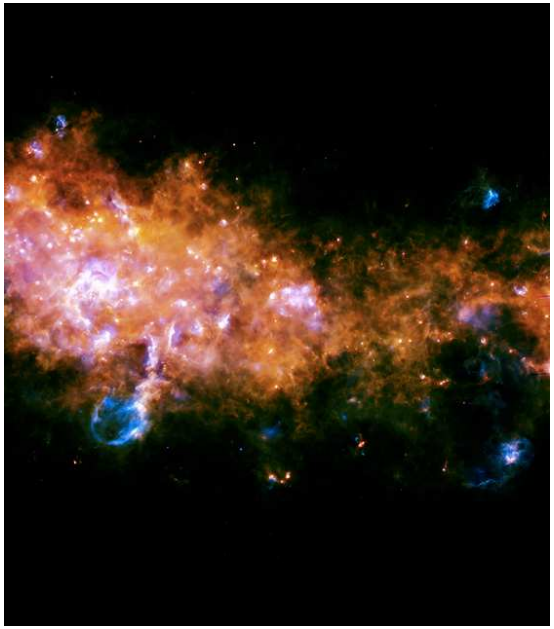
High Resolution FT-Spectroscopy of Transient Species on the FIR AILES Beamline of SOLEIL Synchrotron

Marie-Aline Martin-Drumel,
Olivier Pirali, Didier Balcon, Michel Vervloet,
Pascale Roy & Philippe Brechignac

Institut des Sciences Moléculaires d'Orsay (ISMO)
SOLEIL synchrotron - AILES beamline

66th International Symposium on Molecular Spectroscopy

Astrophysical Background



Stellar pregnancy and birth in the Milky Way

Herschel (ESA)

FIR:

- Favorable region for studying the emission from cold object of the interstellar medium
- Possibility of understanding star forming and galaxies evolution

Spectral range studied by several missions:
HERSCHEL, ALMA, SOFIA *($\sim$ 0.3-5 THz)*

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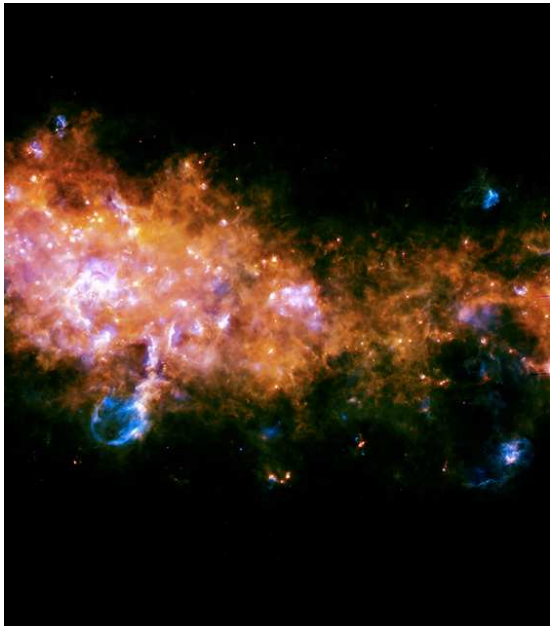

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Transient species (excited molecules, radicals, ions):

- Present in the interstellar medium (non-equilibrium physical conditions)
- Intermediates in chemical reactions

Need to provide FIR data on transient species to the astrophysical community

FIR: Limitations and Applications at AILES

FIR Experimental difficulties

- low probability of spontaneous emission
- low brilliance of classical sources

Einstein coefficient (spontaneous emission):

$$A_{21} = \frac{1}{g_2} \cdot \frac{16\pi^3}{3\epsilon_0 hc^3} \cdot |M_{12}|^2 \cdot \nu^3$$

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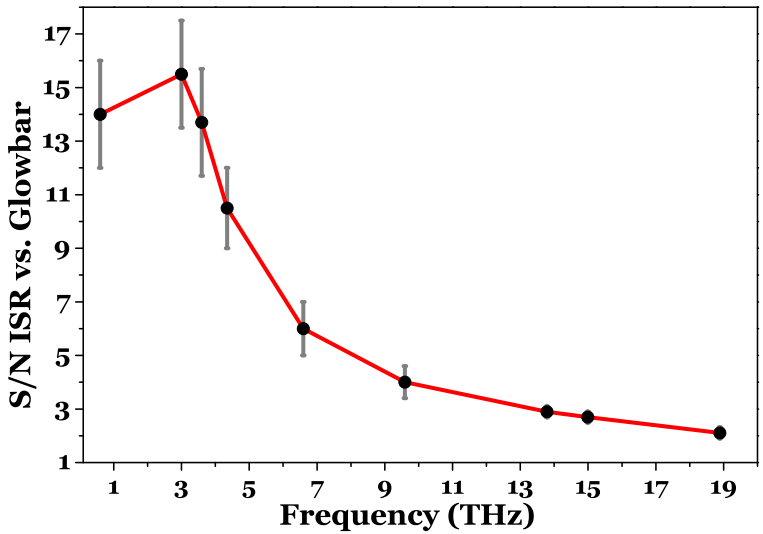

FIR:
7-700 cm^{-1}
($\sim$ 200 GHz - 20 THz)

Advantage SR:
up to 1500 cm^{-1} ($\sim$ 45 THz)

High Resolution FIR Measurements at AILES

Fourier Transform Interferometer

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- OPD_{max}: 8.82 m
- Highest resolution: 0.00102 cm^{-1} ($\sim$ 30 MHz)

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Polypropylene windows (50 μm), Mylar beamsplitter (6 μm),
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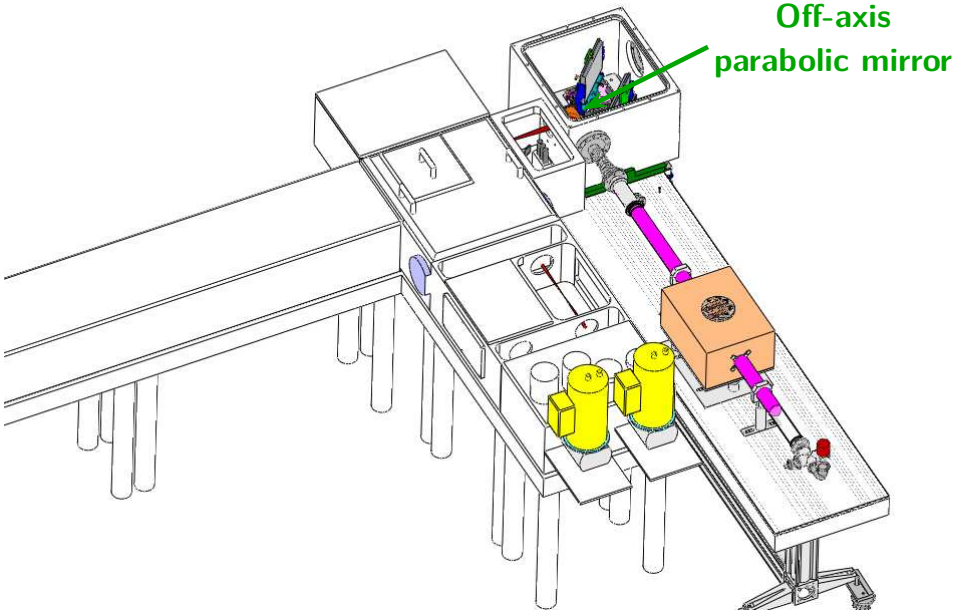
Discharge experiments

- Radio-frequency (RF): emission
- Electrical (DC): absorption

Emission Set-up

- Radio-frequency (RF) discharge (power: 1000 W max.)
- Light source: emission of the plasma (focused at the entrance iris of the FT)



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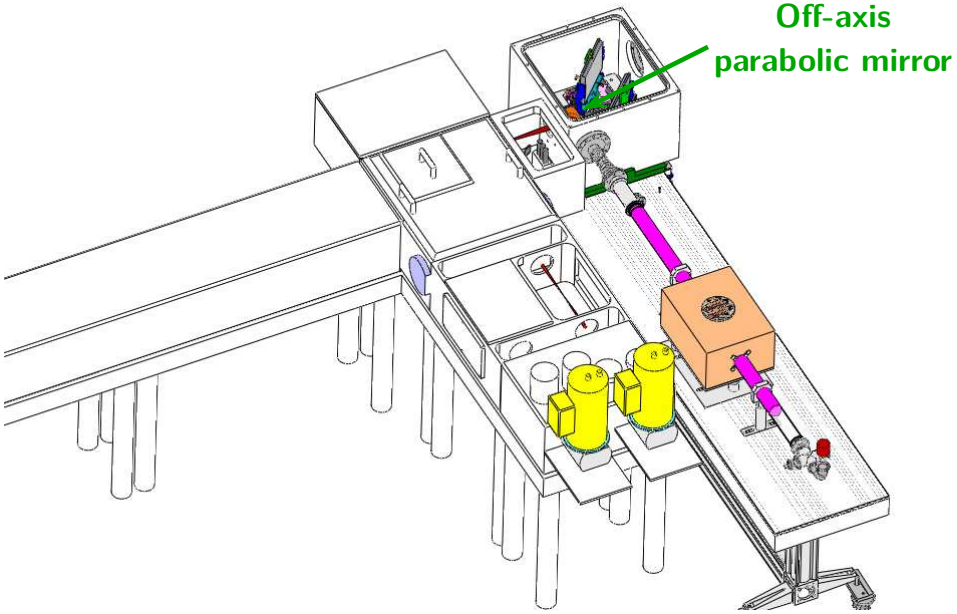
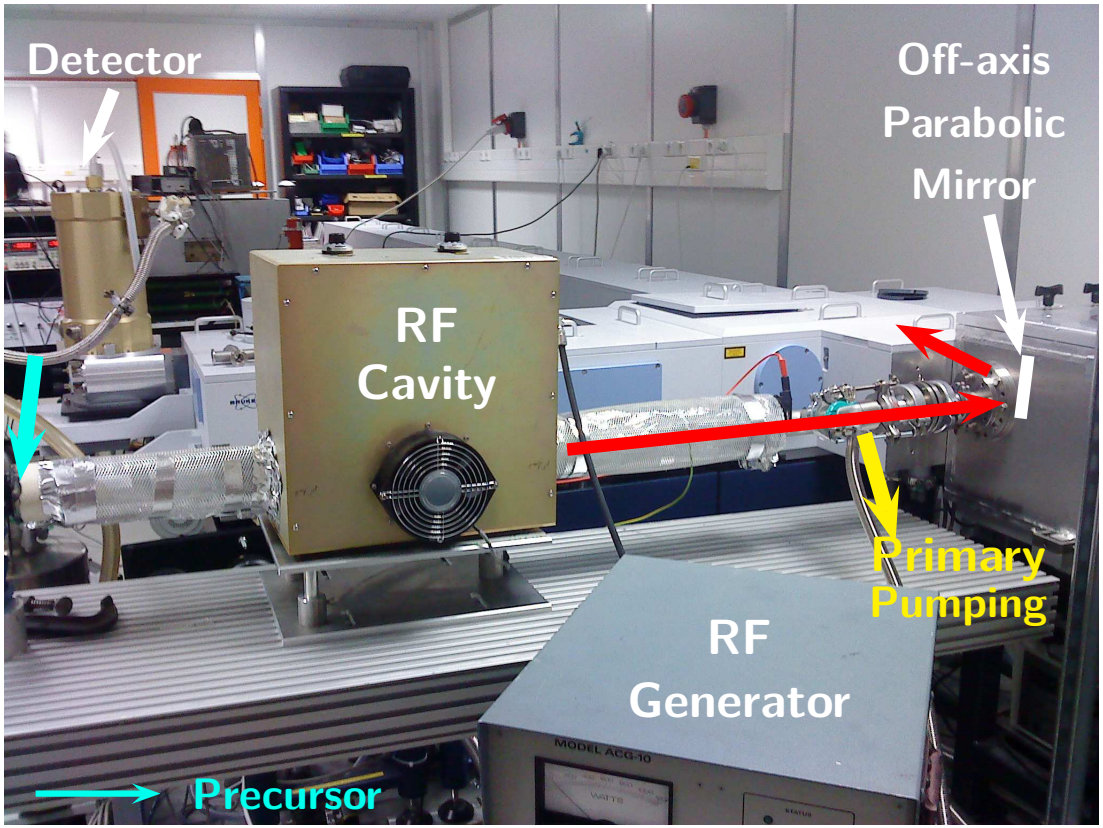
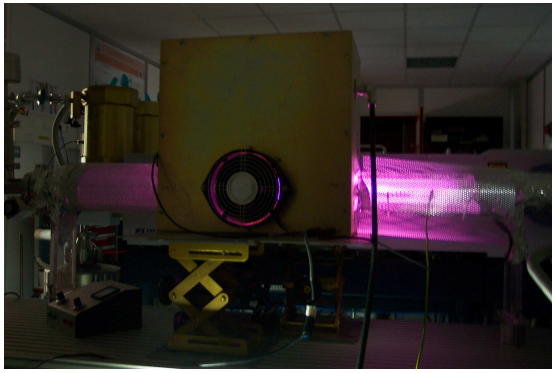
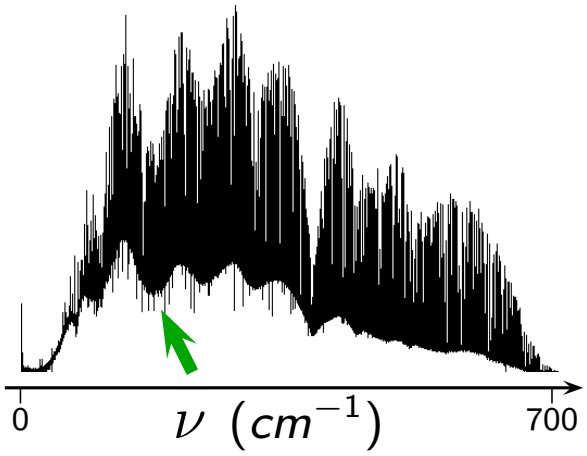


- slow gas flow
- Plasma length: ~ 1 m
- Pressure in the cell: ~ 10 mbar
- Resolution: $0.004\ \mathrm{cm}^{-1}$ (~ 120 MHz)
- Rotational temperature: ~ 2500 K

Pictures and Emission Spectrum







Self-absorptions

Blackbody + Molecular Emission

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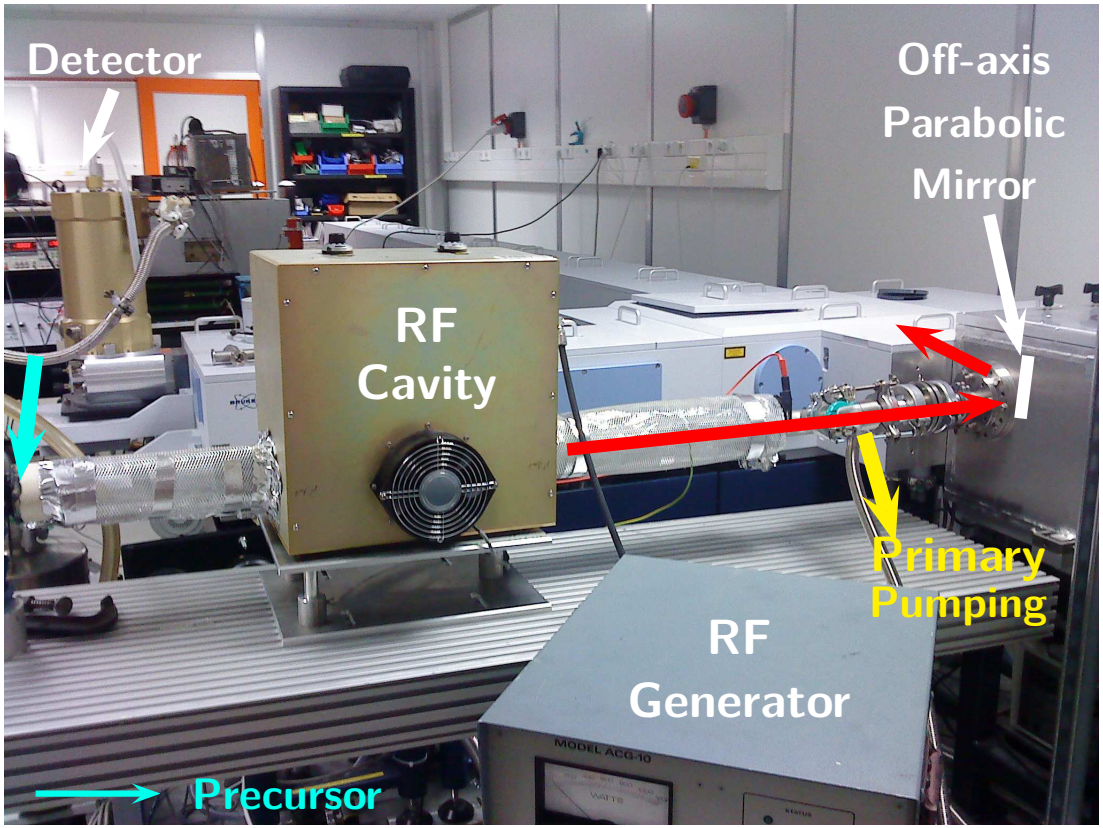

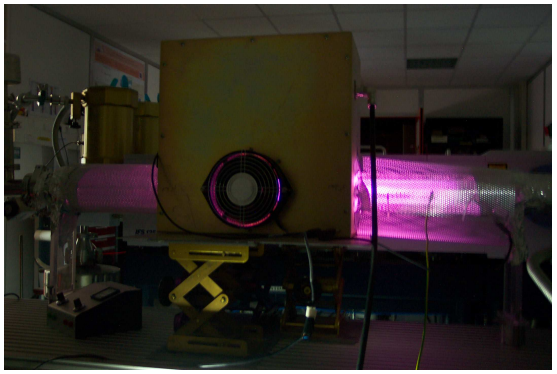

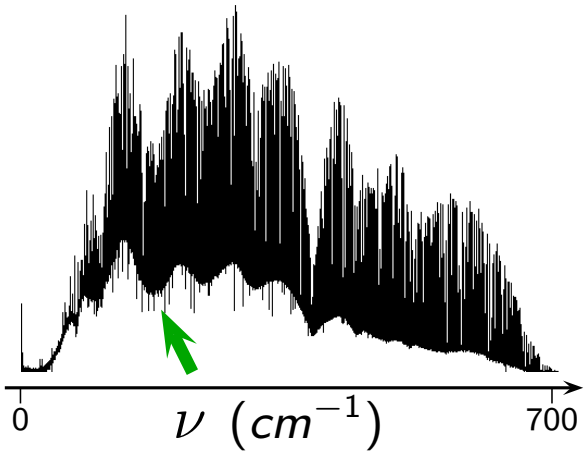

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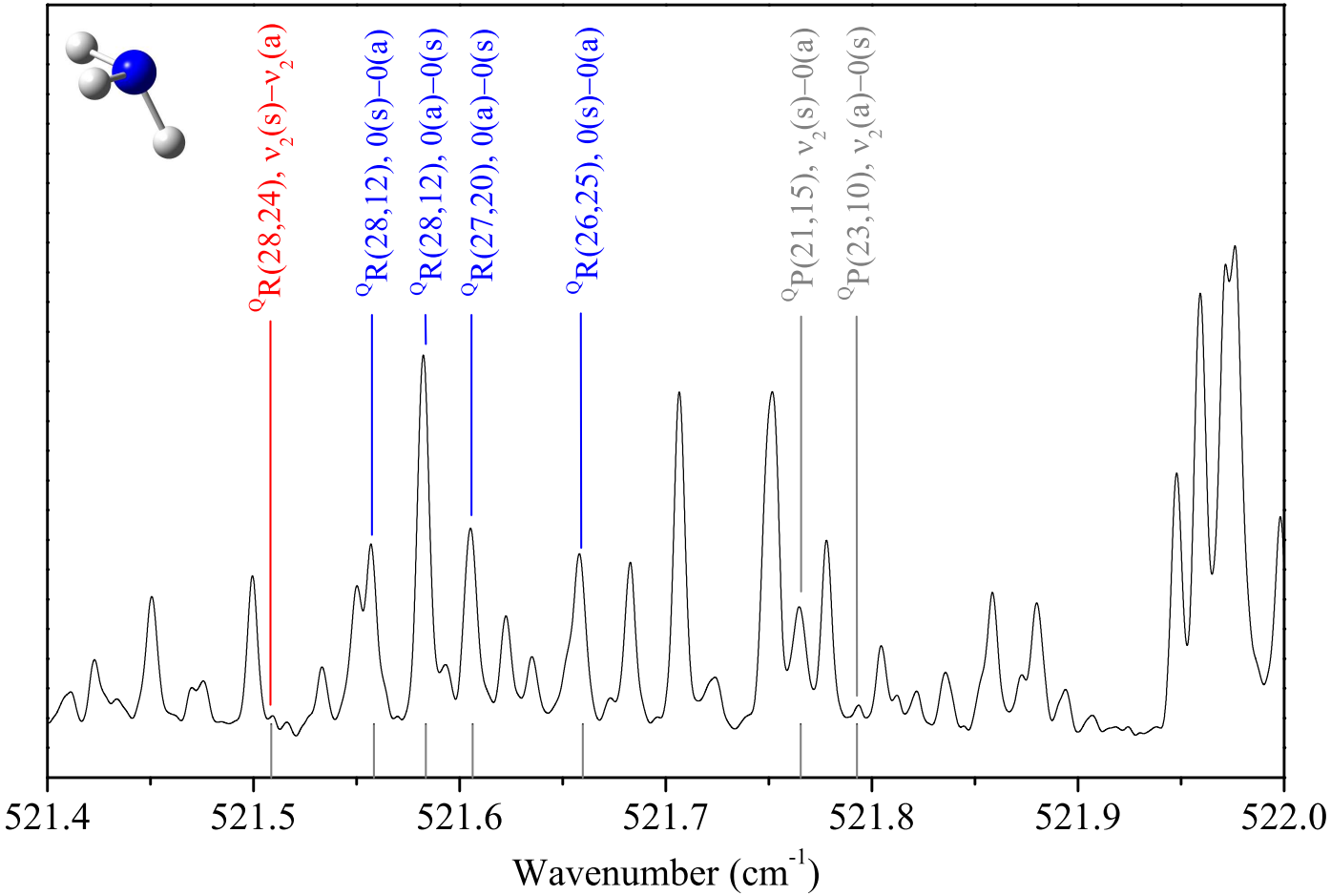
Molecules: NH_3, H_2O, HCN + isotopes (D_2O, HDO)

FIR Emission Epectrum of NH_3



⋆ NH_3: 1510 new pure rotational transitions: (0000) and $\nu_2 = 1$

Previous publication: Pin Chen et al., *J. Mol. Spect.* **236**

Advancement on Molecular Species

- **NH_3** (*symmetric rotor*)
  - ⋆ Pure rotational transitions within the 2 lowest vibrational levels

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  The THz Cosmos, June 23, L. Coudert (RF09, 4h19)

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- **HCN** (*linear molecule*)
  analysis in progress (M. Vervloet)
  - ⋆ Pure rotational transitions within the 8 lowest vibrational states

Studied Radicals

Radicals: NH_2, NH, OH (OD)

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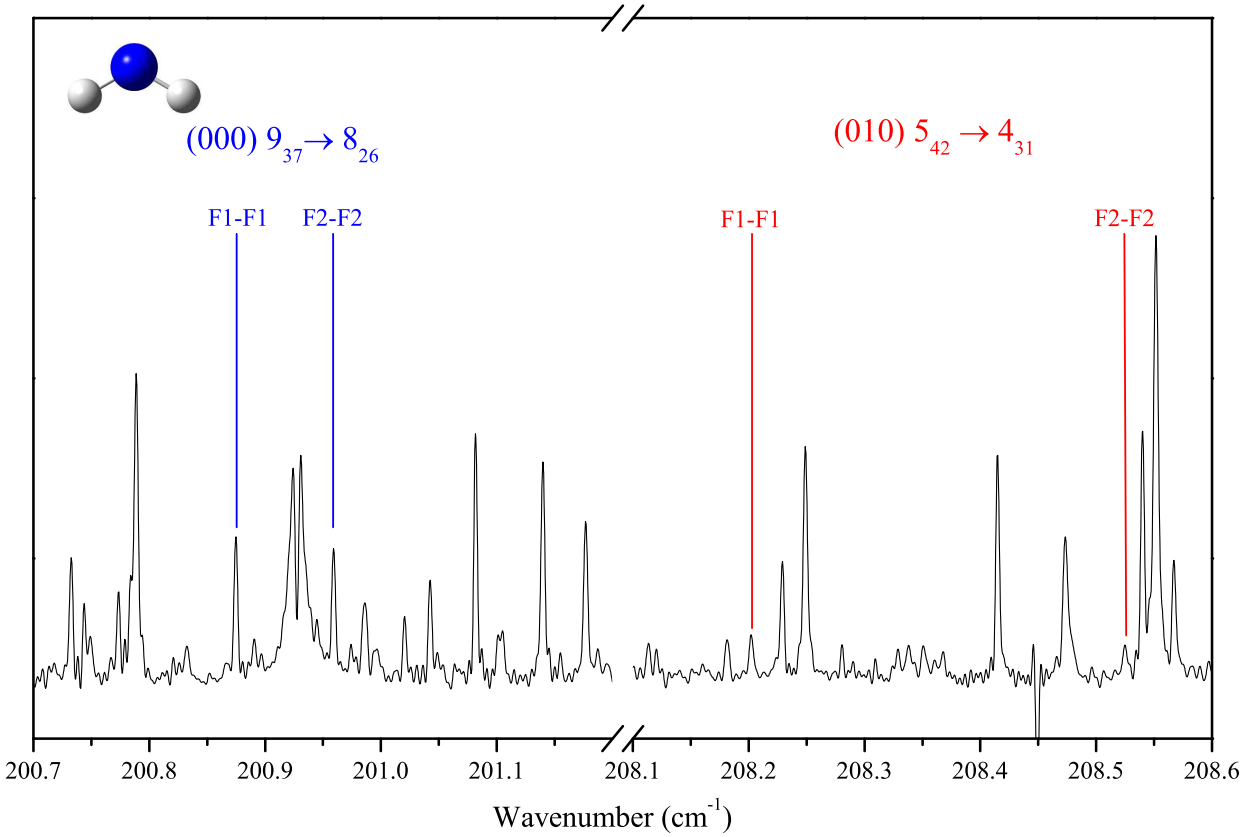
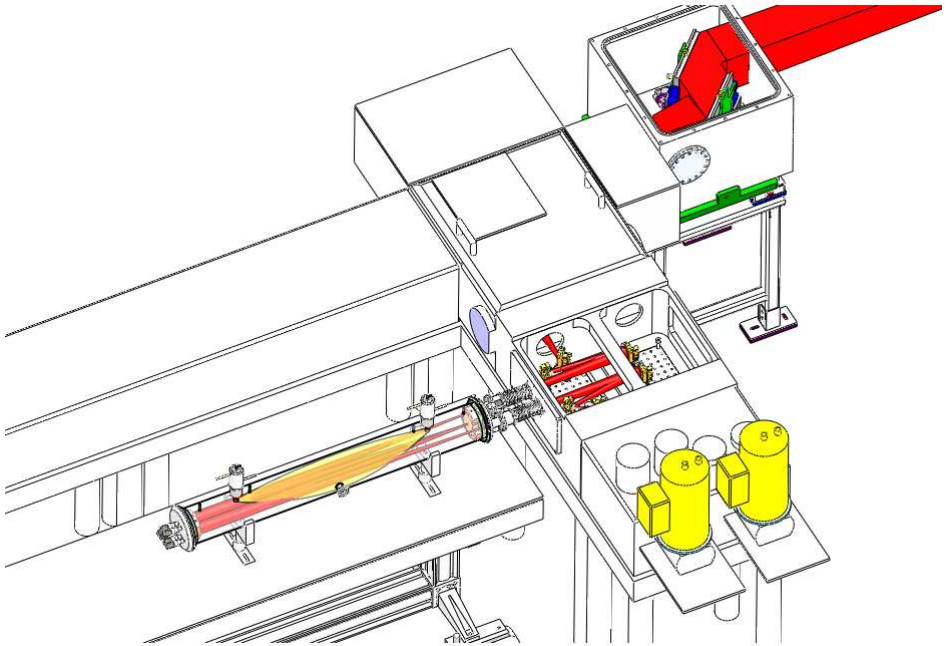


⋆ Pure rotational transitions: (000) and $\nu_2 = 1$

Previous FIR publication: Morino & Kawaguchi, *J. Mol. Spect.* **182** (1997)

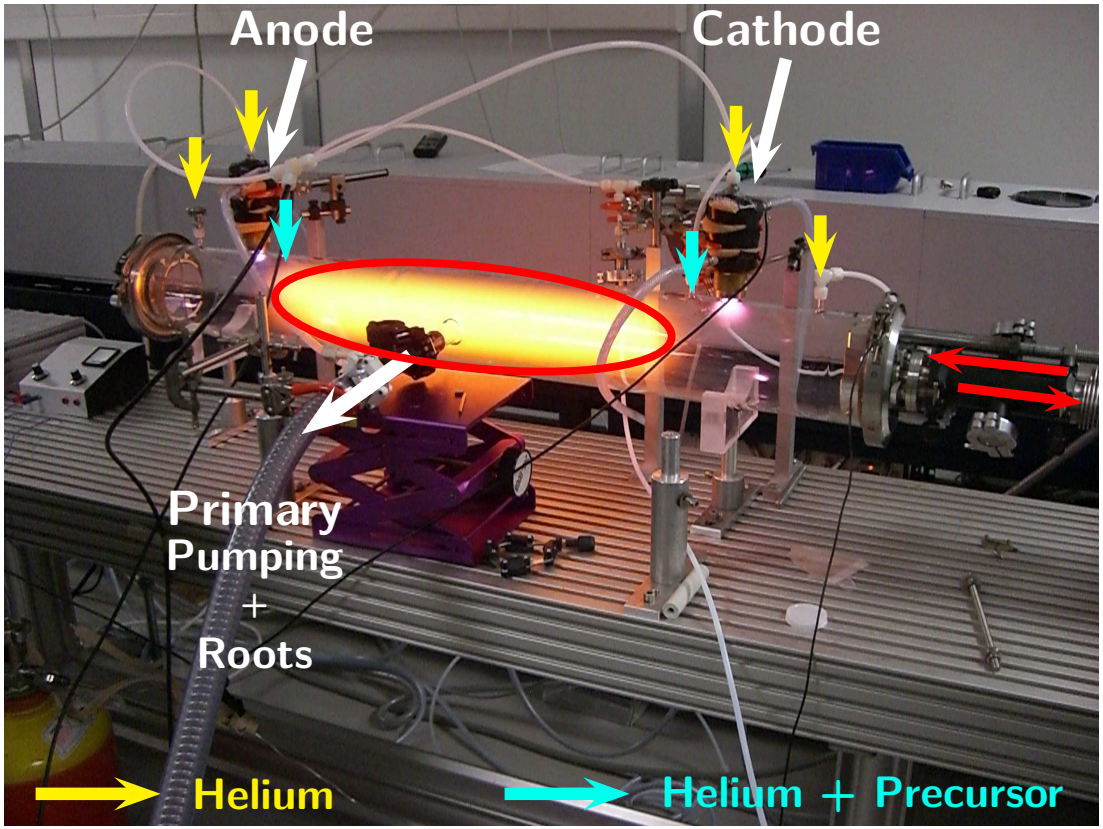
Absorption Set-up

- Electrical discharge (DC) (power: 1 kV / 2 A max.)
- Light source: Synchrotron radiation

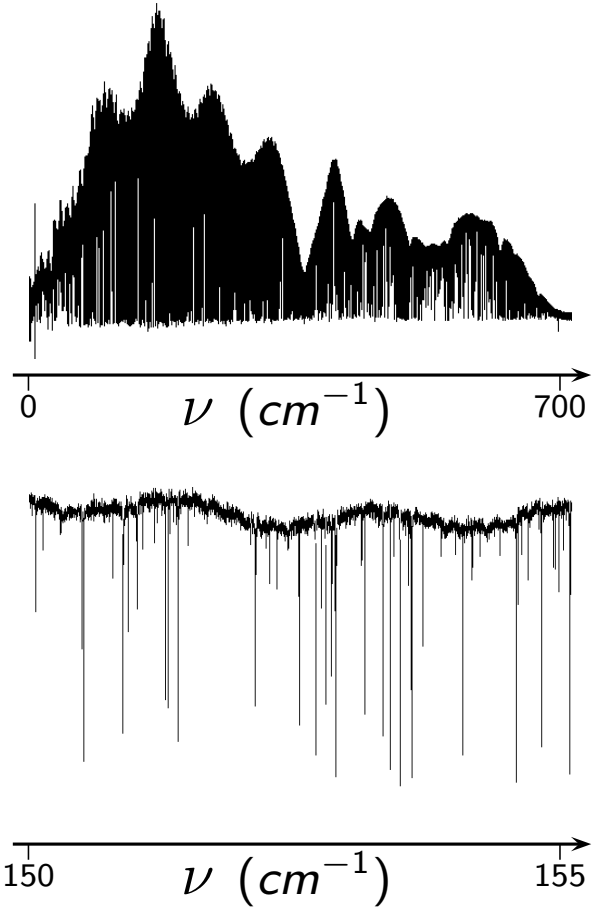


- fast gas flow
- Plasma length:
  $\sim$ 70 cm
- Absorption path length:
  28 m max.
- Pressure in the cell:
  $\sim$ 0.1 mbar (+ He)
- Resolution: 0.001 cm^{-1}
  ($\sim$ 30 MHz)

Picture and Absorption Spectra



Positive Column



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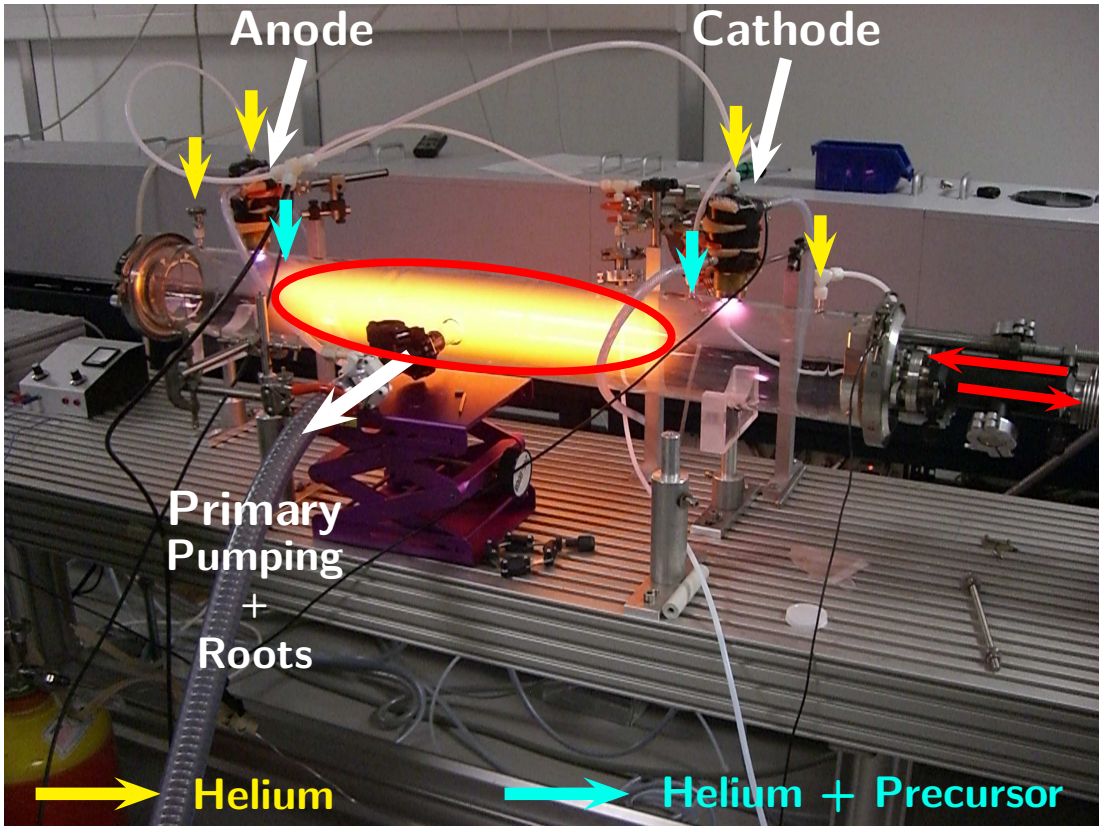

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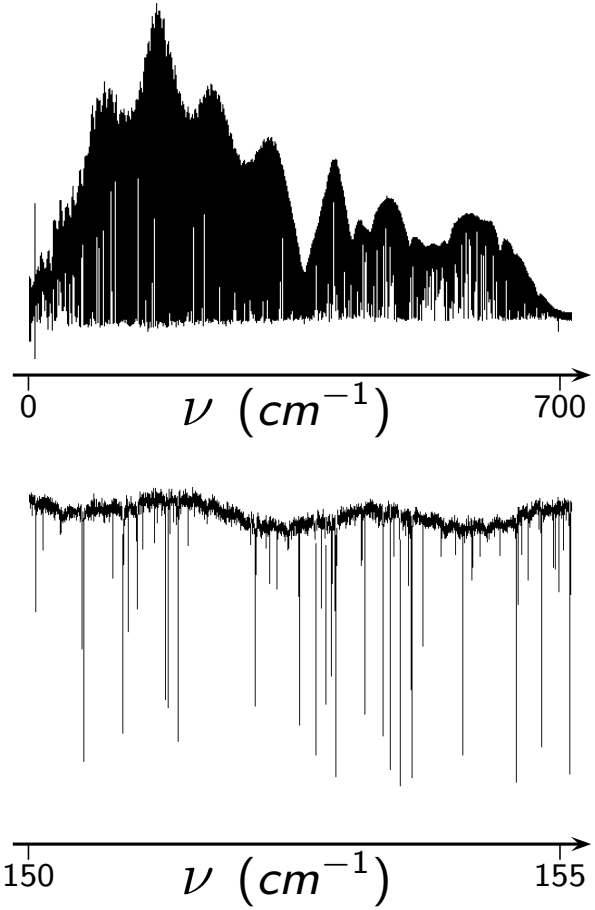
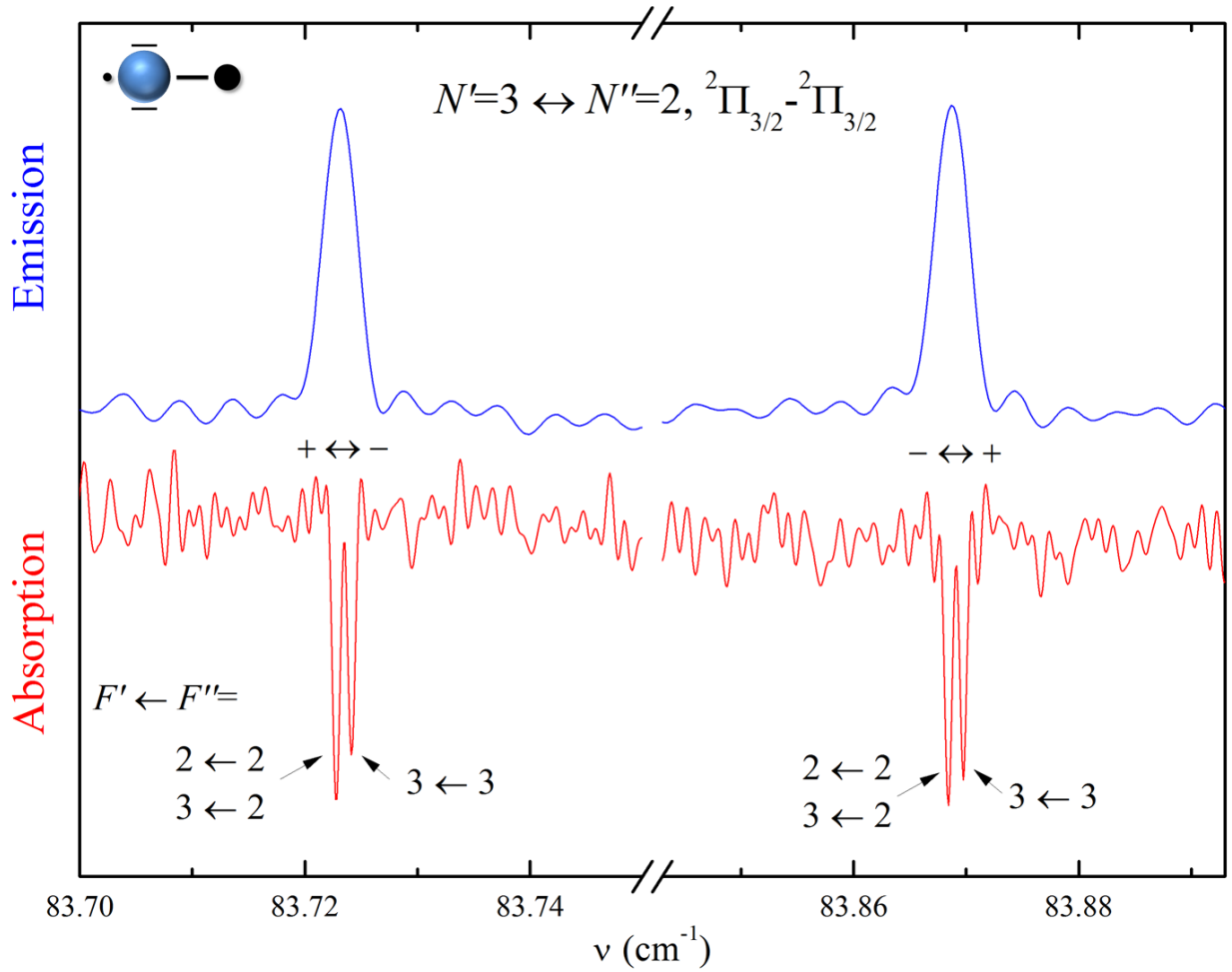


Radicals: NH_2, NH, OH, C_3, CH, CN

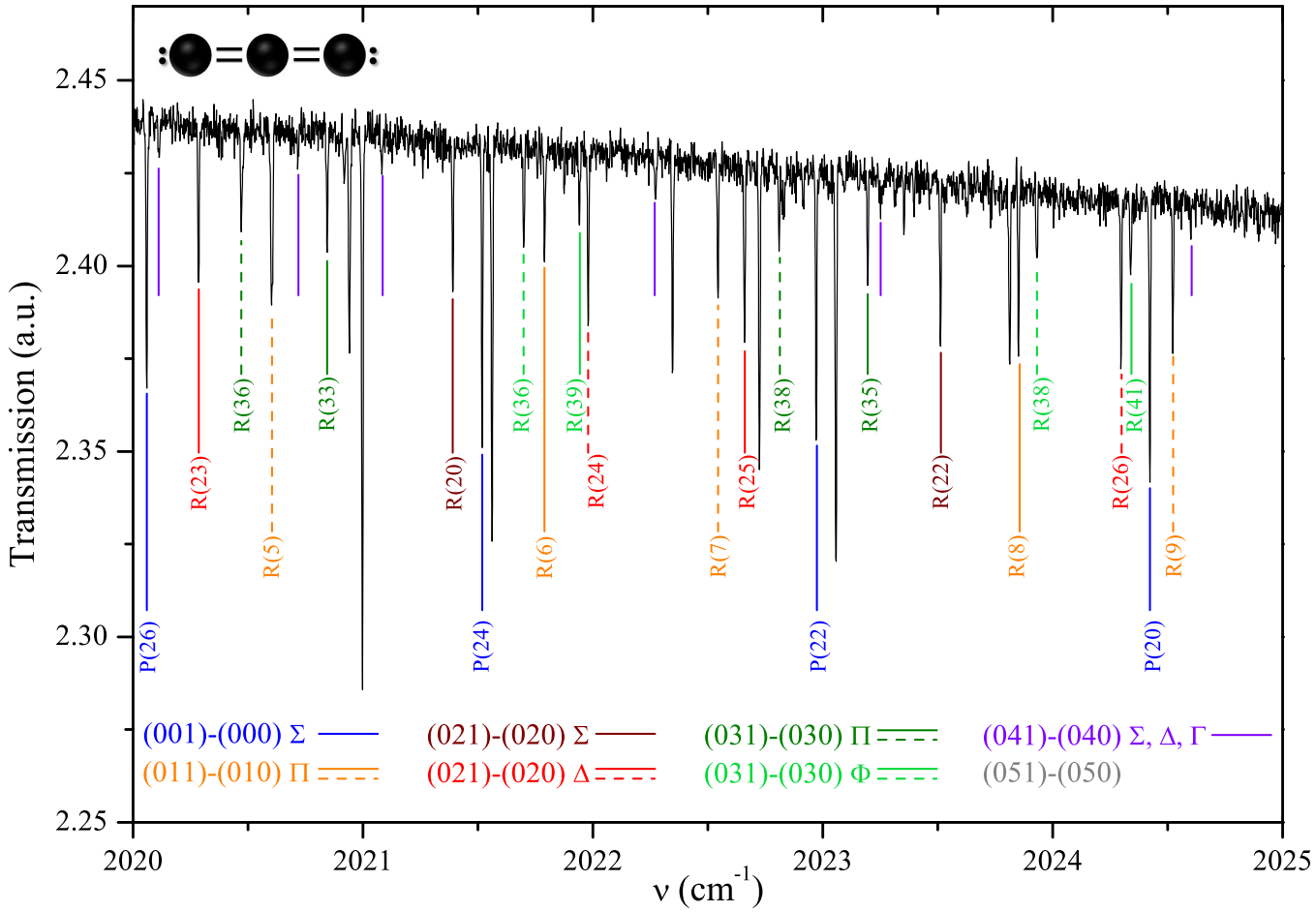
Pure rotational spectra of OH



⋆ OH: Resolution of the hyperfine structure for several transitions

Previous FIR publication: Hardwick & Whipple, *J. Mol. Spect.* **147** (1991)

ν_3 band of C_3 (Mid-IR)



⋆ C_3: Observation of the ro-vibrational ν_3 band + several hot bands

Previous MIR publication: Kawaguchi et al., *J. Chem. Phys.* **91** (1989)

Advancement

- **C_3 ($^1\Sigma$) (Mid-IR)**
  Collaboration D. Tokaryk (University of New Brunswick, Canada)
  - ⋆ ν_3 band (+ hot bands) $\sim$ 2000 cm^{-1} *(in progress)*

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The THz Cosmos, June 23, M.A. Martin-Drumel (RF13, 5h27)

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- **CH, CN** 1st FIR FT-spectra of C-bearing radicals **(absorption)**

Conclusion: Two Complementary Techniques

	Emission	Absorption
Discharge	RF	DC
Power	1000 W	1-3 kV, 0.6-2 A
Pressure	∼10 mbar	∼0.1 mbar (+ 2 mbar He)
Light Source	plasma	SR
Resolution	0.004 cm^{-1}	0.001 cm^{-1}
Accuracy (l.p.)	$< 5{\cdot}10^{-4}$ cm^{-1} (12 MHz)	$< 1{\cdot}10^{-4}$ cm^{-1} (3 MHz)
Abs. length	0.7 m	24 m
Rot. temp.	2500 K	300 K

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- **Absorption:**
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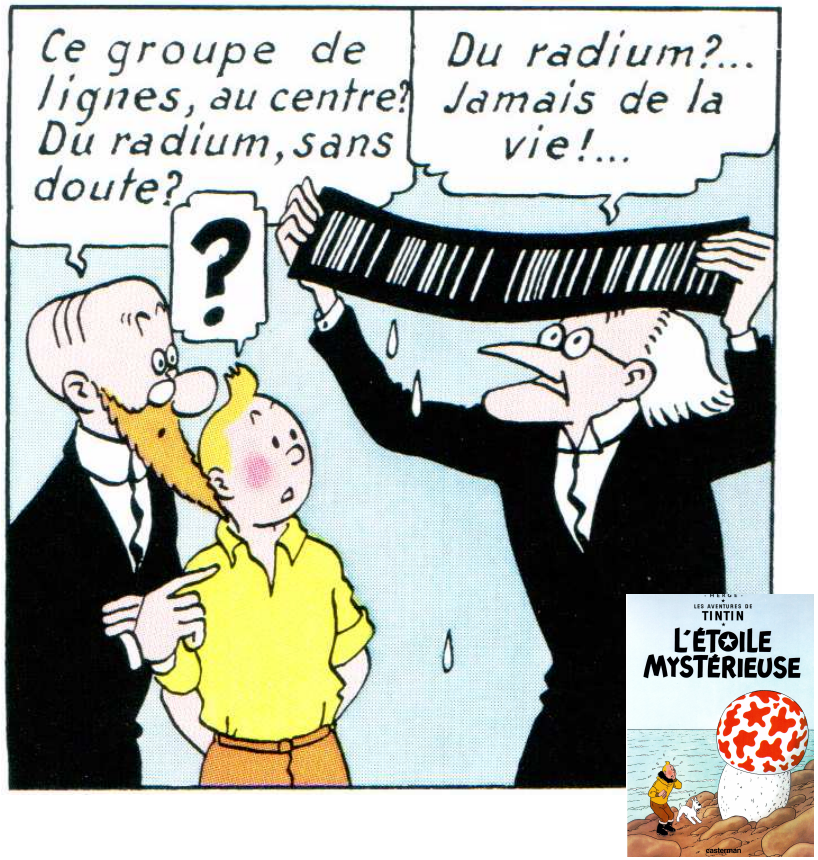
  - High sensitivity: observation of unstable species (C-bearing radicals)



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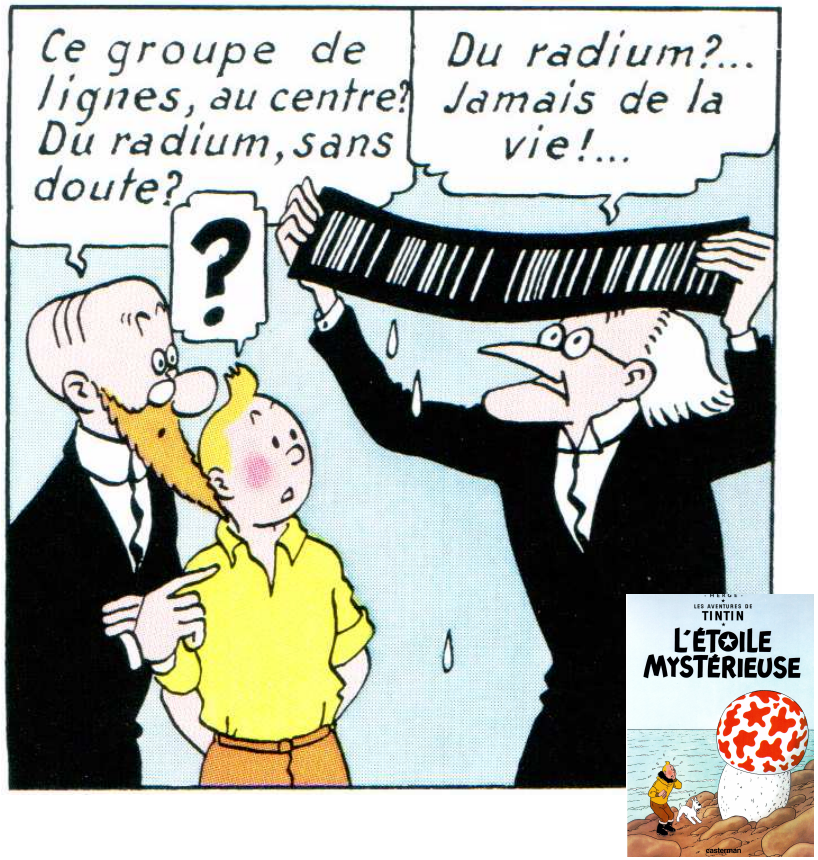

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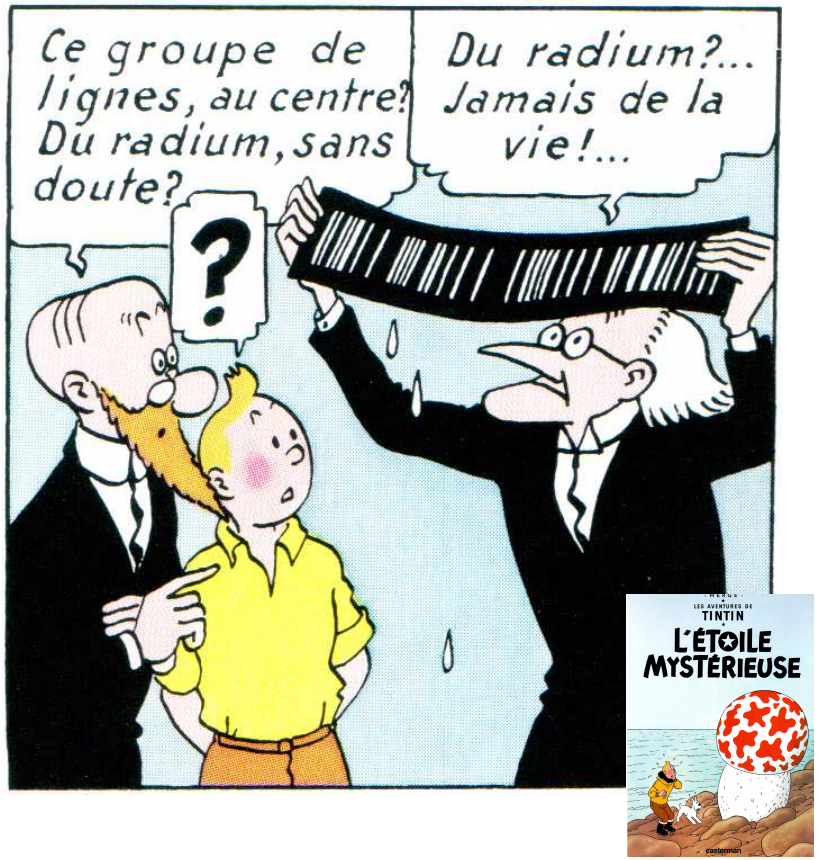

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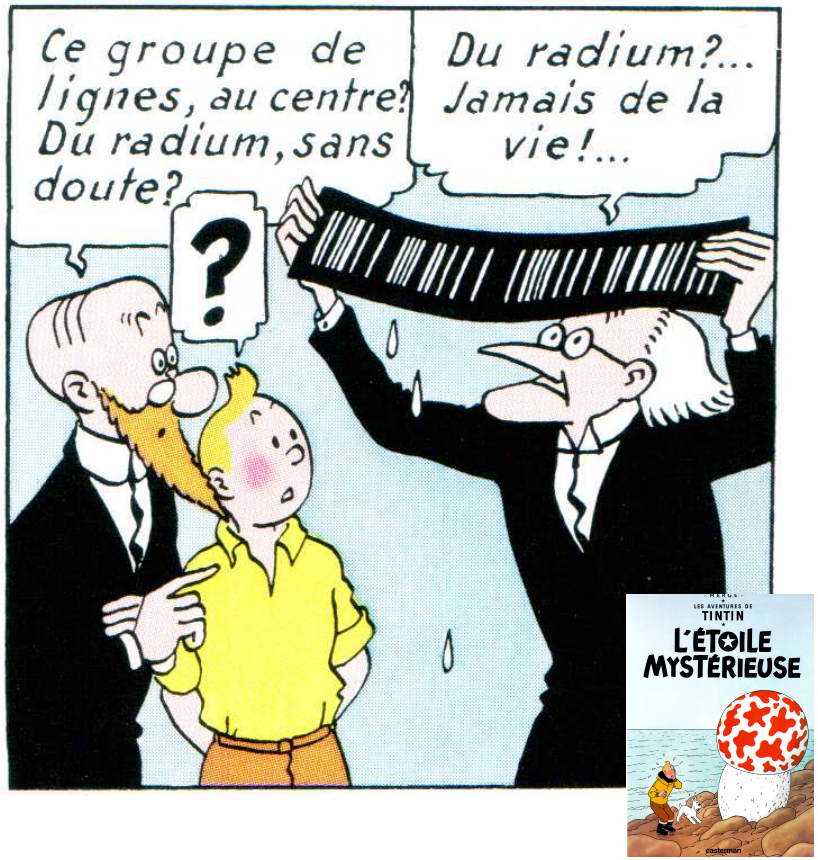

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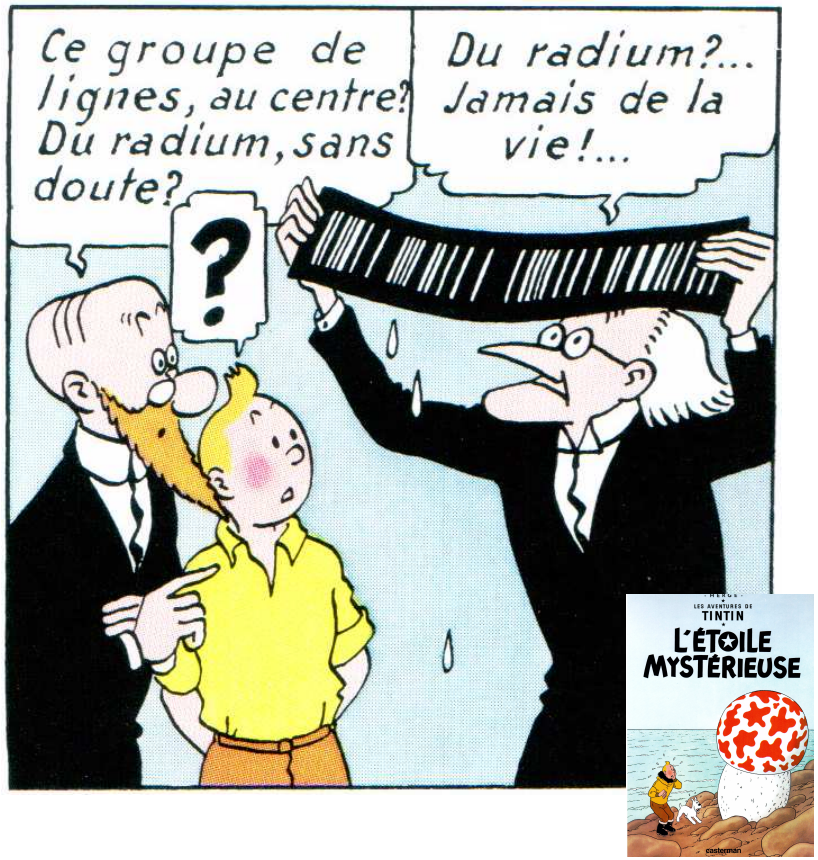

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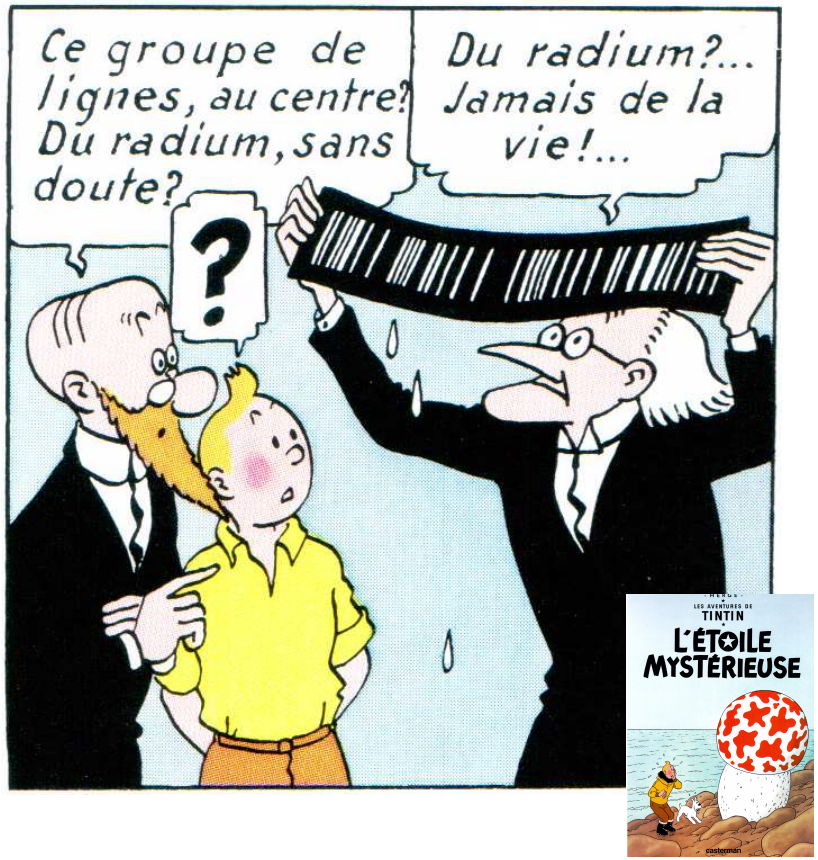

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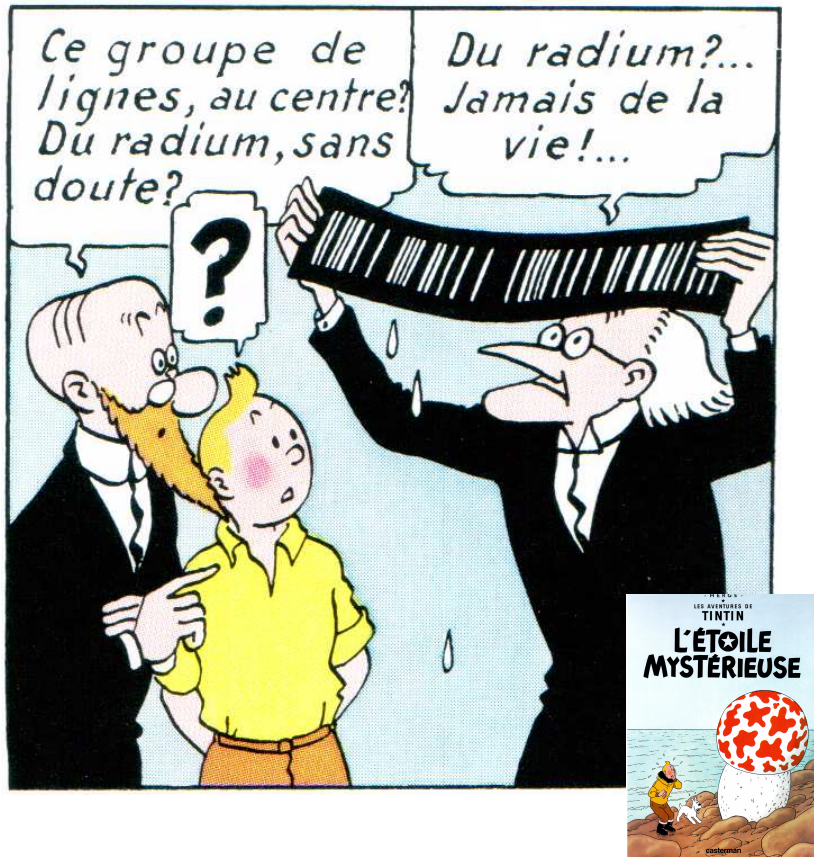


Radicals:

- ^{15}N radicals:
  Possible detection?
- C-bearing radicals:
  new discharge? new power supply?

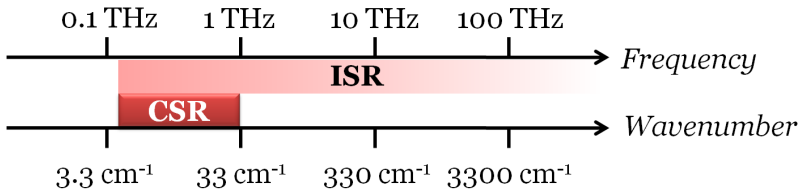
Ions:

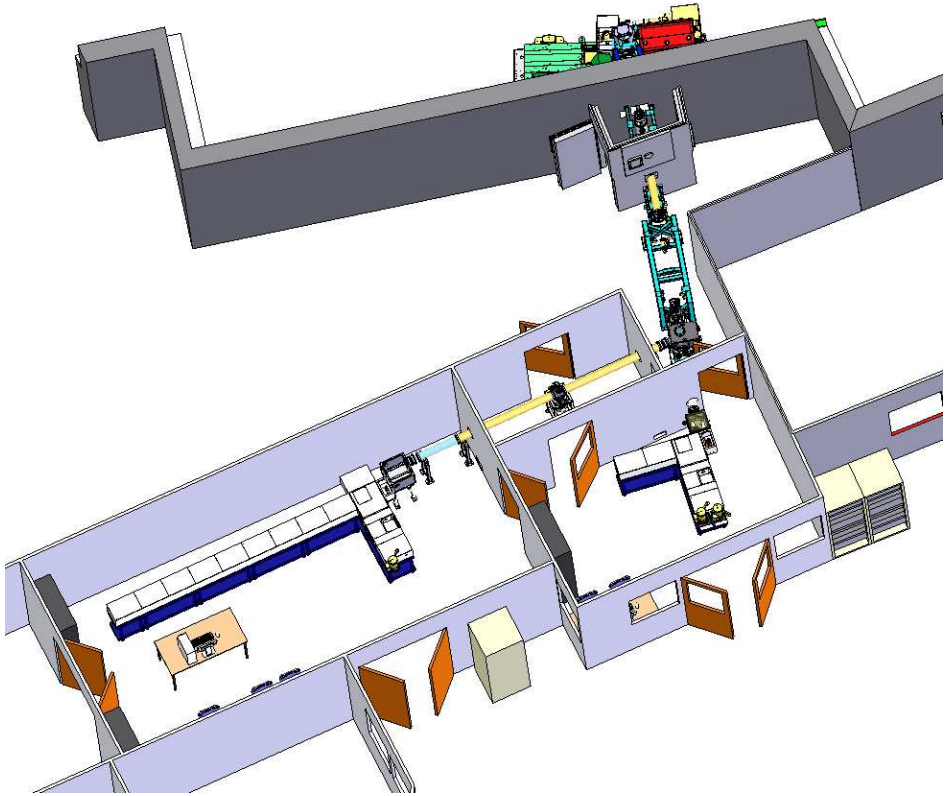
- Hollow Cathode (PCMI)

High temperature molecules:

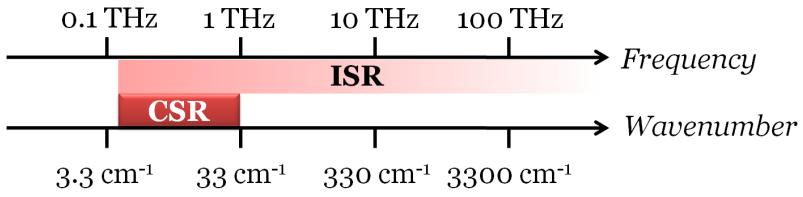
- *Warm cell* (*project*)

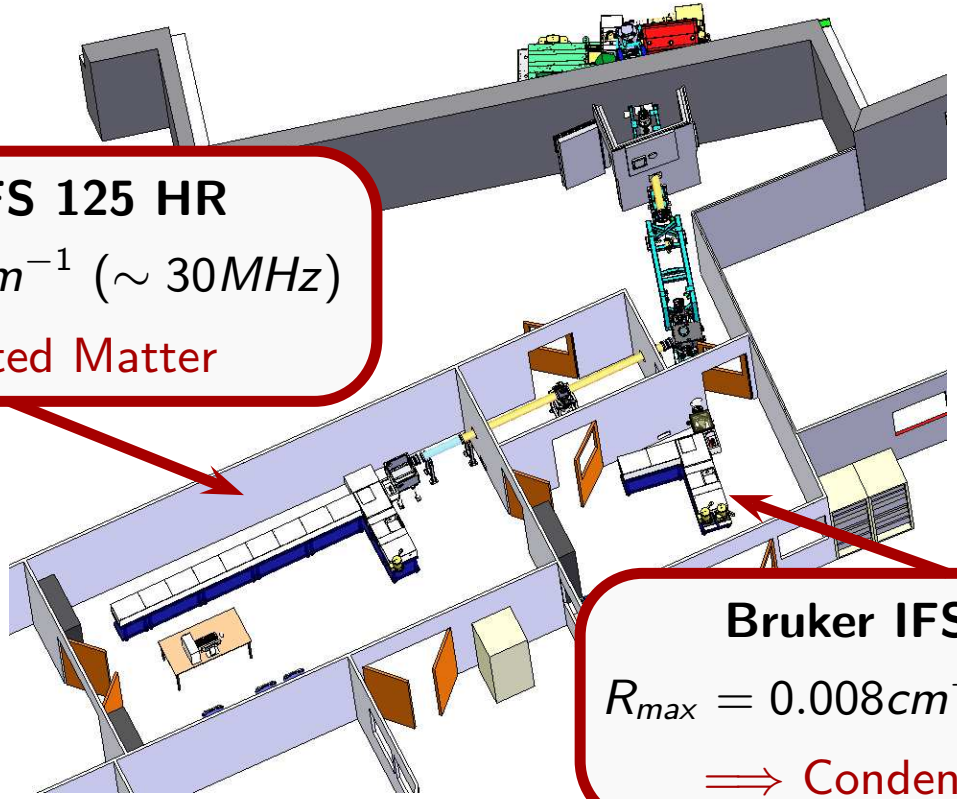
AILES Beamline





AILES Beamline





Bruker IFS 125 HR

$R_{max} = 0.001 cm^{-1}$ ($\sim 30 MHz$)

$\Longrightarrow$ Diluted Matter

Bruker IFS 125 MR

$R_{max} = 0.008 cm^{-1}$ ($\sim 240 MHz$)

$\Longrightarrow$ Condensed Matter