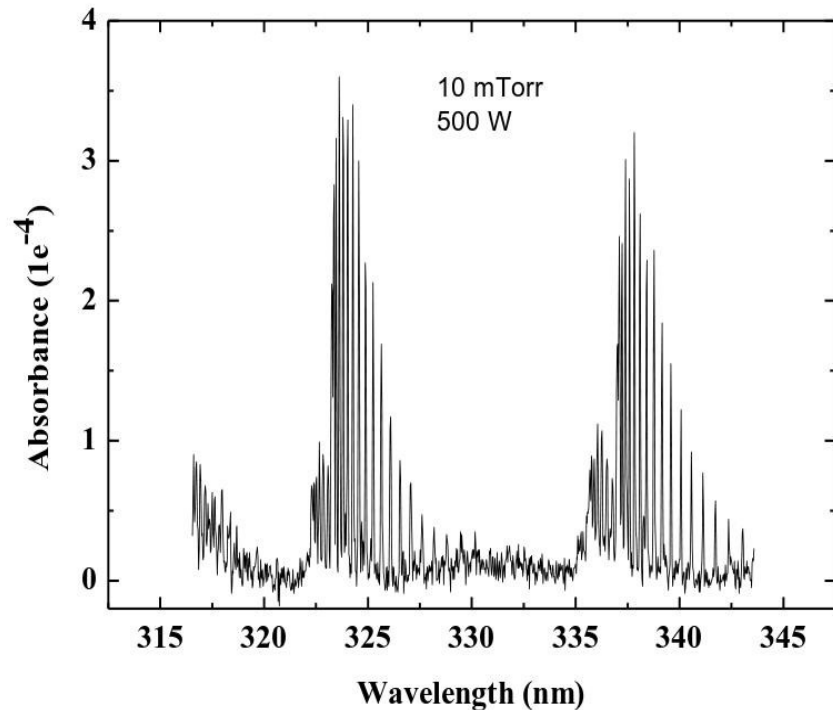
- The dissociation quickly increase from 0 to 20 mTorr but then saturates and decrease.

Pure O₂ : Absorption spectroscopy



- Vibrational structures of O₂ → important $T_{\text{vib}} \sim 15000$ K

Pure O₂ : Absorption spectroscopy

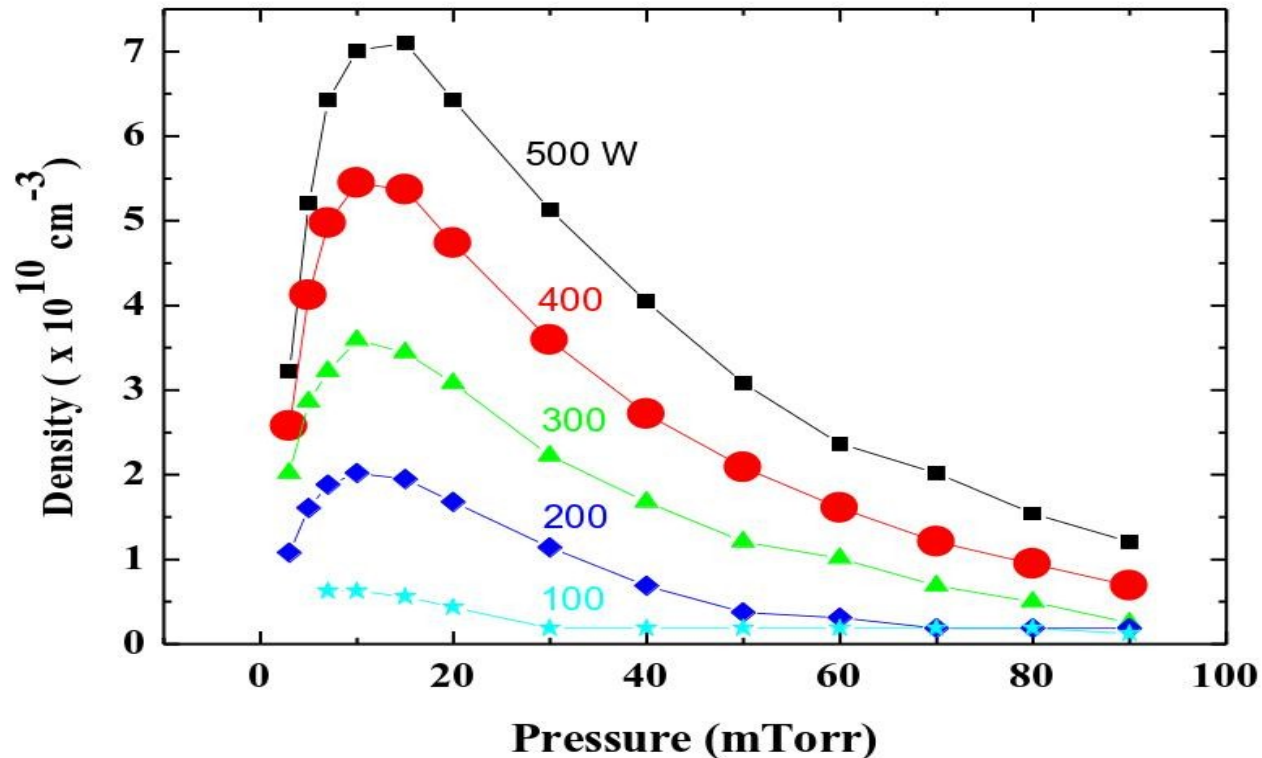


➤ Rotational structures of O₂ → System of two temperatures ($T_{rot} = 300 \text{ K} + 400 \text{ K}$)

↳ O₂ in plasma + O₂ close to windows

Results in pure Cl_2

Pure Cl₂ : Electron densities

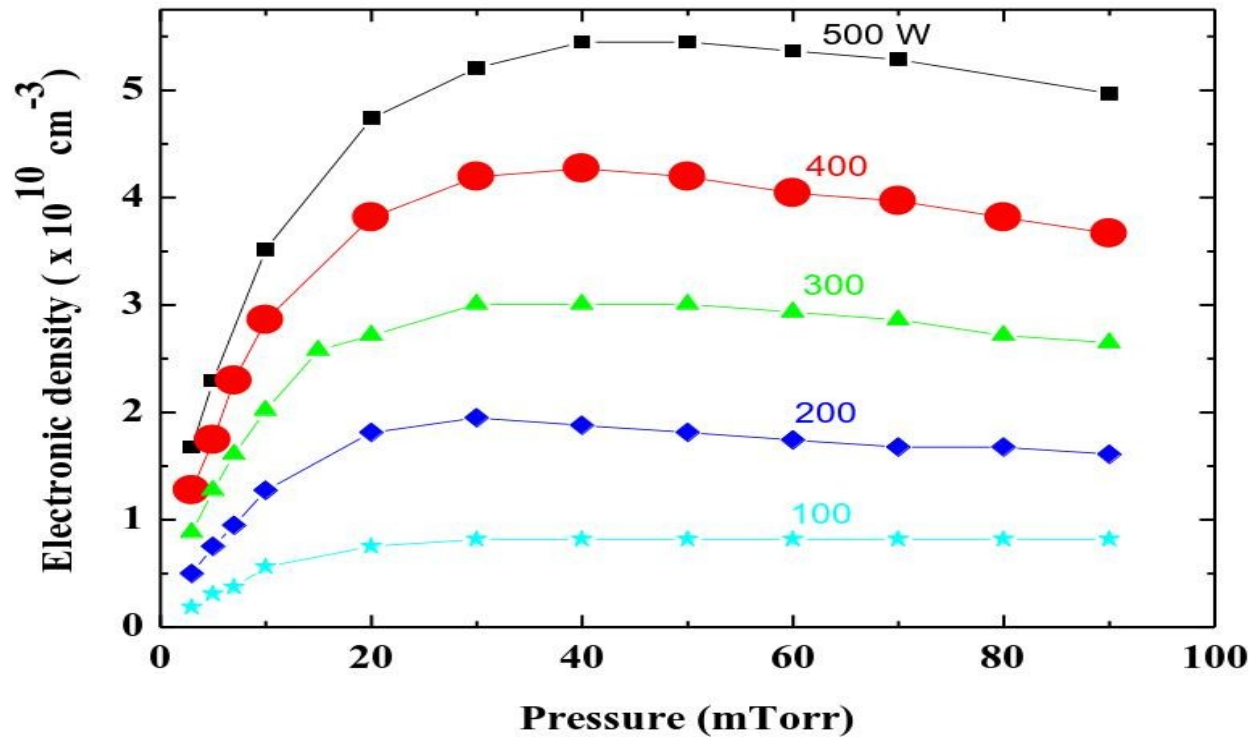


- Electron density max. for ~ 10 mTorr
- Competition between ionization and electron attachment

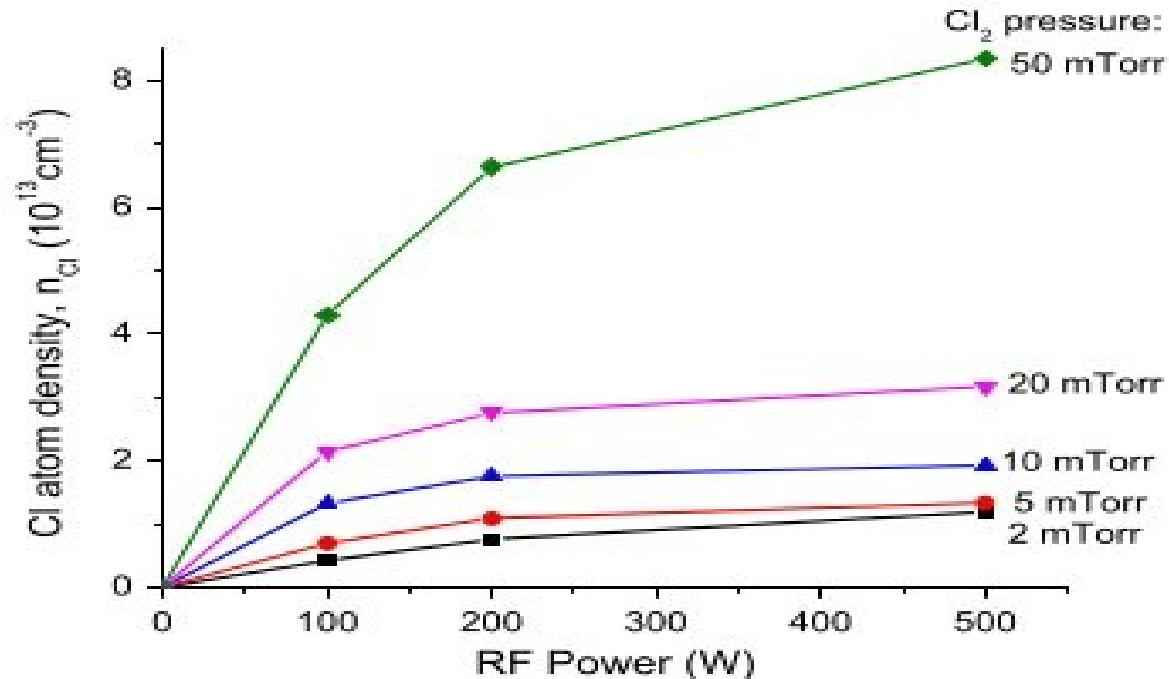
Pure Cl₂ : Electron densities



Comparison with O₂

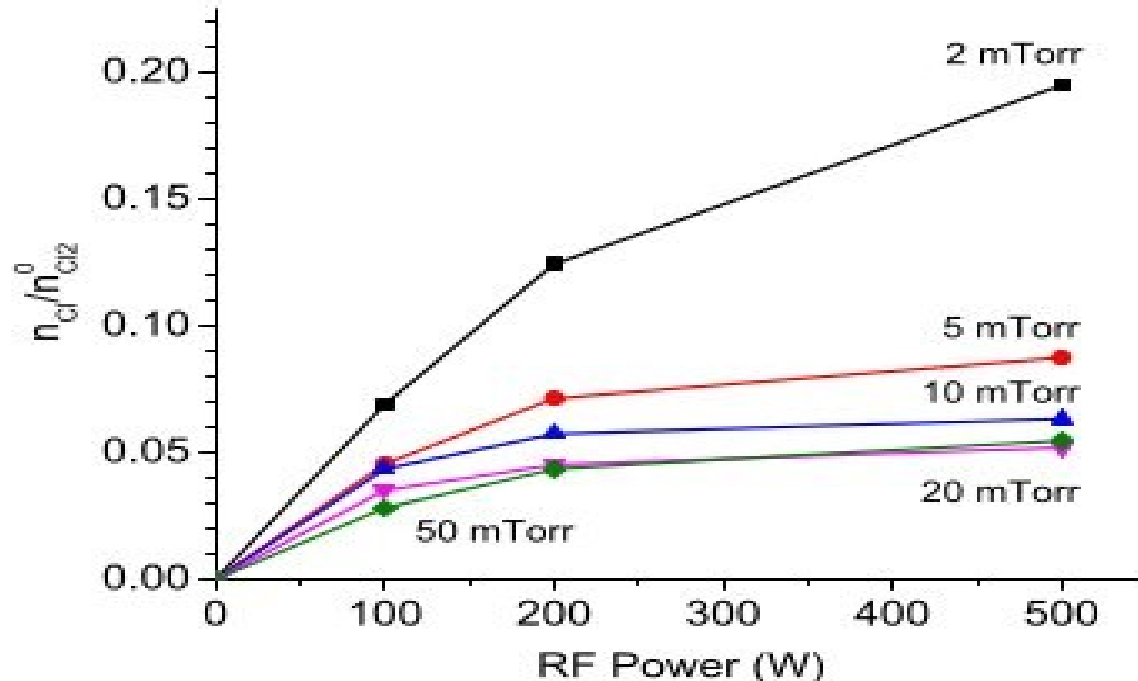


Pure Cl₂ : Atom density



- Increase with power but saturation occurring for high powers

Pure Cl₂ : Atom density (dissociation)

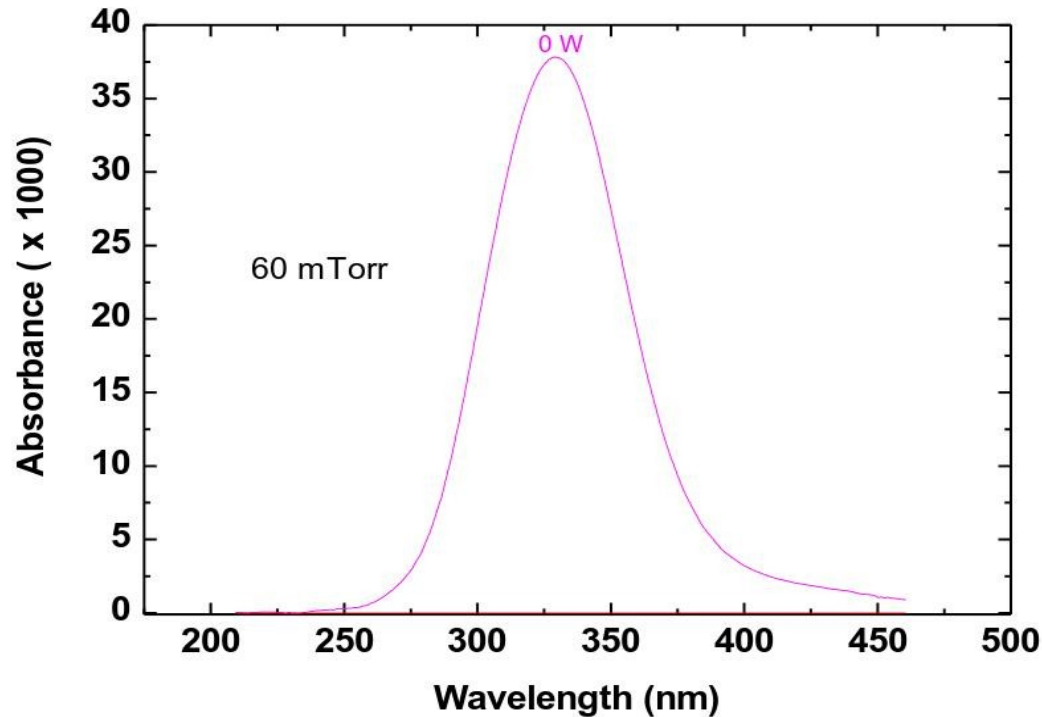


- The dissociation decreases with the pressure
- The dissociation increases with the power and saturates

Pure Cl₂ : Absorption spectroscopy

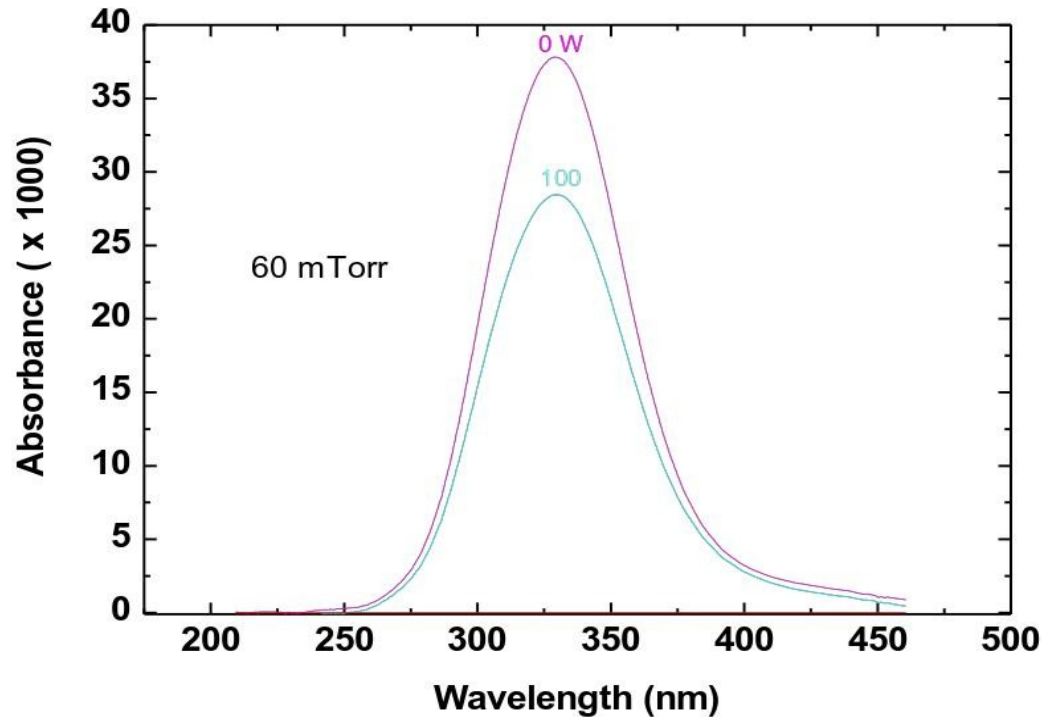


No power



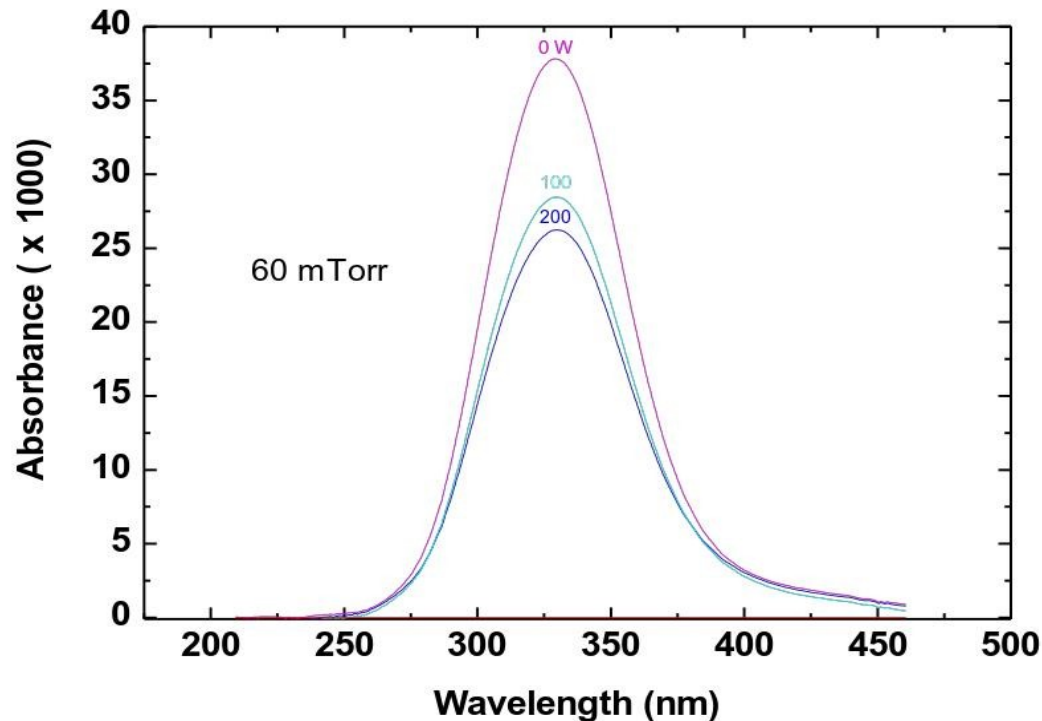
- Absorption continuum of Cl₂ :
- When power increases the Cl₂ density decreases due to dissociation, gas heating ?

Pure Cl₂ : Absorption spectroscopy



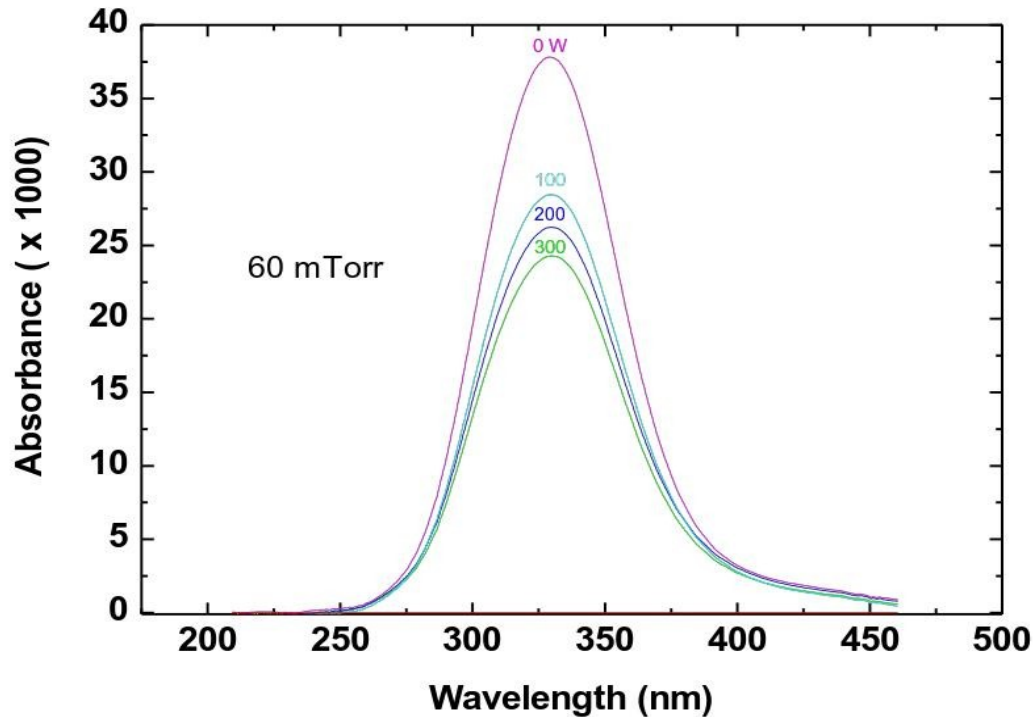
- Absorption continuum of Cl₂ :
- When power increases the Cl₂ density decreases due to dissociation, gas heating ?

Pure Cl₂ : Absorption spectroscopy



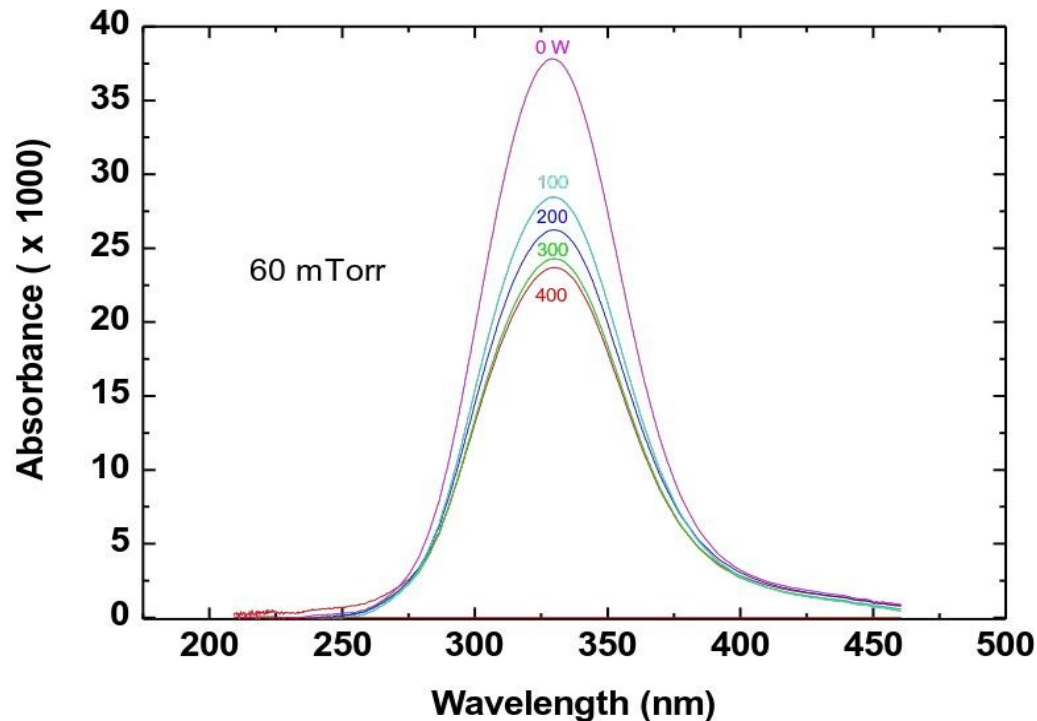
- Absorption continuum of Cl₂ :
- When power increases the Cl₂ density decreases due to dissociation, gas heating ?

Pure Cl₂ : Absorption spectroscopy



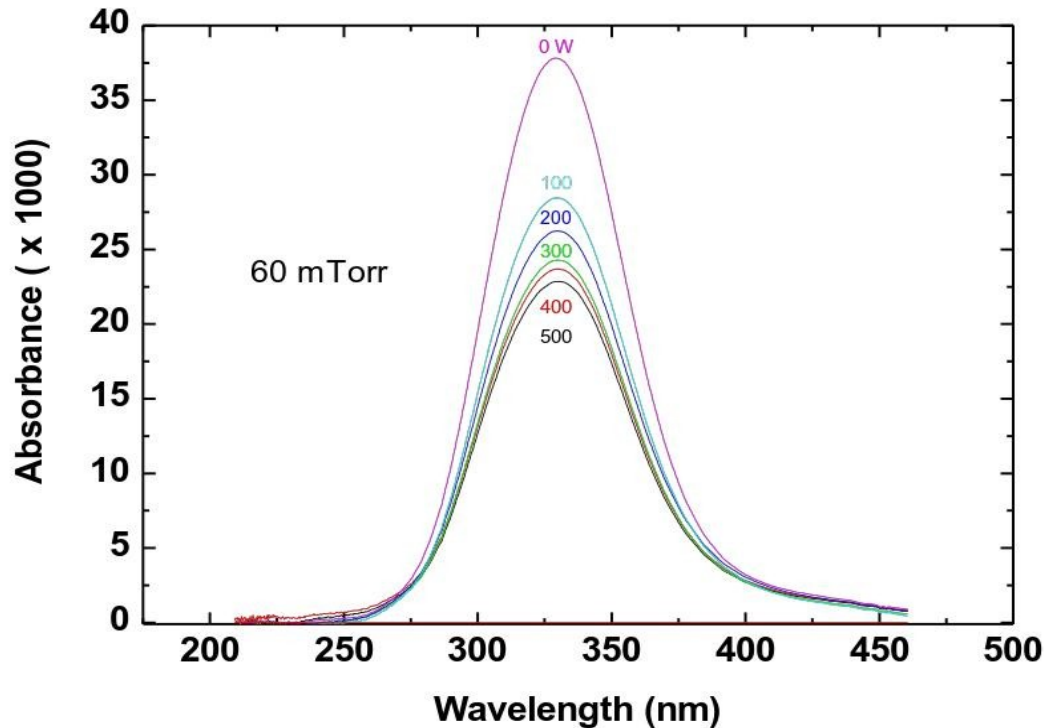
- Absorption continuum of Cl₂ :
- When power increases the Cl₂ density decreases due to dissociation, gas heating ?

Pure Cl_2 : Absorption spectroscopy



- Absorption continuum of Cl_2 :
- When power increases the Cl_2 density decreases due to dissociation, gas heating ?

Pure Cl_2 : Absorption spectroscopy

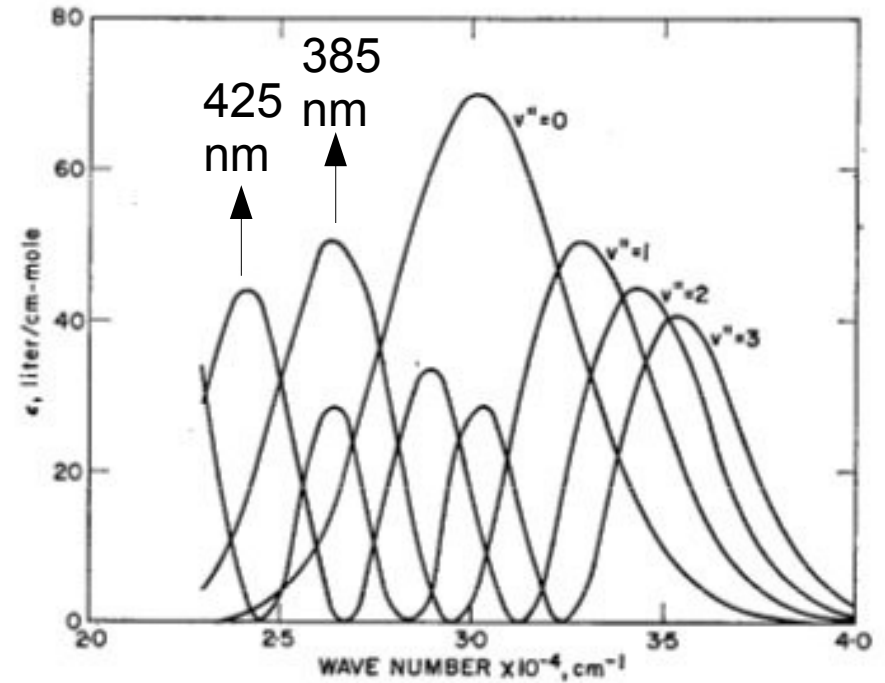
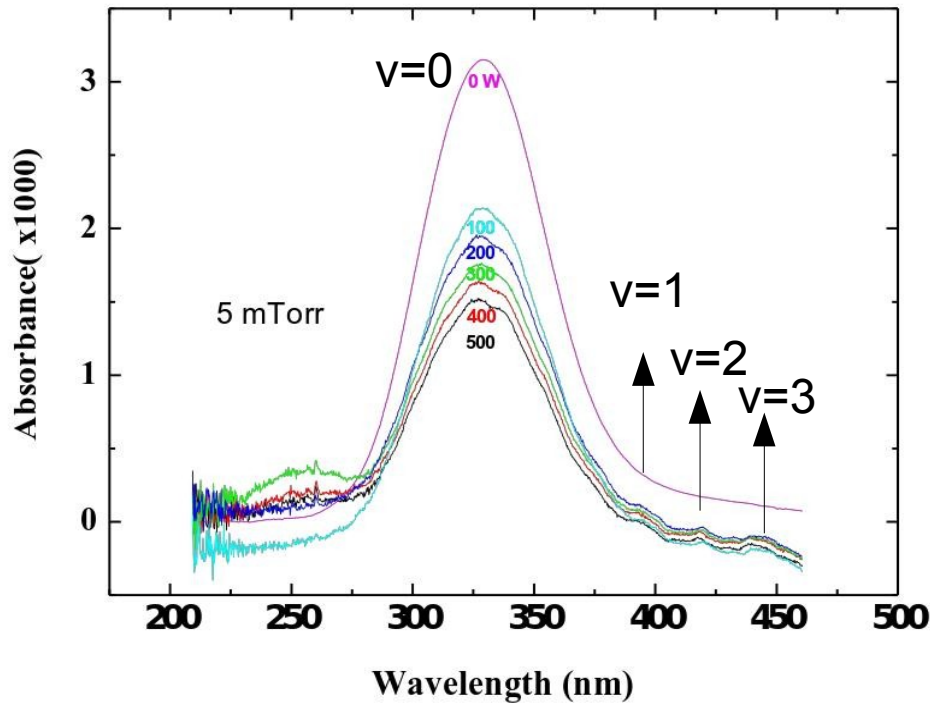


- Absorption continuum of Cl_2 :
- When power increases the Cl_2 density decreases due to dissociation, gas heating ?

Pure Cl₂ : Absorption spectroscopy



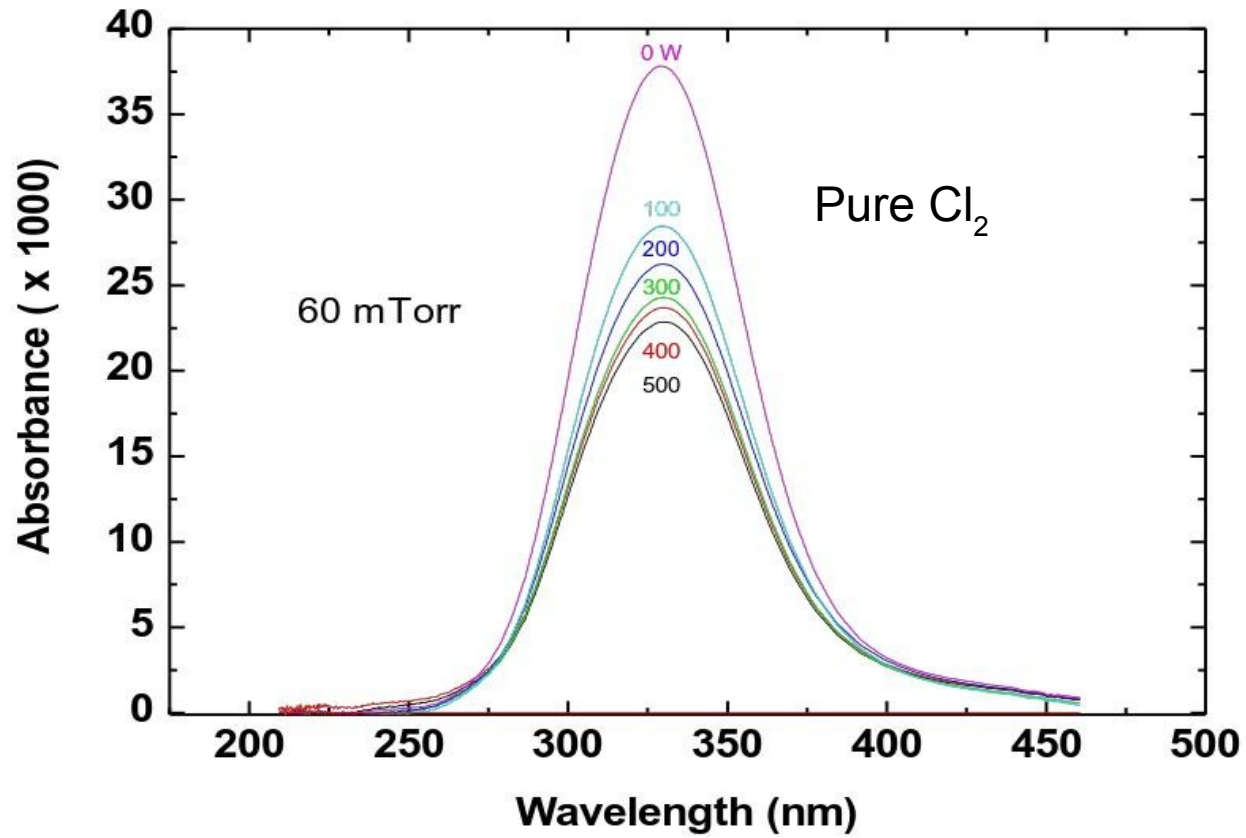
Lower pressure



- Vibrational states of Cl₂ visible but weak $\rightarrow T_{\text{vib}} \sim T_{\text{trans}}, 1000 \text{ K}$

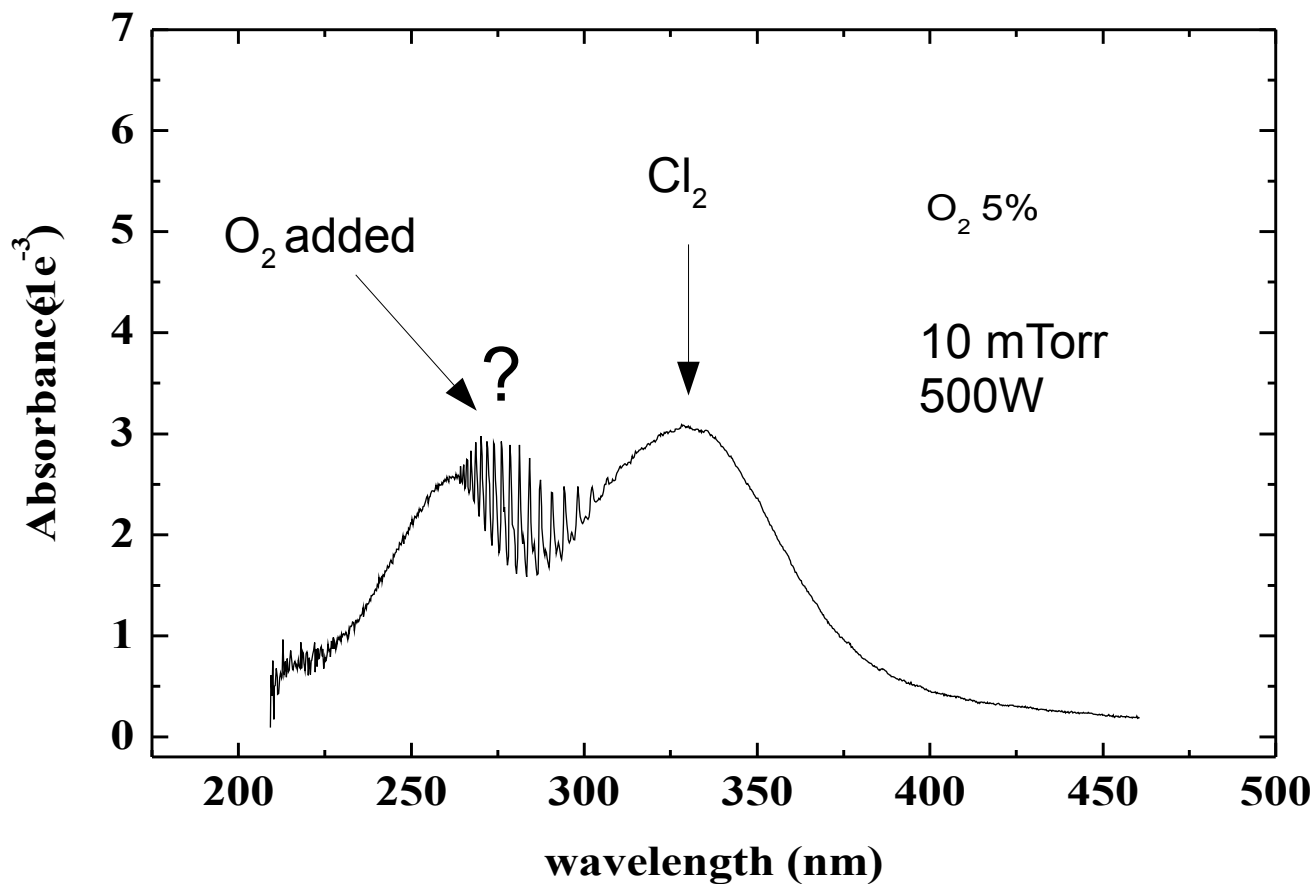
Results in Cl_2/O_2 mixtures

Mixtures : Absorption spectroscopy



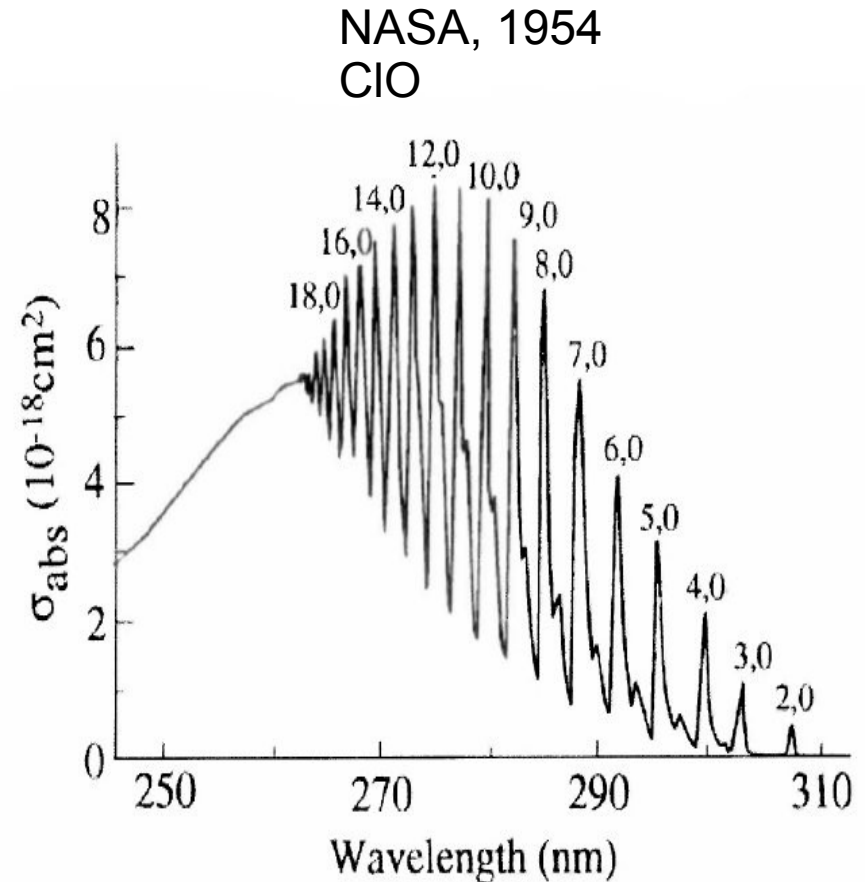
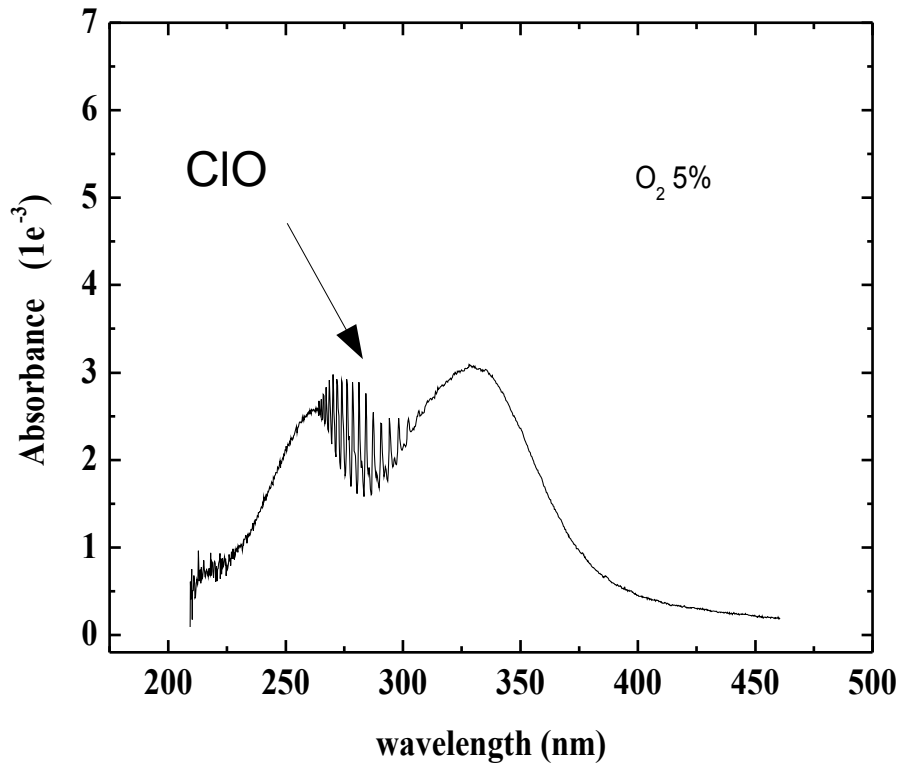
- We start with pure Cl_2 and we add O_2

Mixtures : Absorption spectroscopy



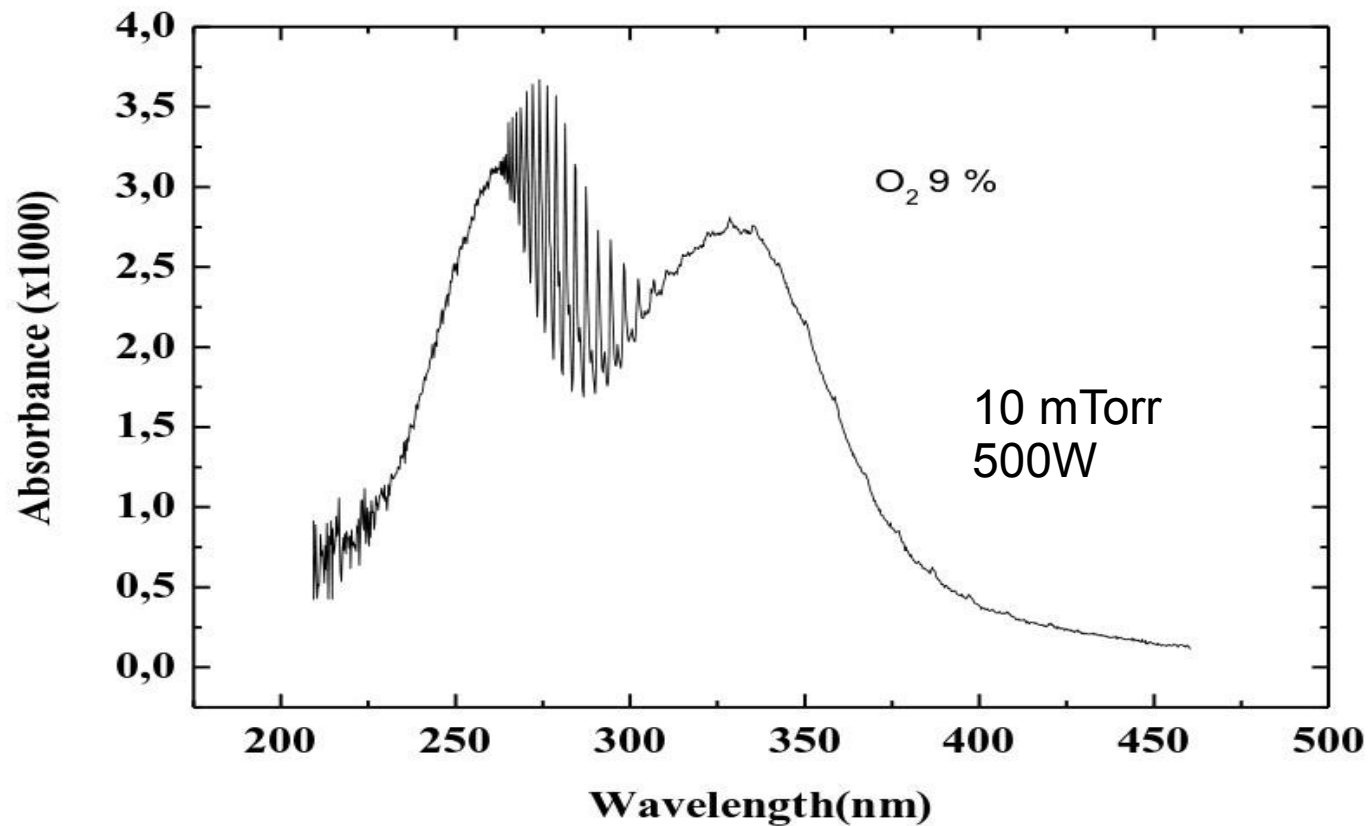
- Structures appear when a small fraction of O₂ is added.

Mixtures : Absorption spectroscopy

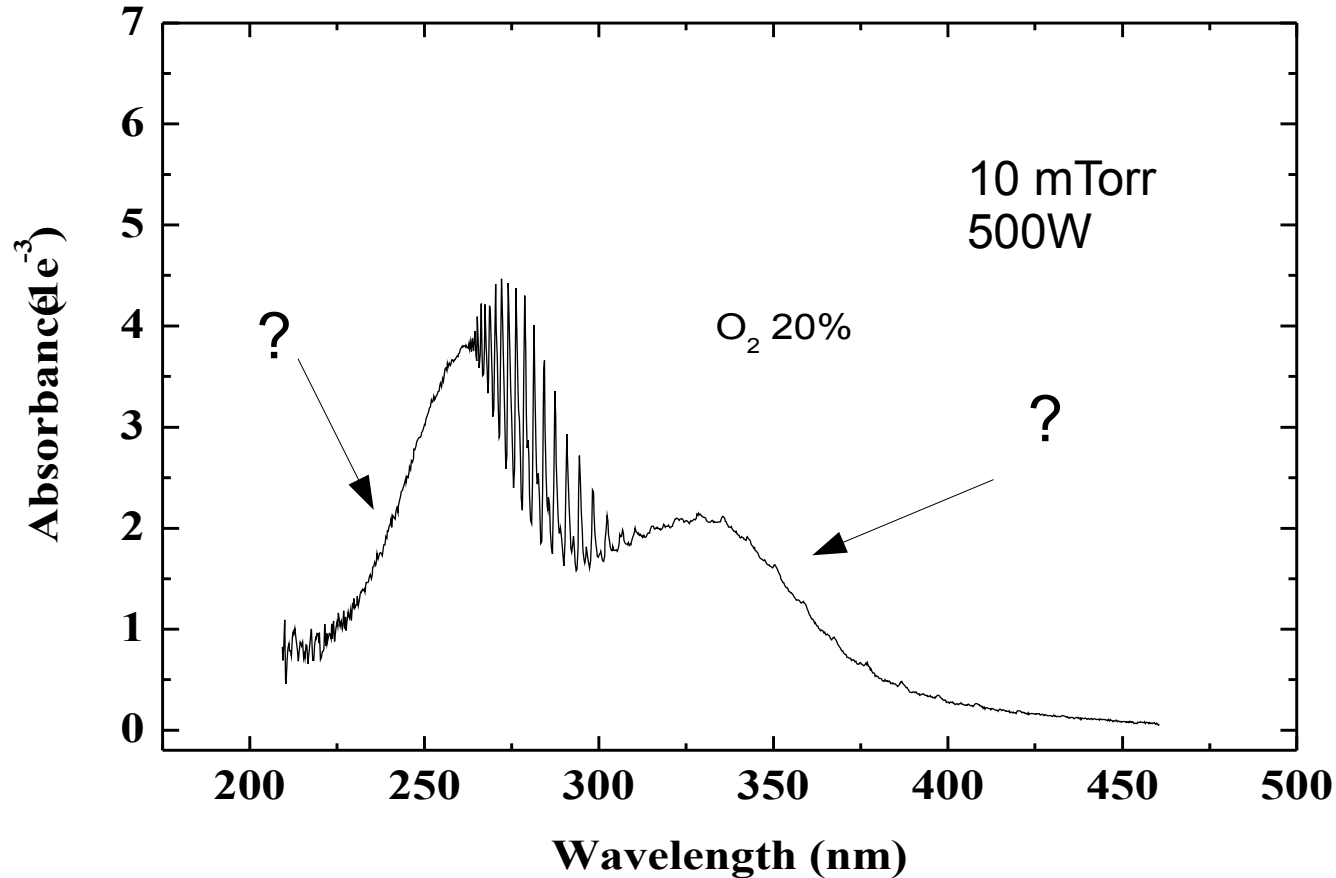


- Vibrational structures of ClO appear → oxychlorides are formed.

Mixtures : Absorption spectroscopy

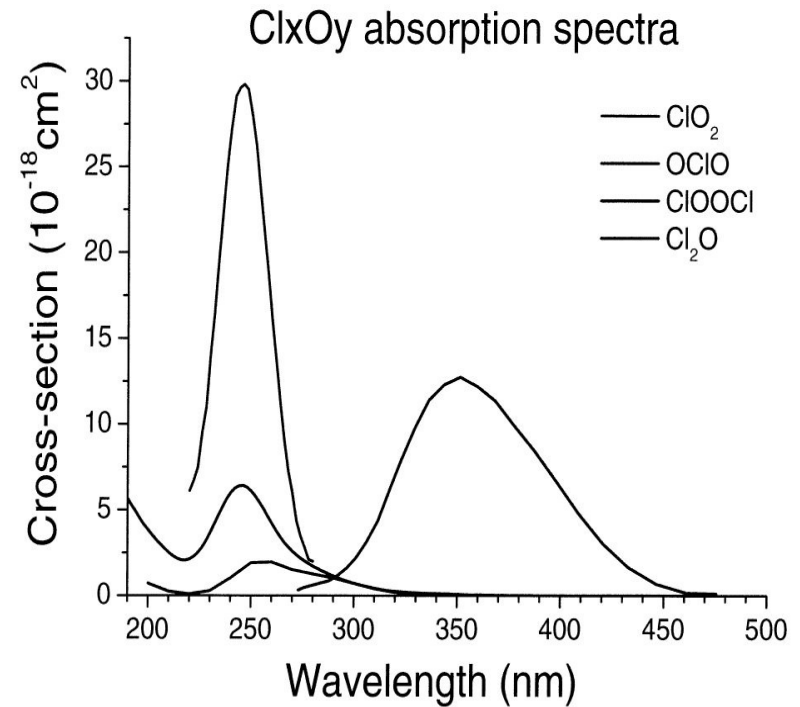
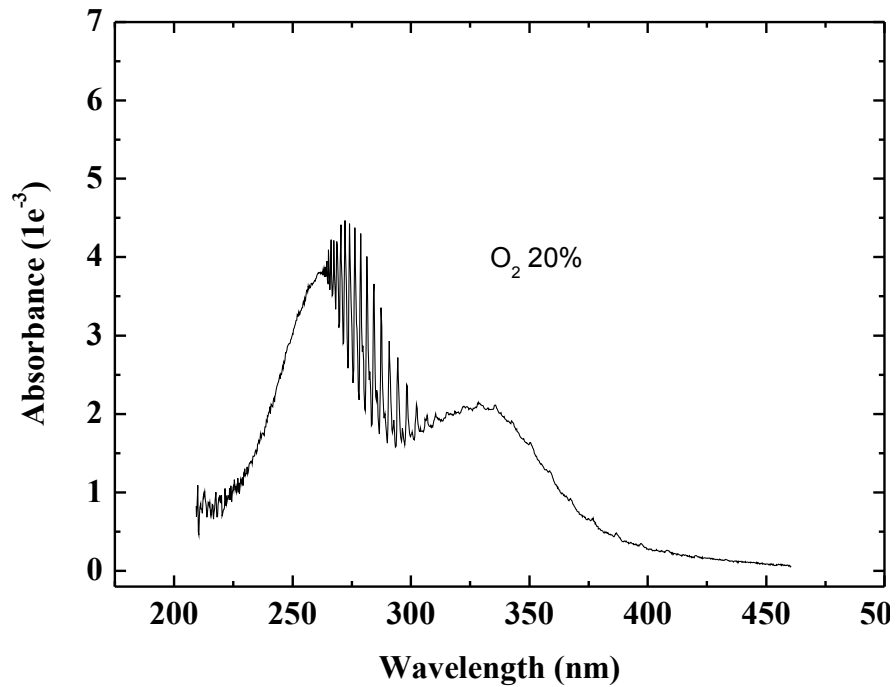


Mixtures : Absorption spectroscopy

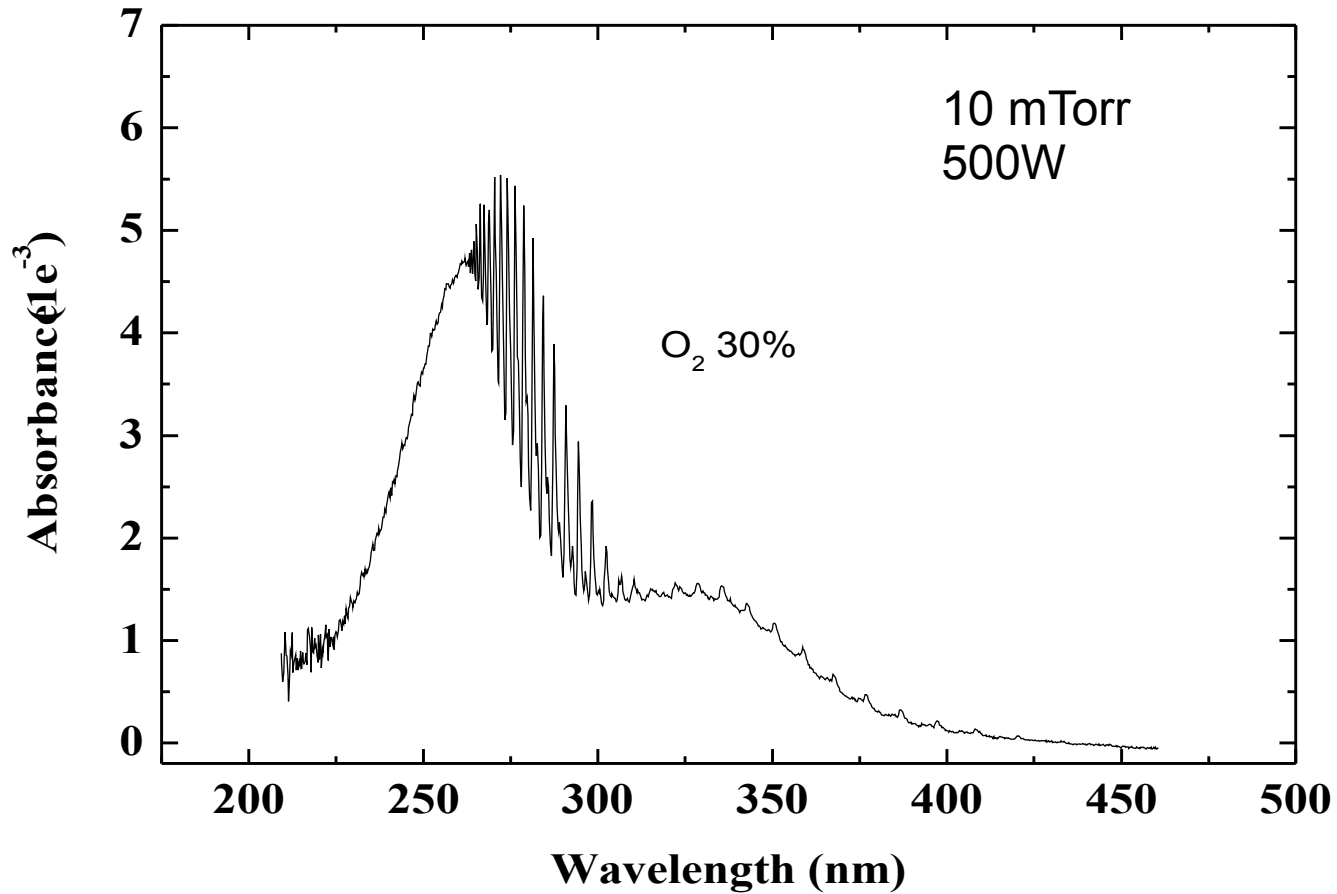


- Other structures appear when the fraction of O₂ increases

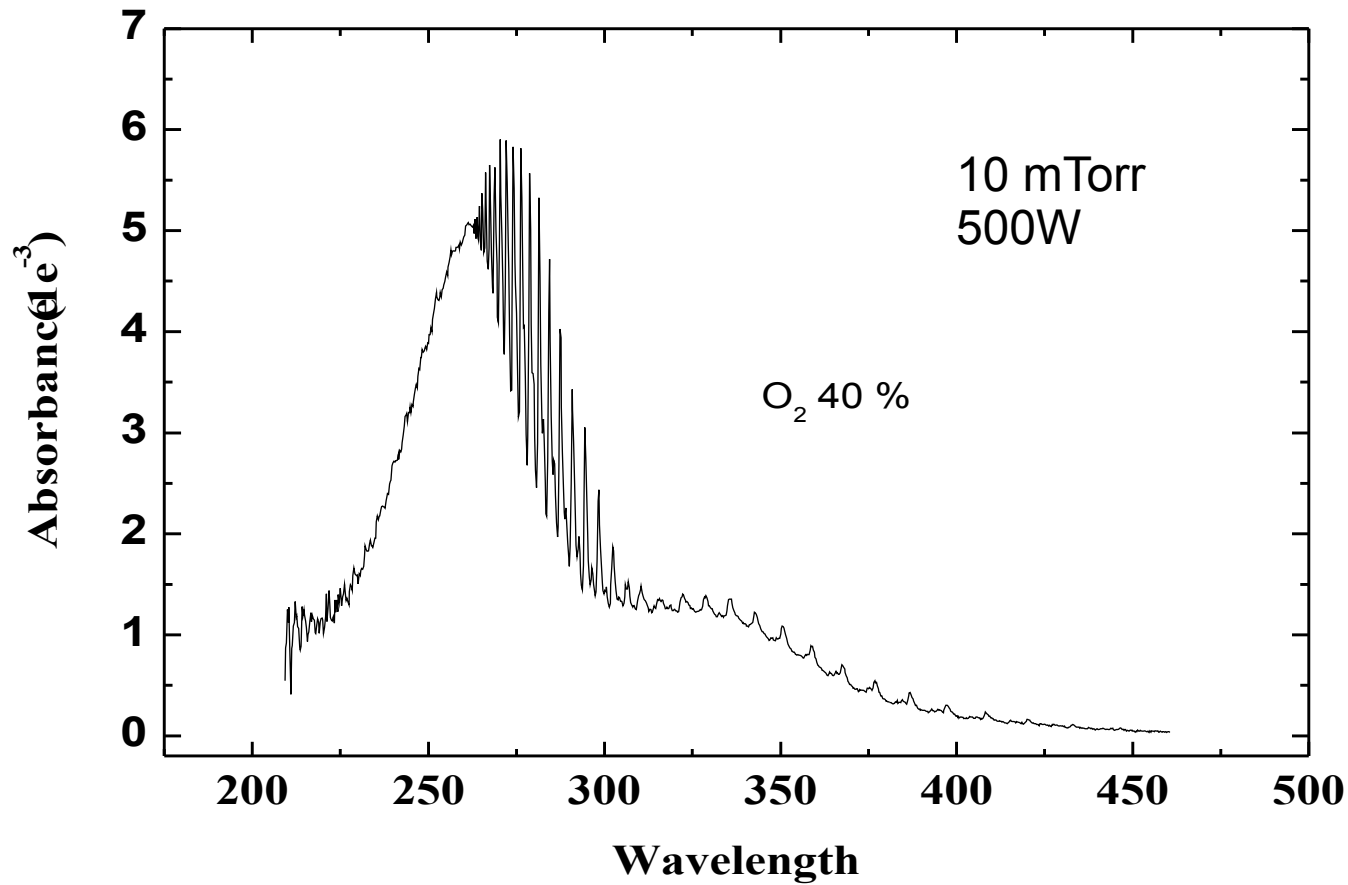
Mixtures : Absorption spectroscopy



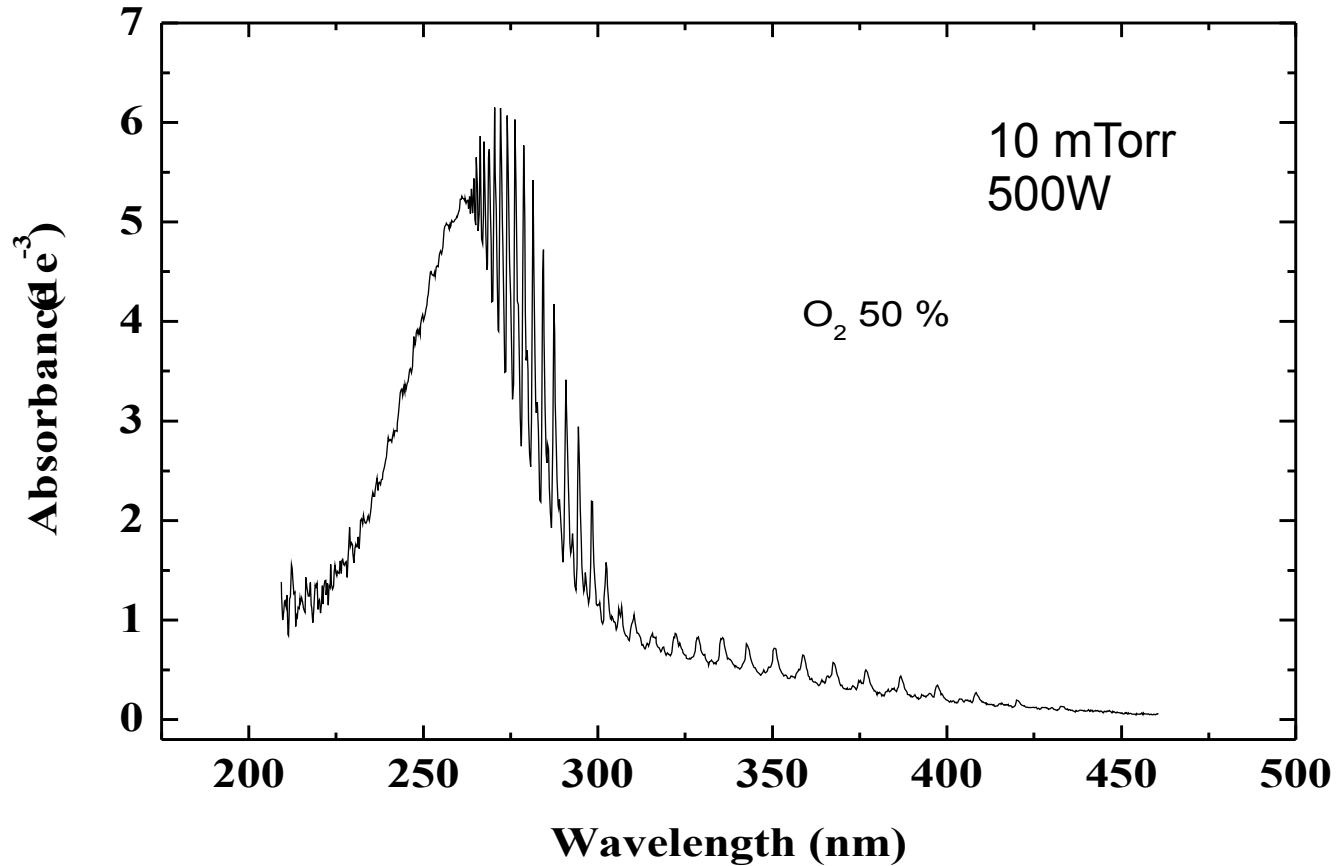
Mixtures : Absorption spectroscopy



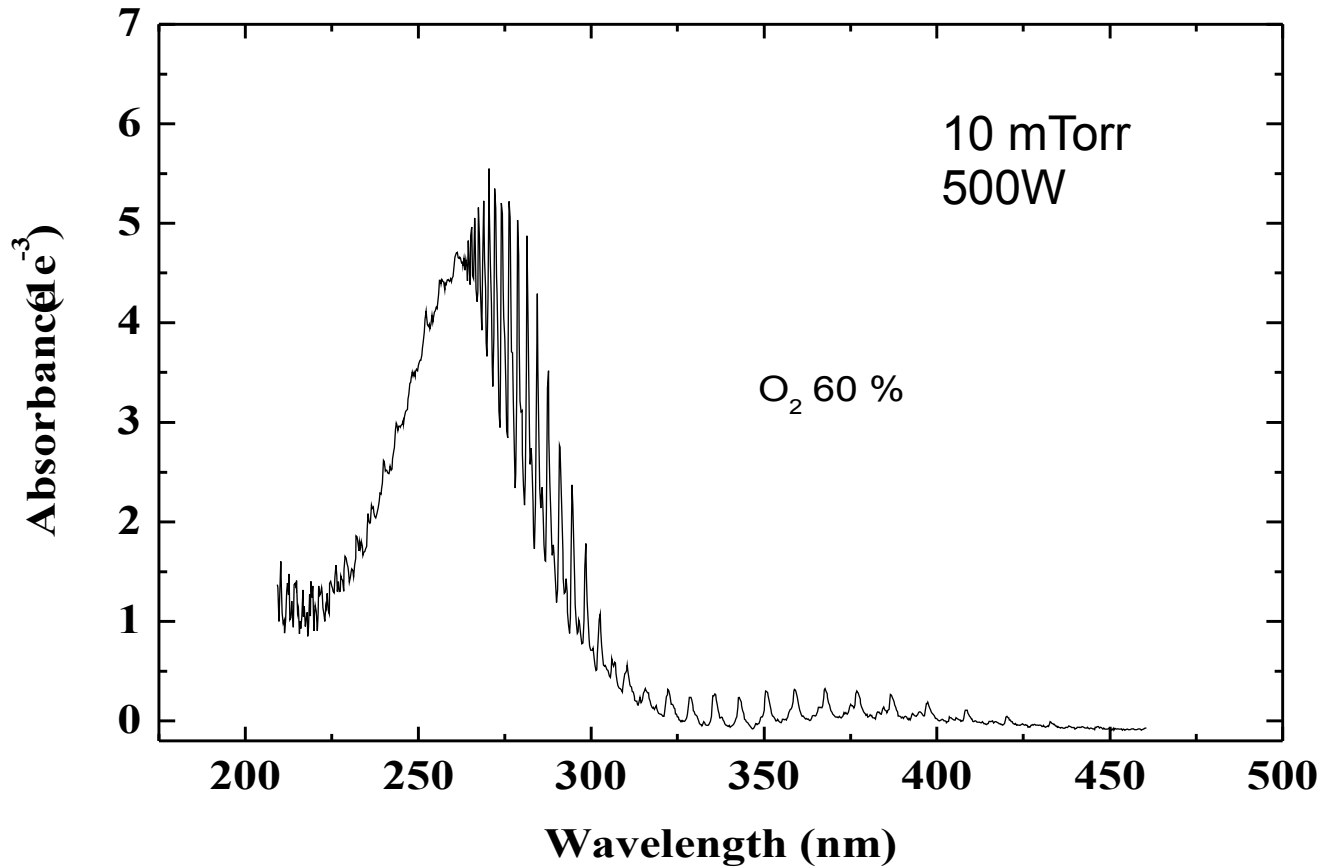
Mixtures : Absorption spectroscopy



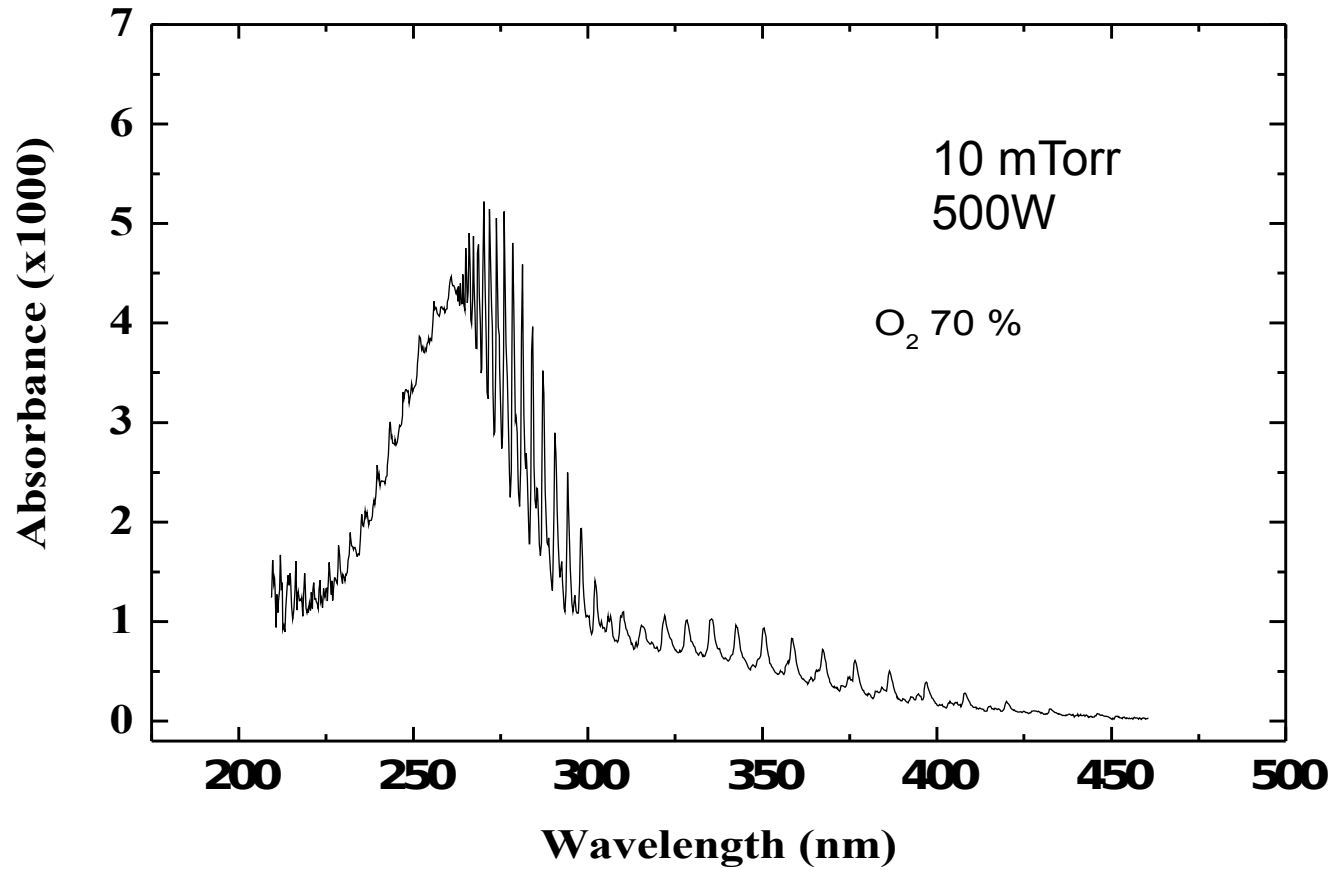
Mixtures : Absorption spectroscopy



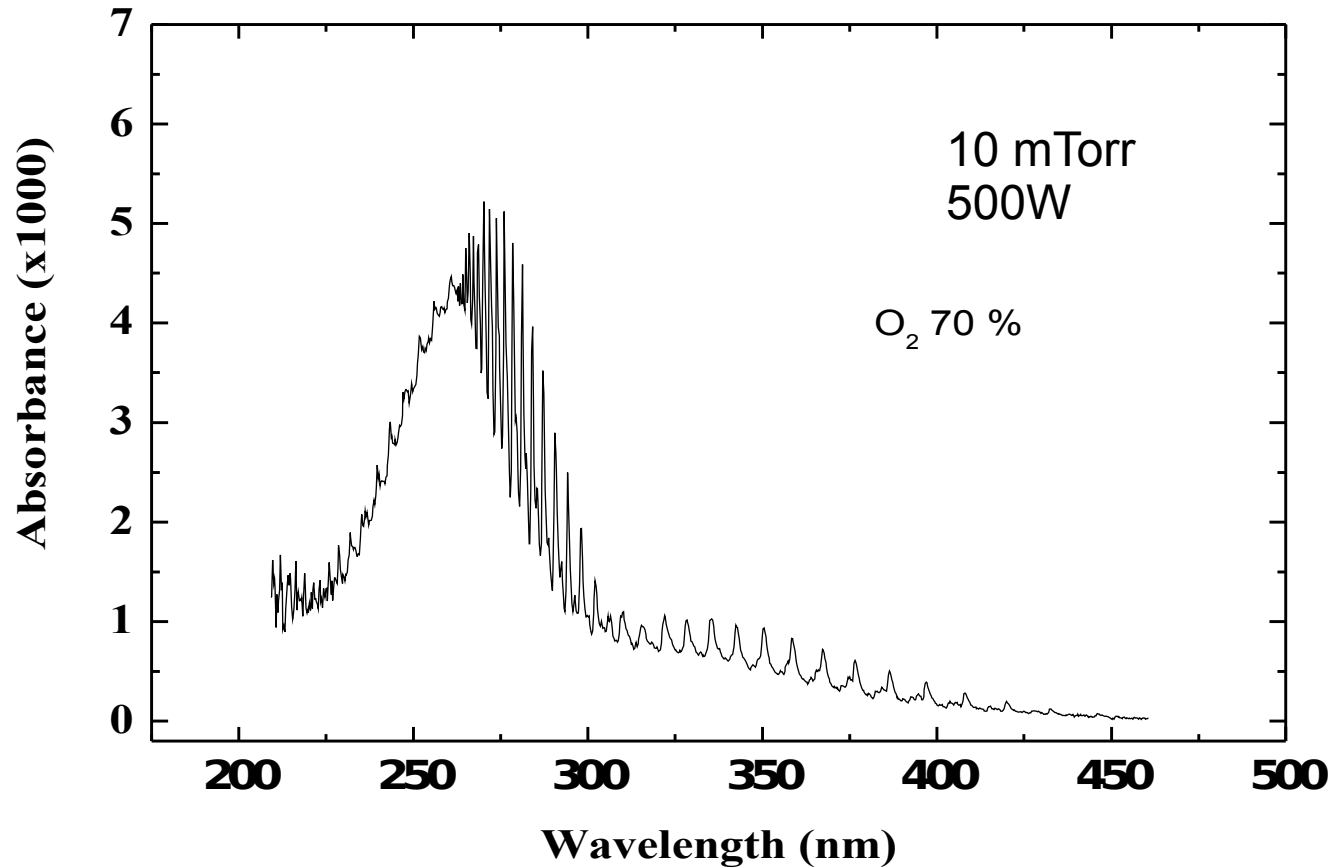
Mixtures : Absorption spectroscopy



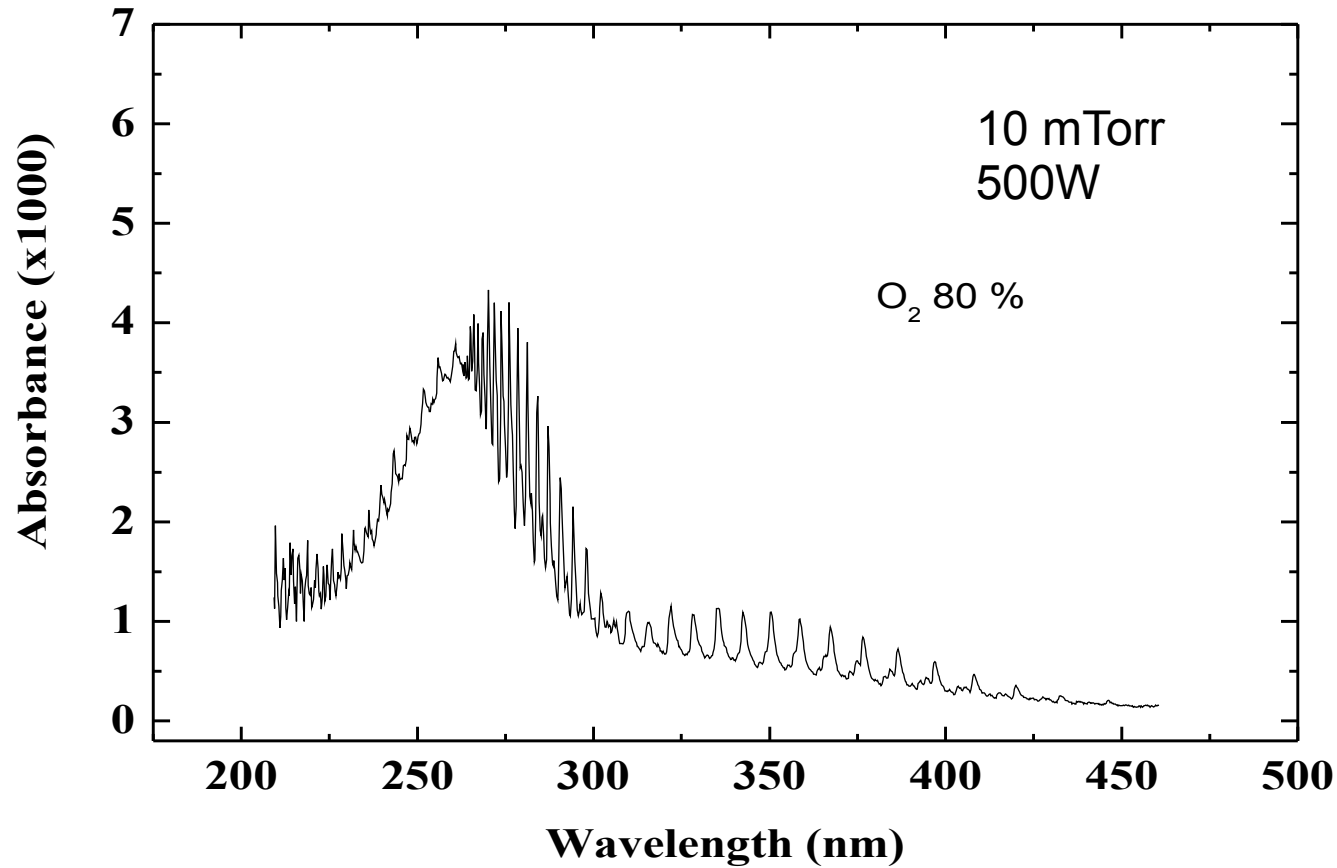
Mixtures : Absorption spectroscopy



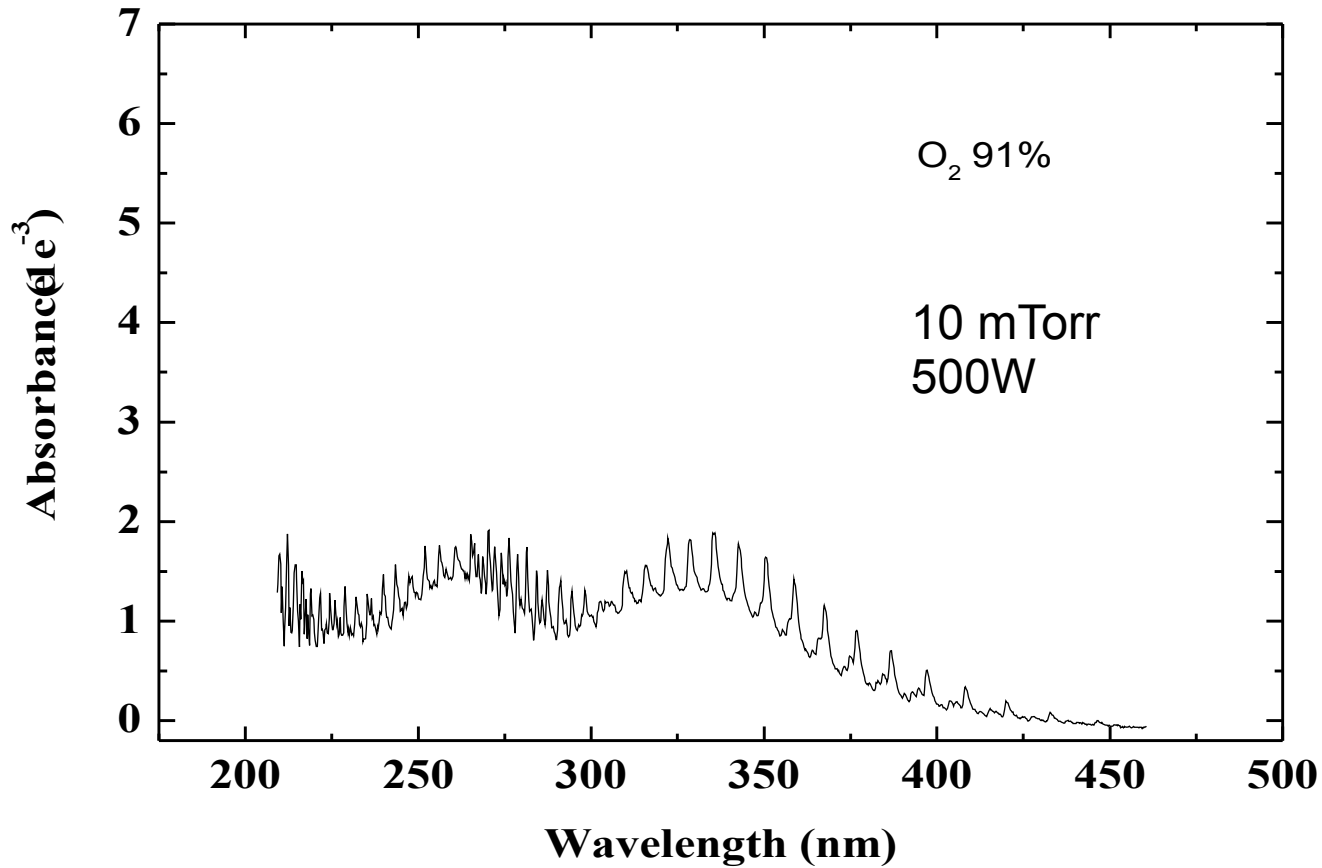
Mixtures : Absorption spectroscopy



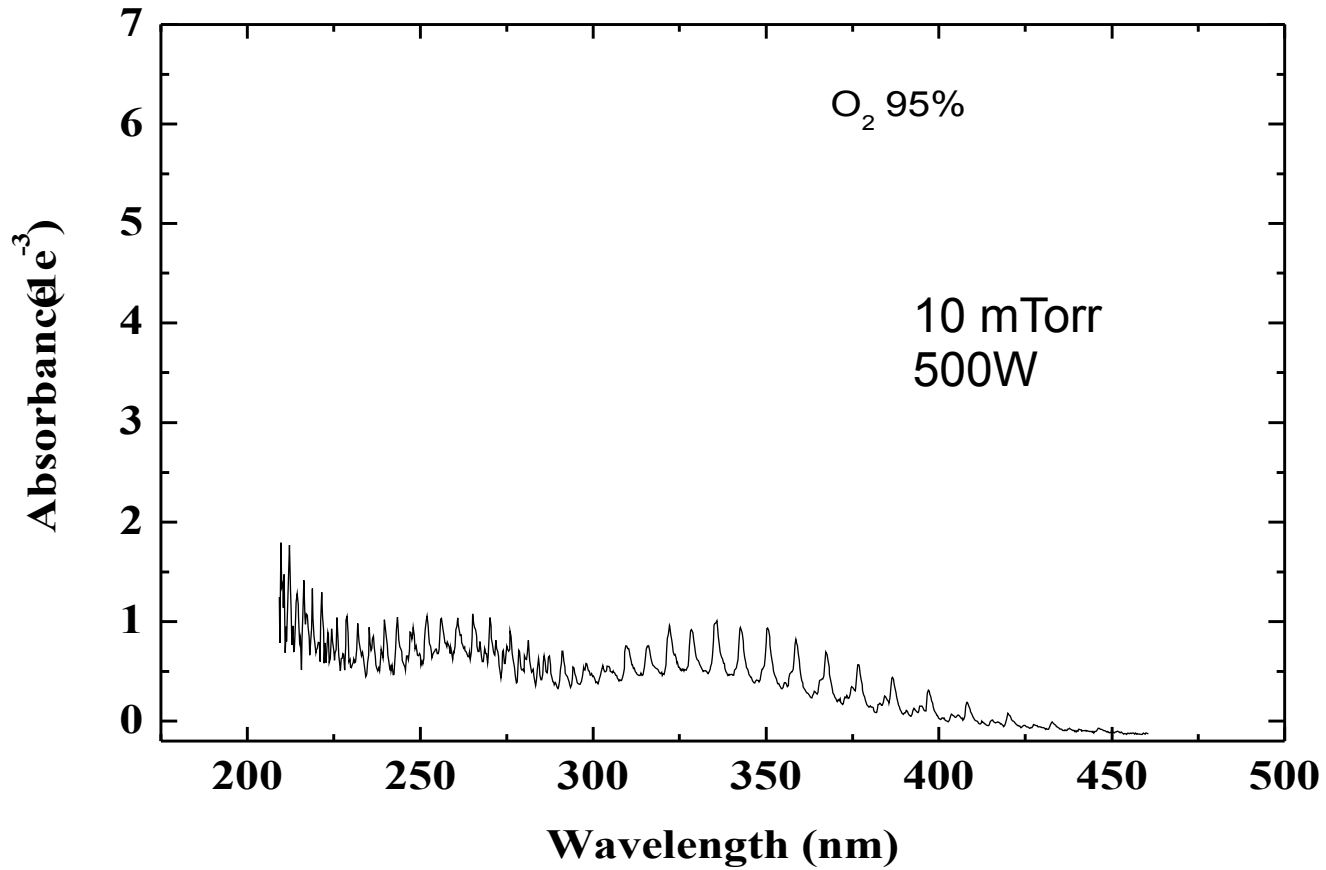
Mixtures : Absorption spectroscopy



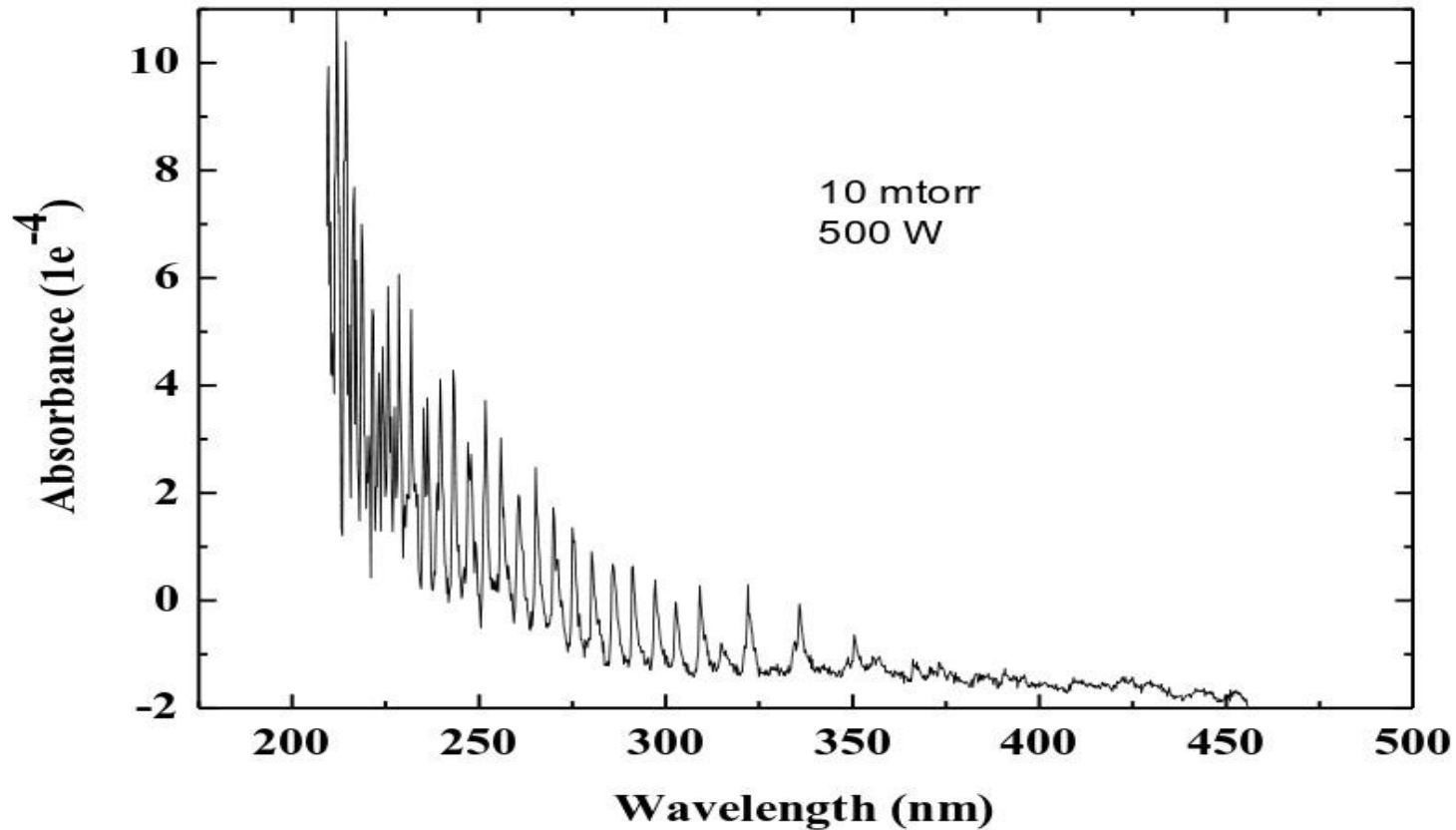
Mixtures : Absorption spectroscopy



Mixtures : Absorption spectroscopy



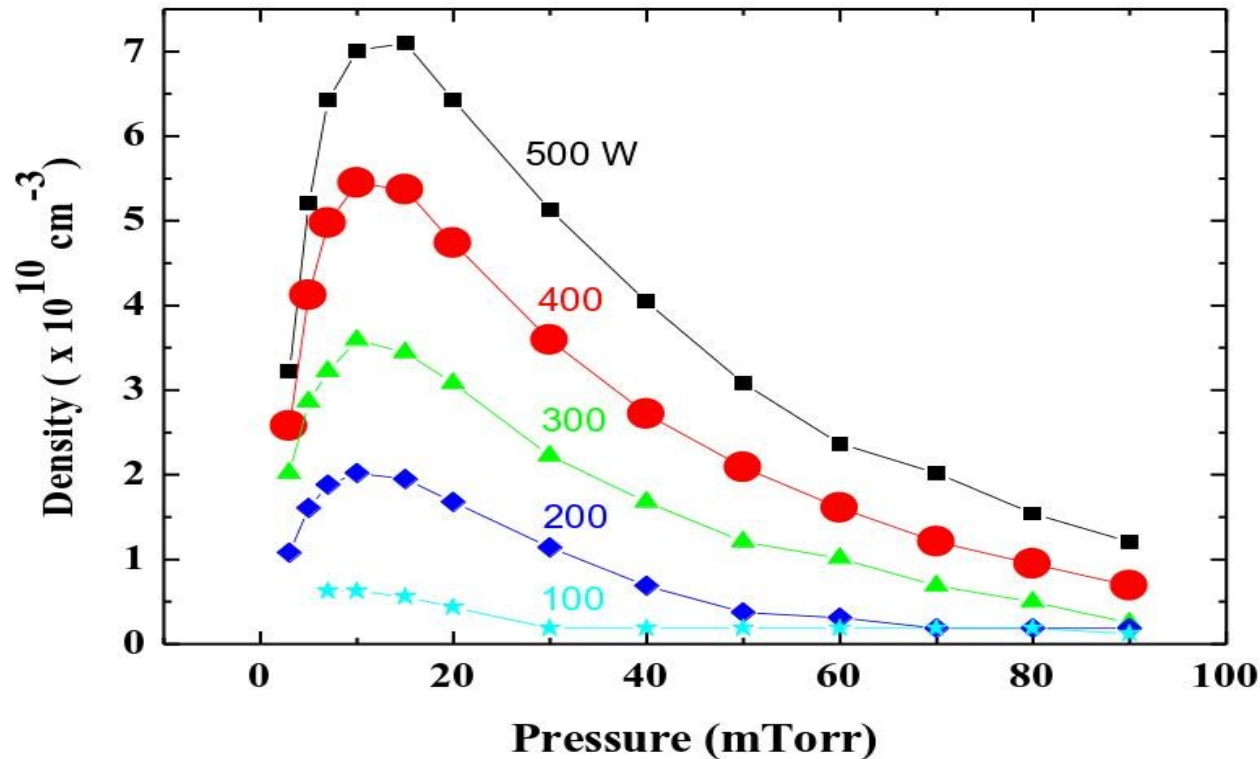
Pure O₂ : Absorption spectroscopy



Mixtures : Electron densities

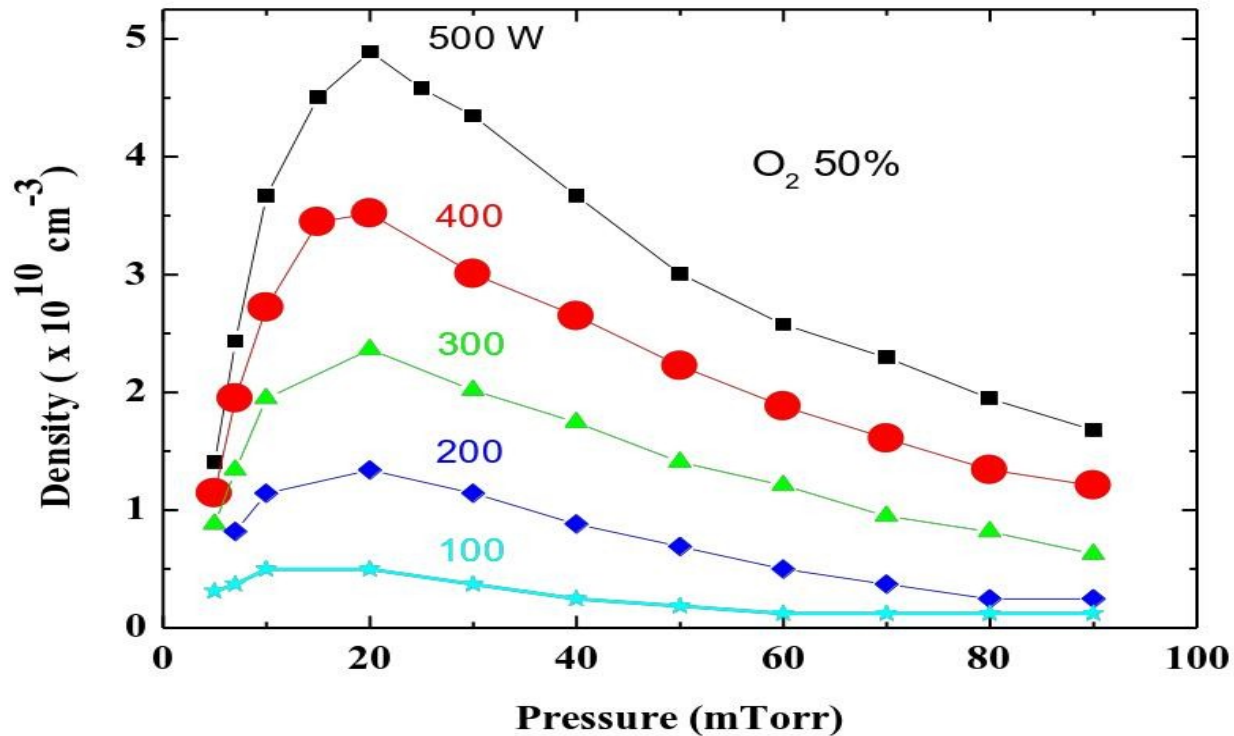


Comparison with
 Cl_2



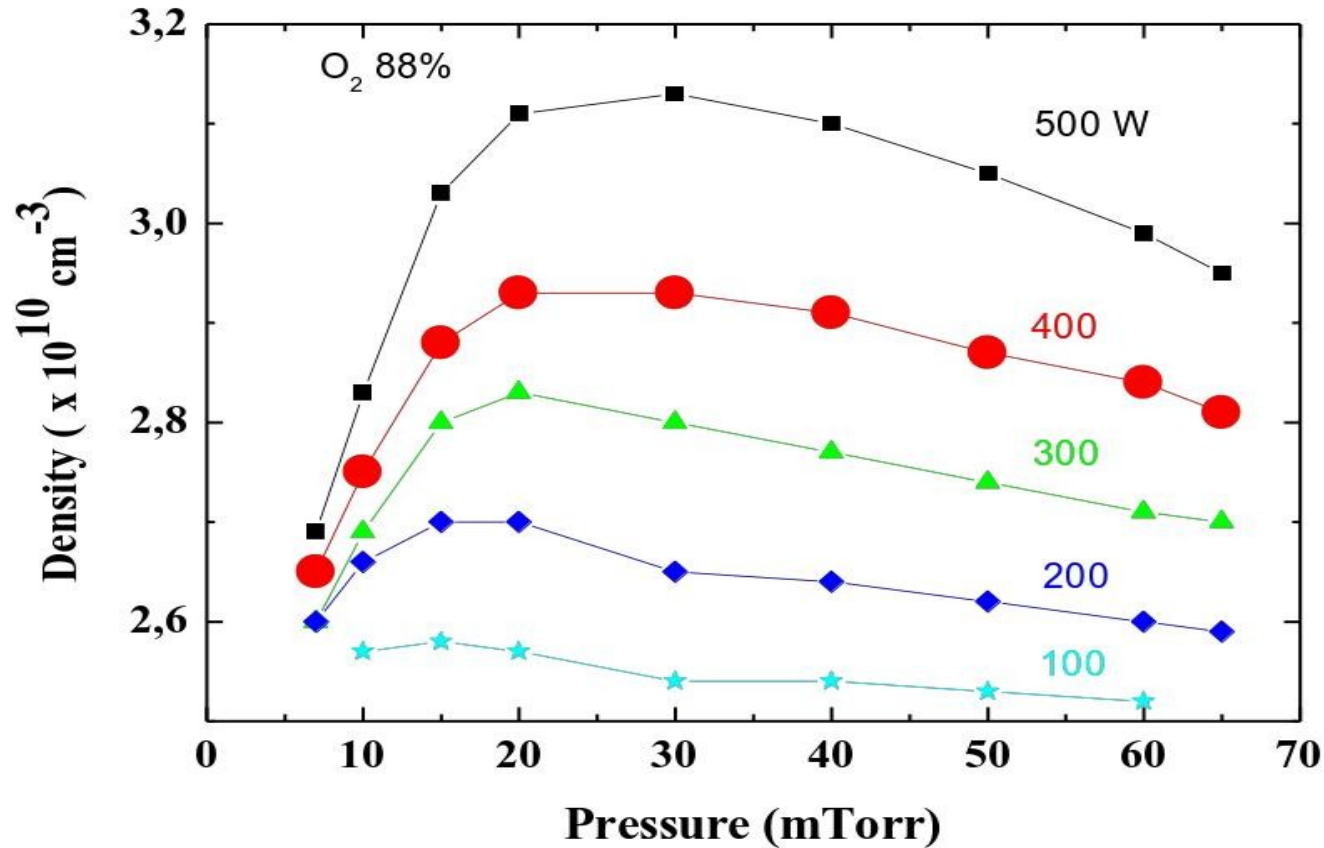
- Electron density max. for ~ 10 mTorr
- Competition between ionization and electron attachment

Mixtures : Electron densities



- Electron densities max. for ~ 20 mTorr

Mixtures : Electron densities

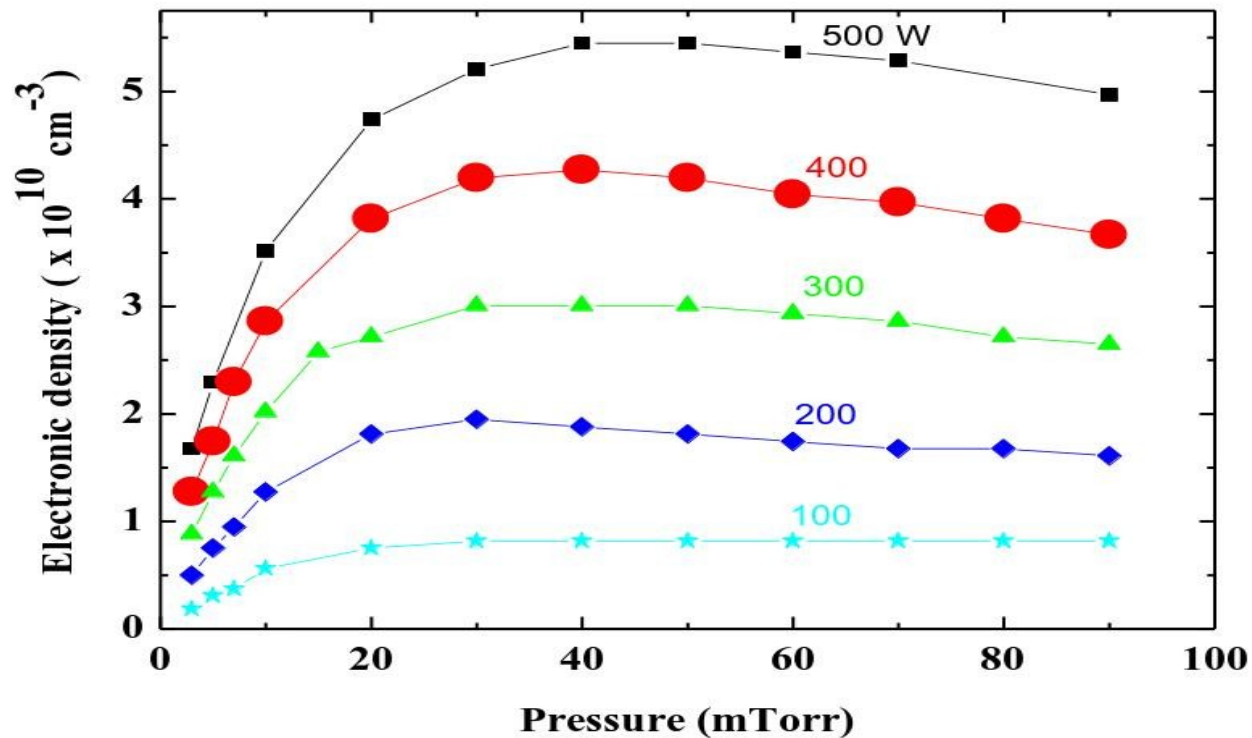


- Electron densities max. for ~ 30 mTorr

Mixtures : Electron densities

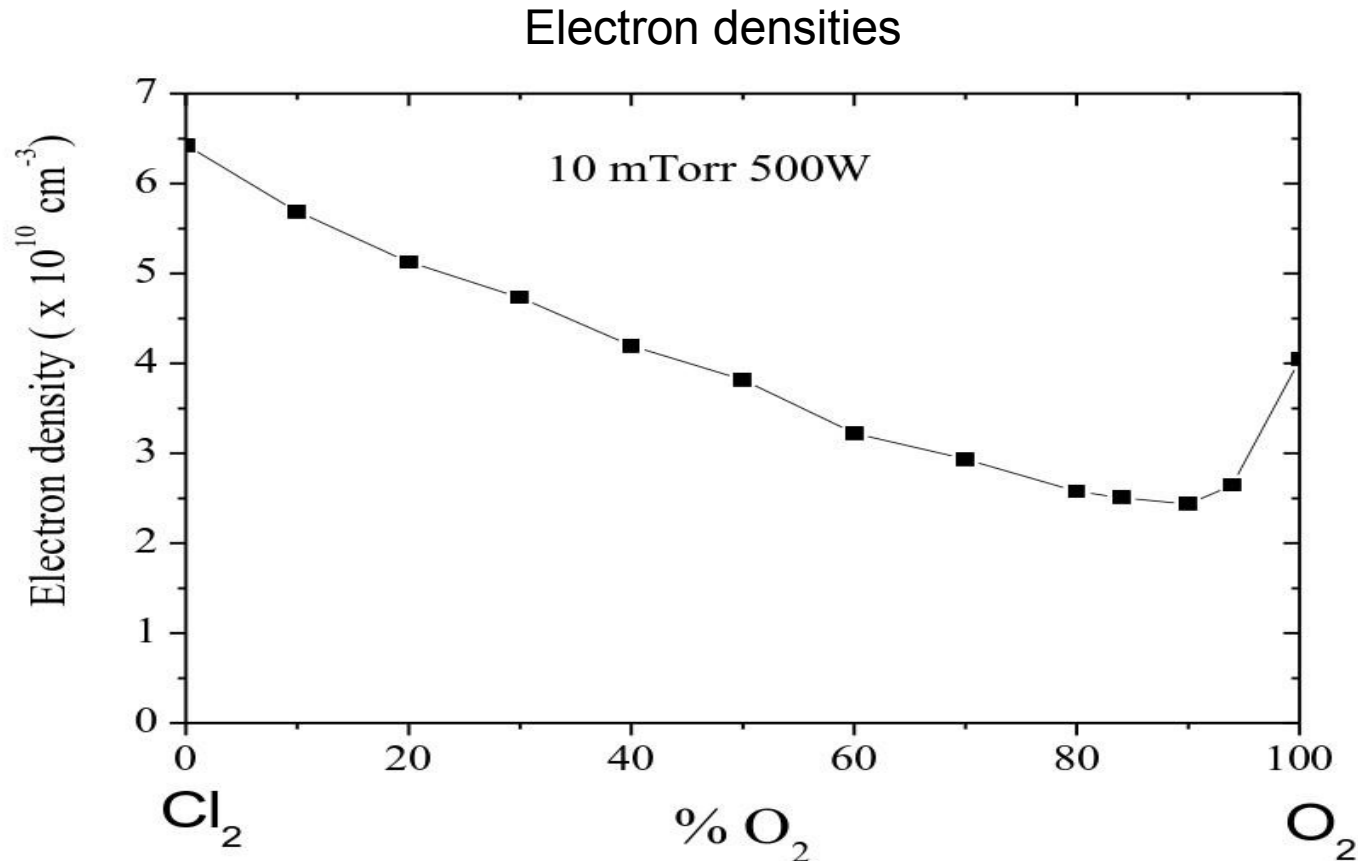


Comparison with O₂



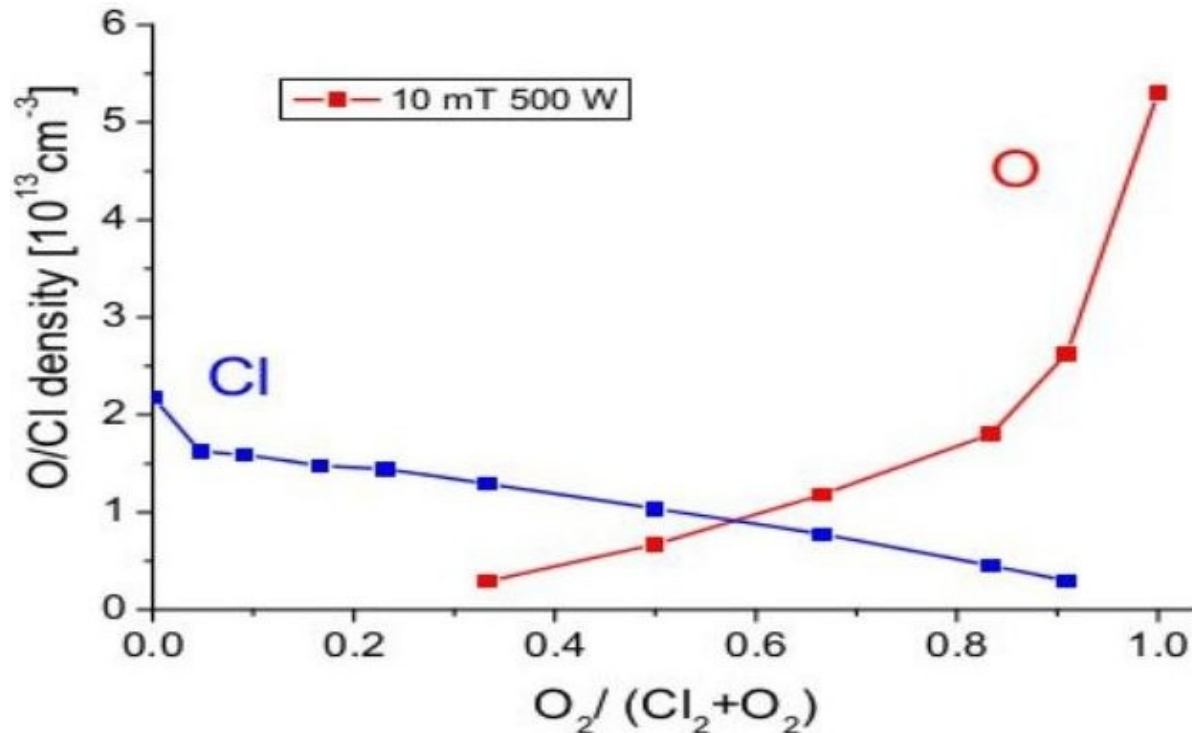
- Electron density max. for ~ 40 mTorr

Mixtures : Electron densities



- The electron density decreases with the injection of Cl₂ in pure O₂ and conversely due to oxychlorides formation

Mixtures : Atoms densities



- Drop in the densities when both Cl₂ and O₂ are injected due to oxychlorides

Conclusion



Various measurements have been and constitute the beginning of a complete set of data on ICP of Cl_2/O_2

- **Absorption spectroscopy** : qualitative measurements → quantitative measurements (densities, temperatures) will be done in future works.
- **TALIF + Hairpin**: absolute ground-state of atom densities measured at the center of the reactor → a possible work is to measure a density spatial profile.

Acknowledgement



Thank you !

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