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Laboratory Measurements of Atomic Hyperfine Structures

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A tribute to Jean-François Wyart

EGAS conference 1990 in Uppsala (Sweden)

Laboratory Measurements of Atomic Hyperfine Structures

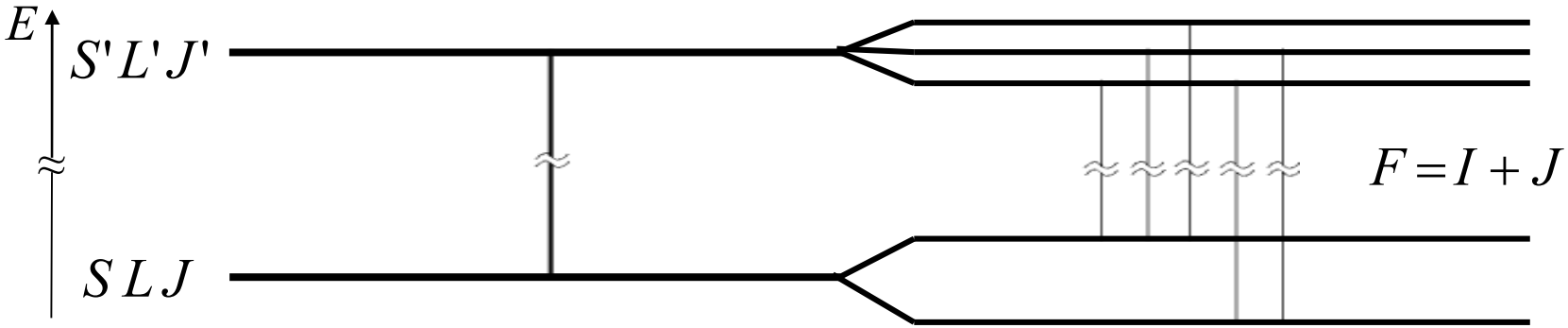
- At the beginning of my career :
  more a theorist than an experimentalist
- started with “pre-Cowan” semi-empirical calculations of fine structure (fs) and hyperfine structure (hfs) using Chain of programs *AGENAC, ASSAC, DIAGAC, GRAMAC* by Bordarier, Y., Bachelier, A. and Sinzelle, J., unpublished, Orsay (Paris)
- later: semi-empirical calculations with Cowan-Code (only fs), hfs with self written code
- later: I left the task of calculations to the group of J. Dembczynski and co-workers in Poznan (Poland)
- theory acts as a door-opener to the good equipped labs

- Introduction
- Experimental methods
- Challenges, effects, special problems
- Summery and outlook

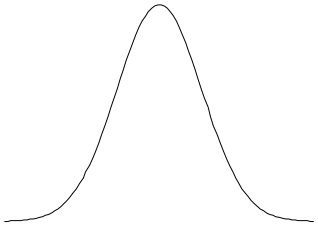
Hyperfine structure

Interactions of electrons with higher electromagnetic moments of nucleus

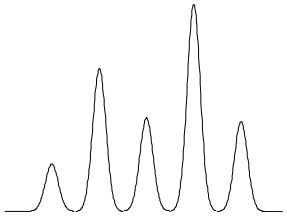
⇒ splitting of fine structure energy levels in hyperfine sublevels



⇒ splitting of spectral lines:



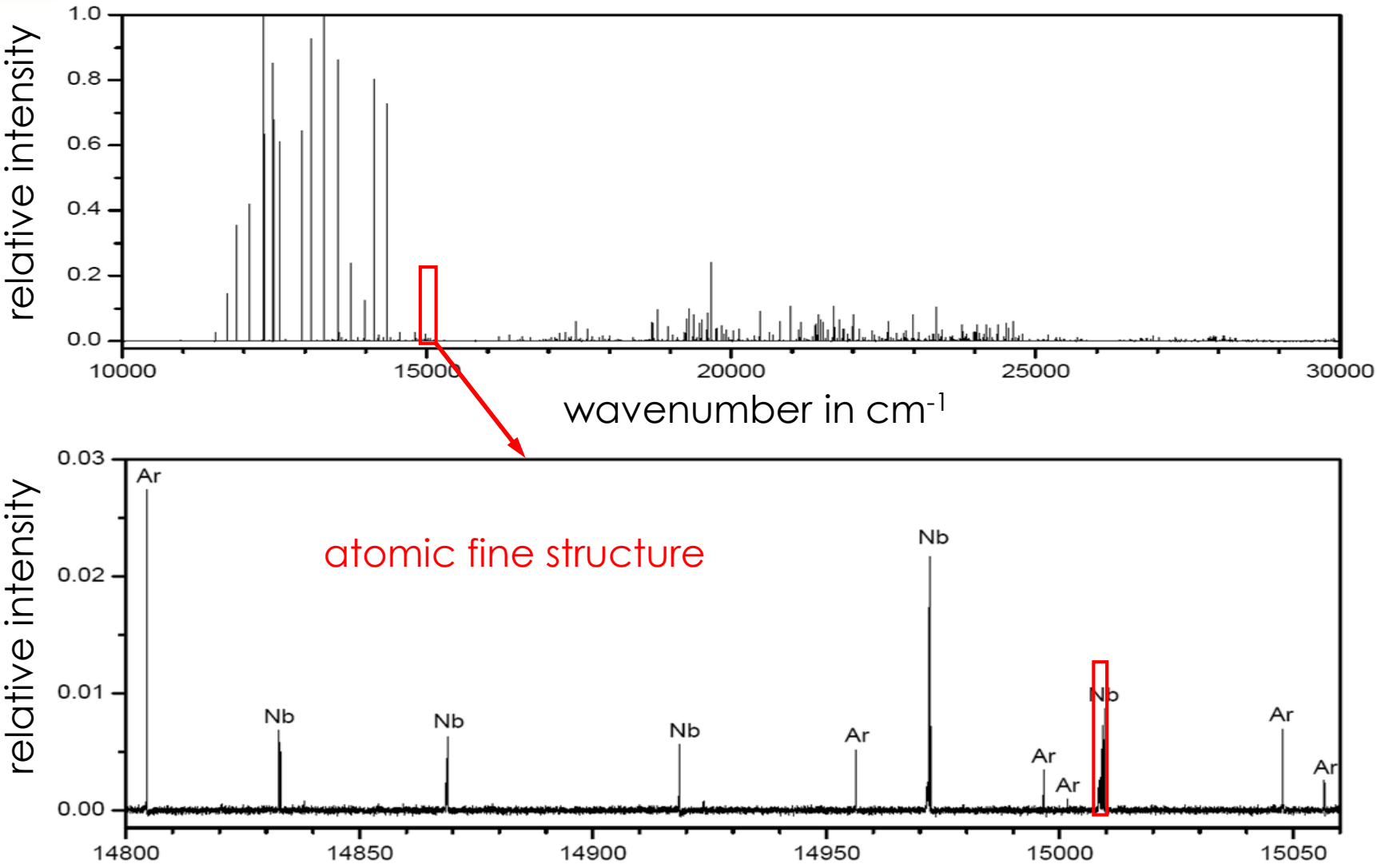
monochromator



FT or laser spectroscopy

Hyperfine structure

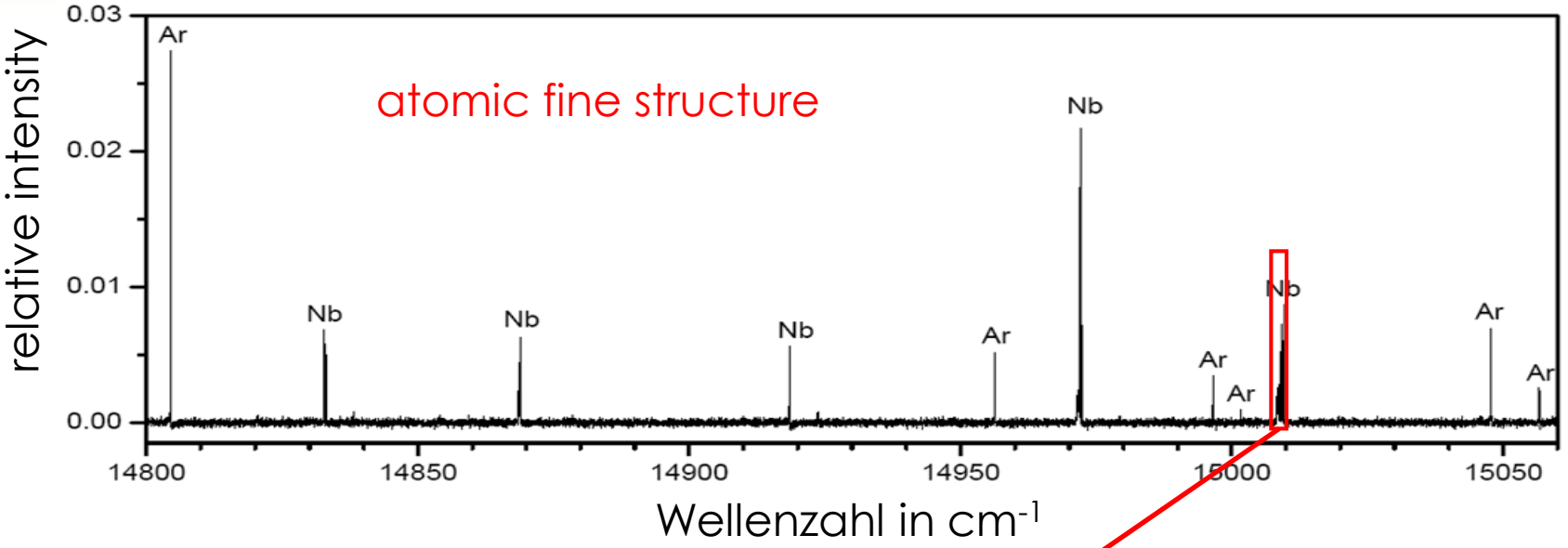
Example: FT Spectrum of Niobium

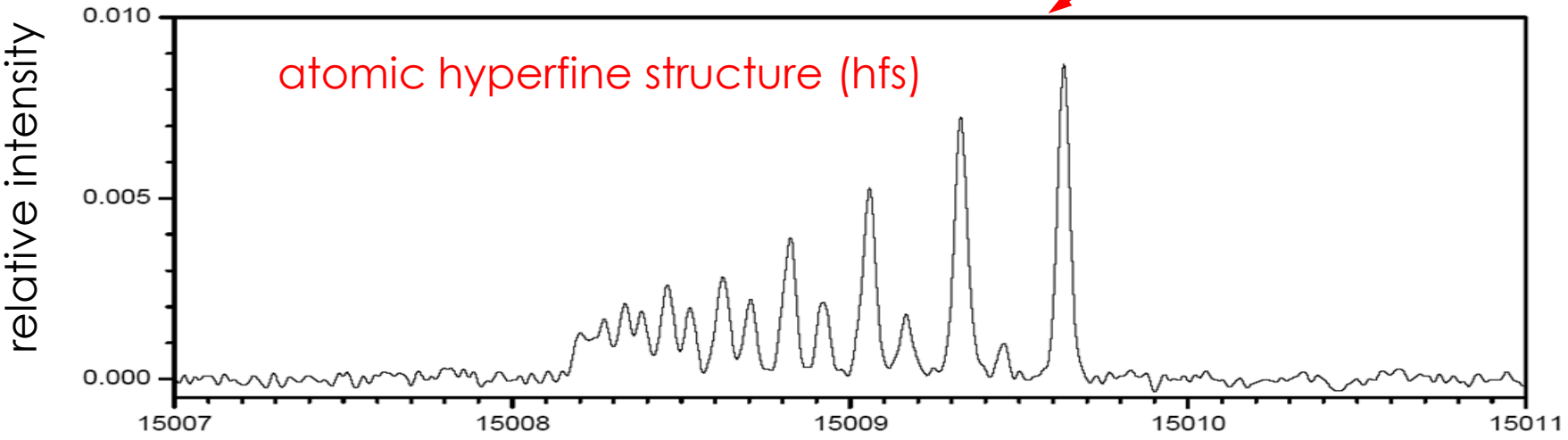


reference.: S Kröger et al, 2010, A&A 516, A70 (doi.org/10.1051/0004-6361/200913922)

Hyperfine structure

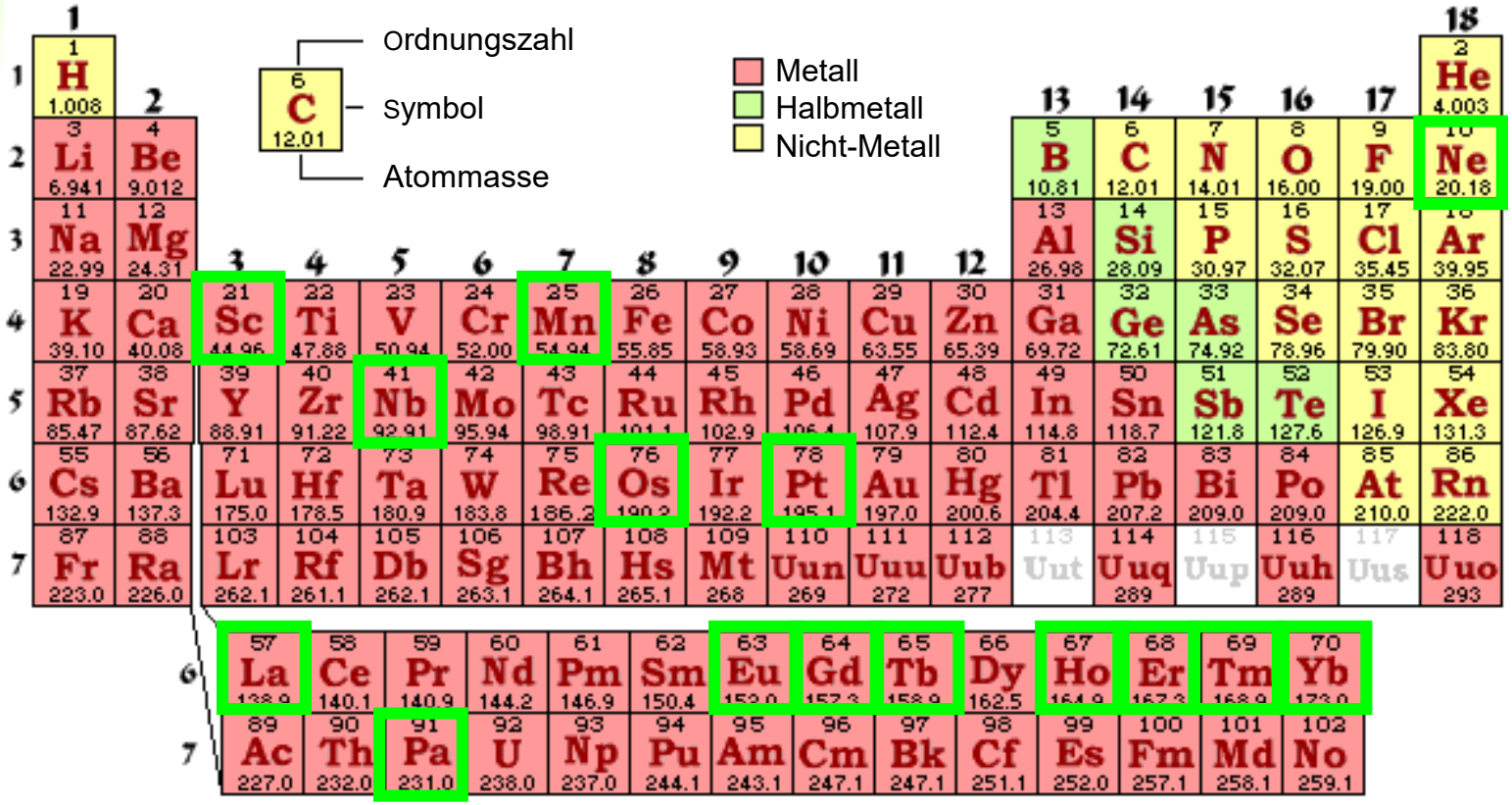
Example: Spectrum of Niobium





reference.: S Kröger et al, 2010, A&A 516, A70 (doi.org/10.1051/0004-6361/200913922)

Periodensystem der Elemente

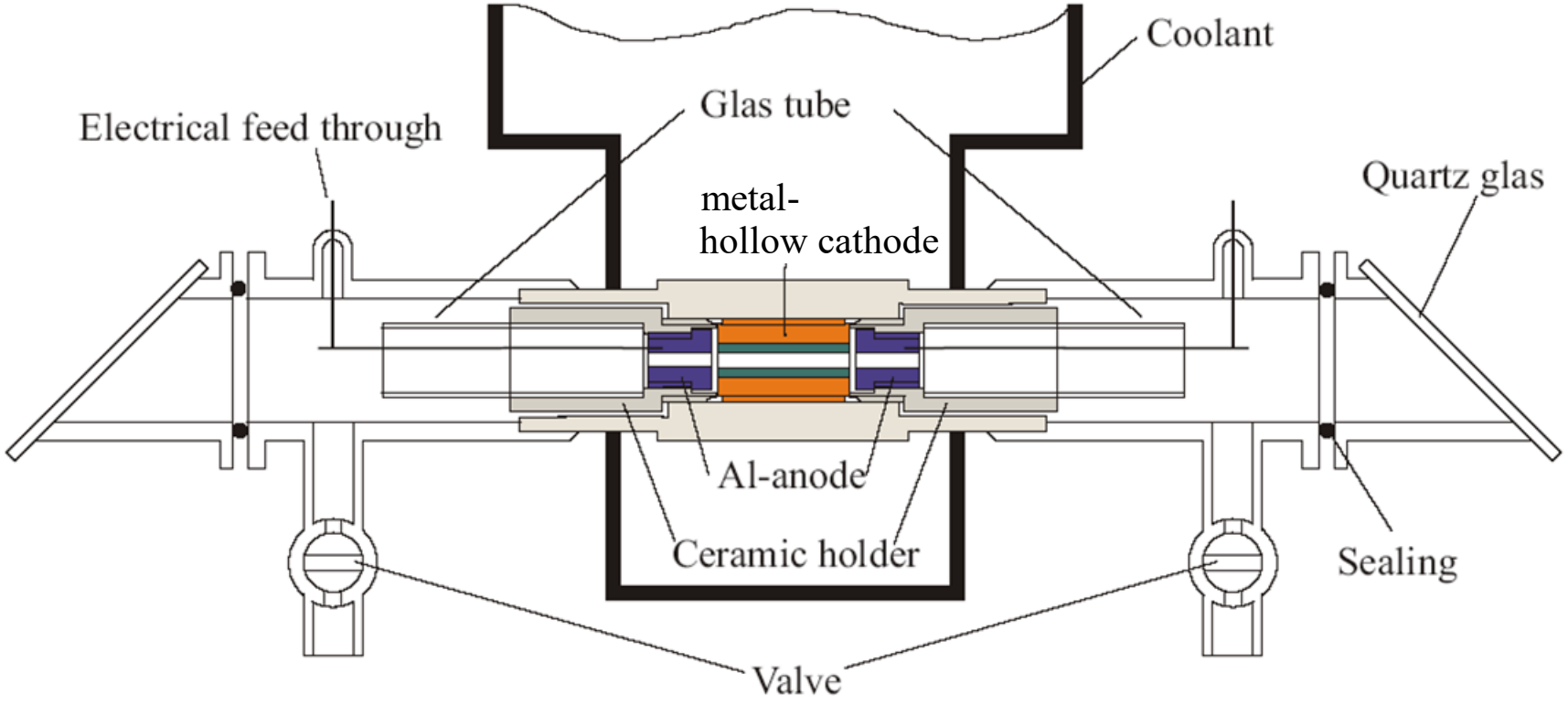


: investigated element

mostly atoms, sometimes singly ionized ions

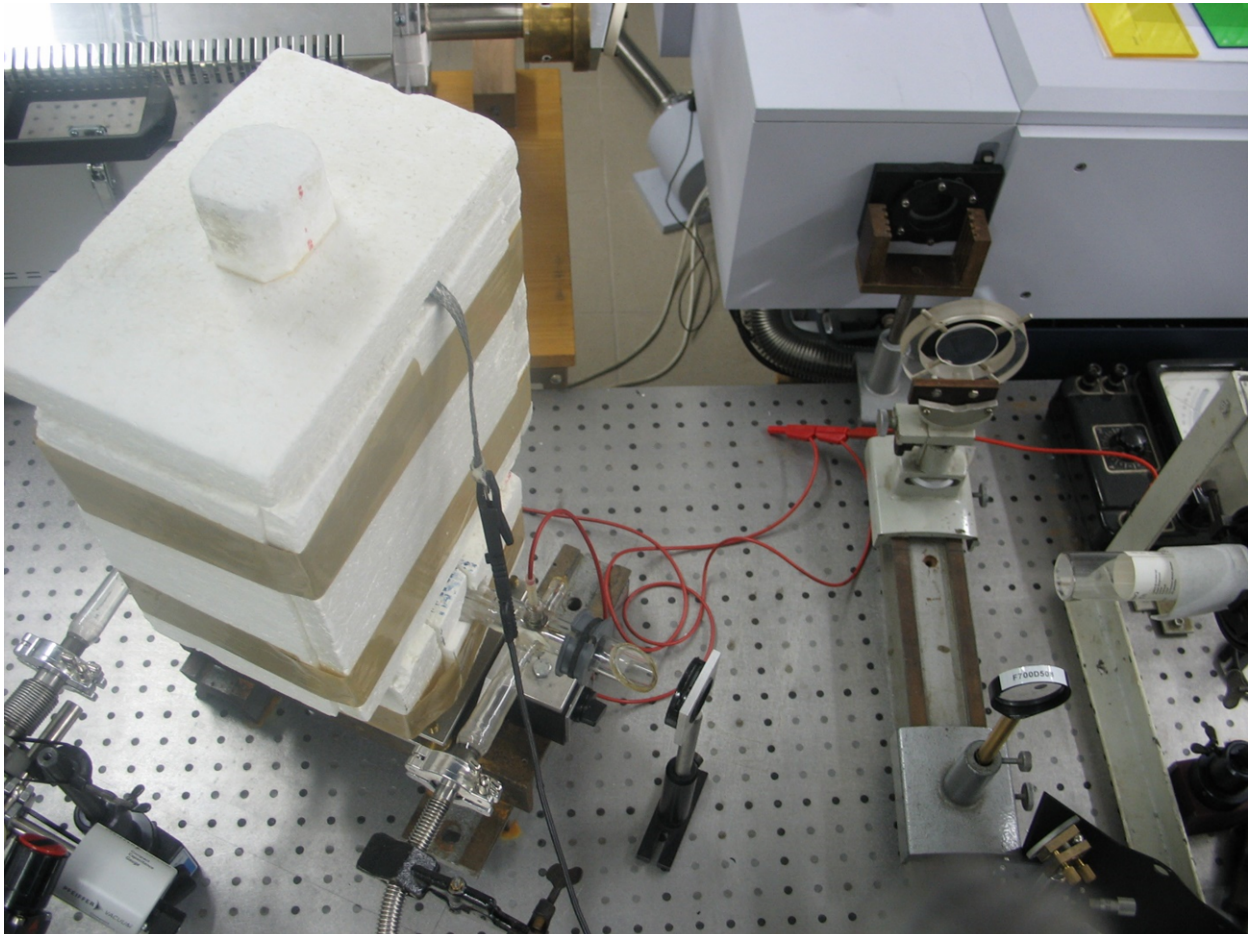
How to get free atoms and ions?

hollow cathode gas discharge, liquid nitrogen cooled

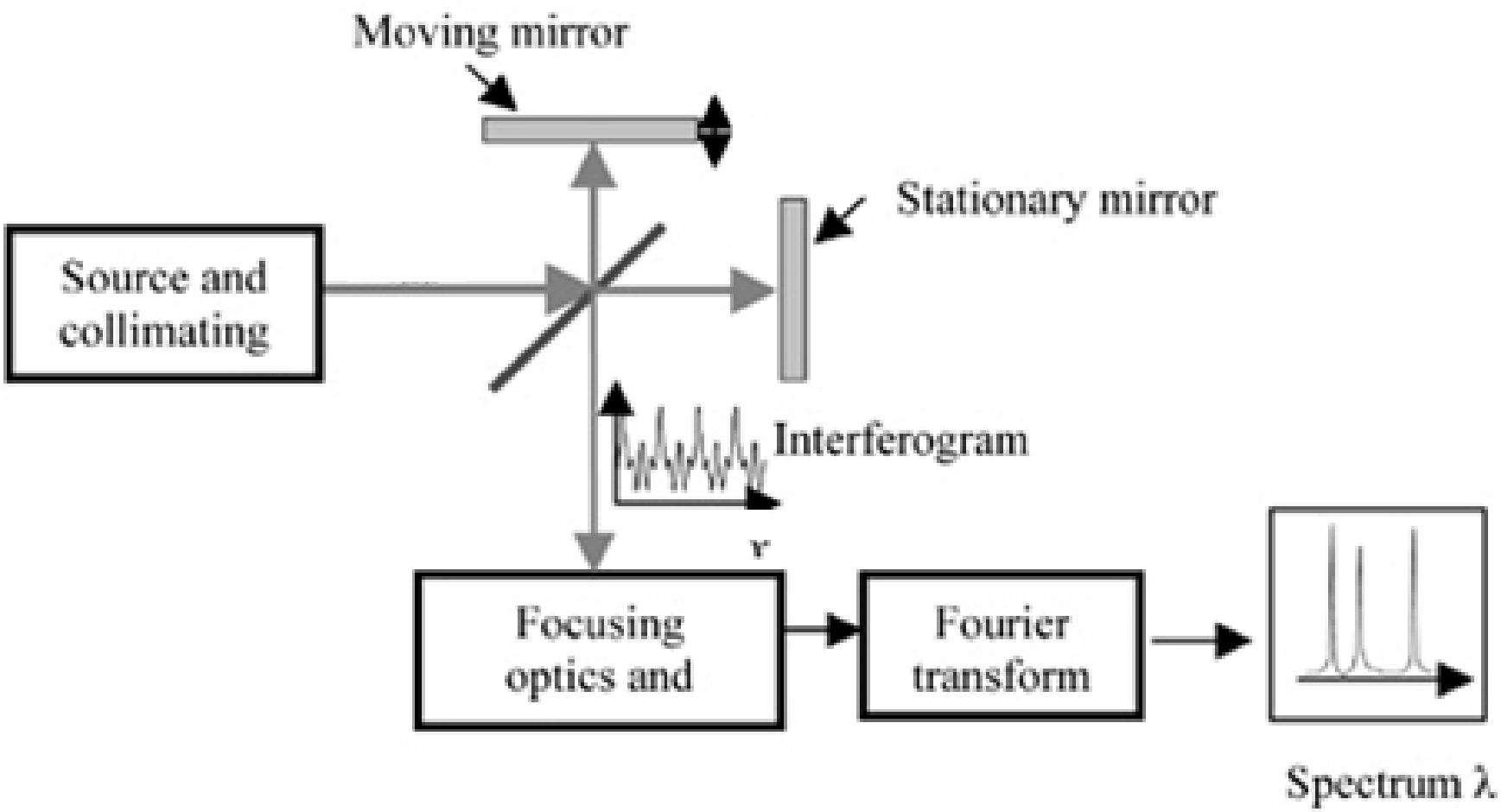


Experimental methods

hollow cathode



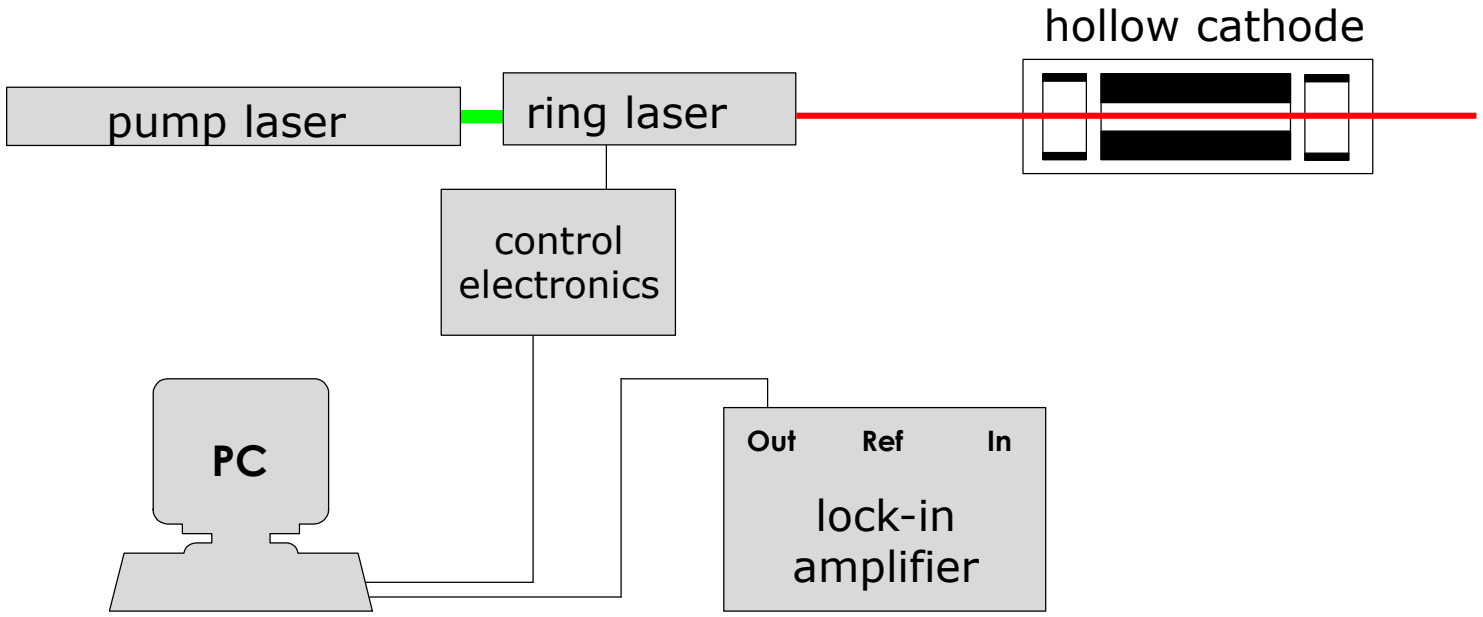
Fourier-Transform-Spektroskopie (FT)



Laser Centre, University of Latvia, Riga, Latvia (Bruker IFS 125HR)

Experimental methods

laser spectroscopy

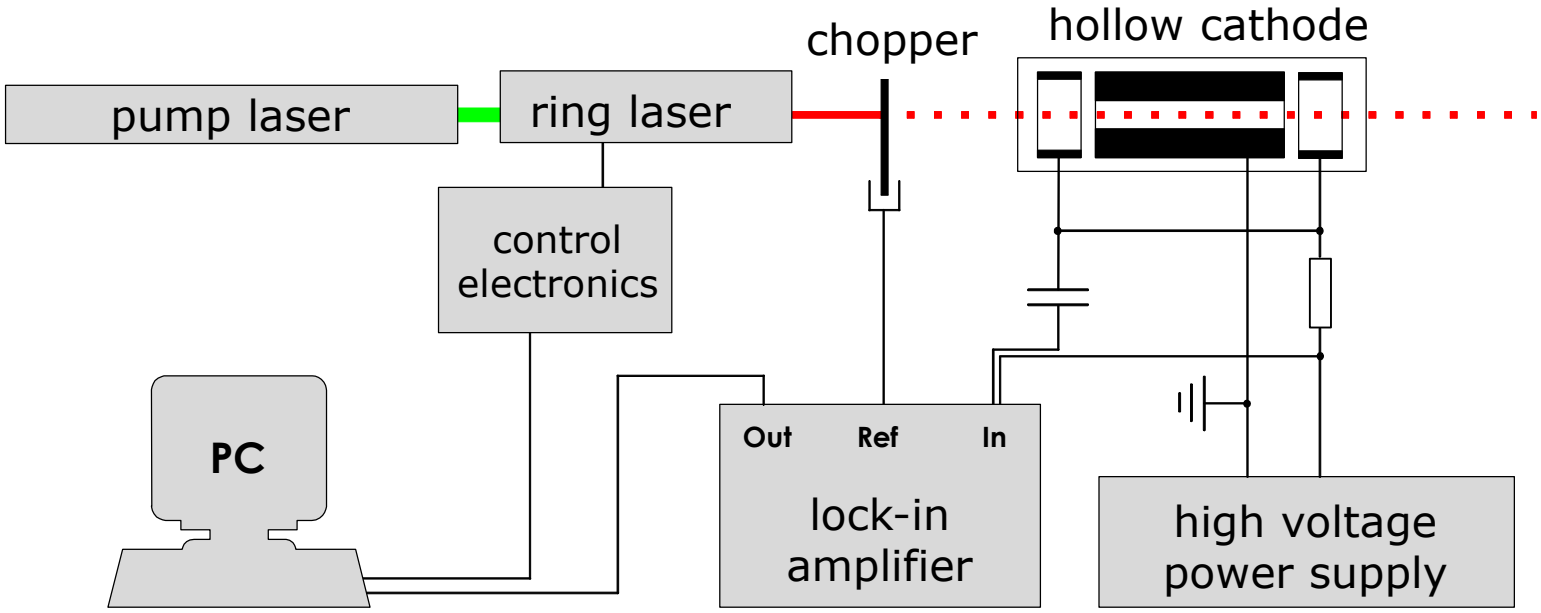


mostly at the Laser-Lab of the Istanbul University

Experimental methods

laser spectroscopy

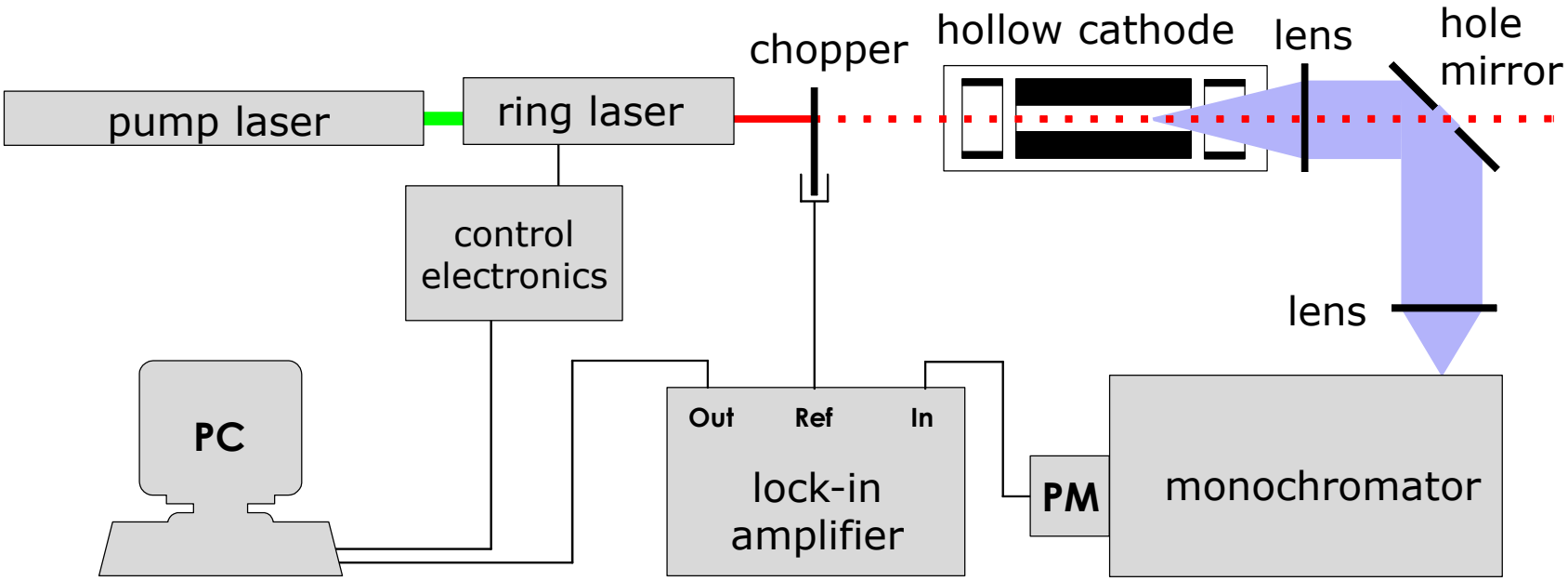
optogalvanic spectroscopy (OGS)



Experimental methods

laser spectroscopy

laser induced fluorescence spectroscopy (LIF)

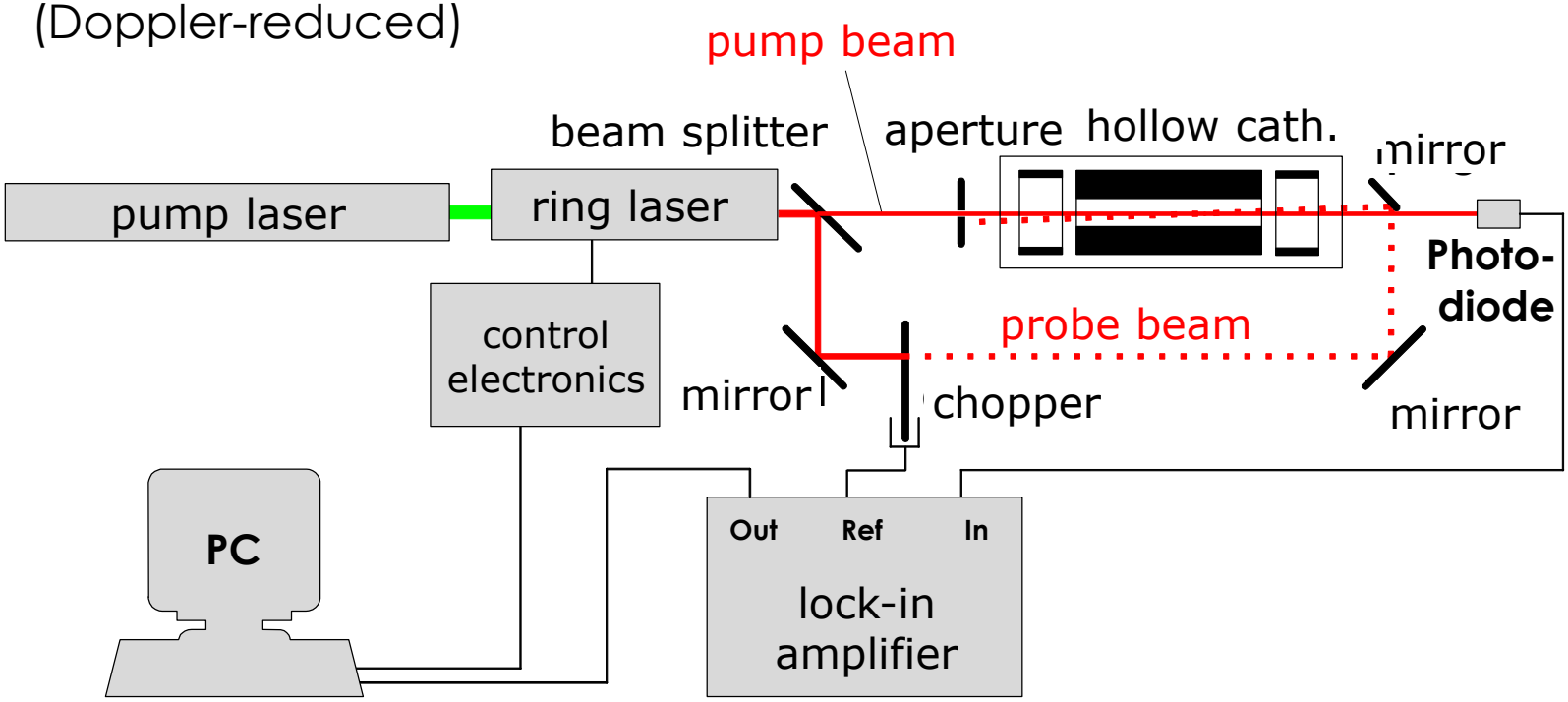


Experimental methods

laser spectroscopy

saturation absorption spectroscopy (SAS)

(Doppler-reduced)



intermodulated optogalvanic spectroscopy (IMLIF)

Experimental methods

FT spectroscopy

advantage:

large wavelength range

disadvantage:

lower resolution

lower sensitivity

versus

laser spectroscopy

advantage:

higher resolution

higher sensitivity

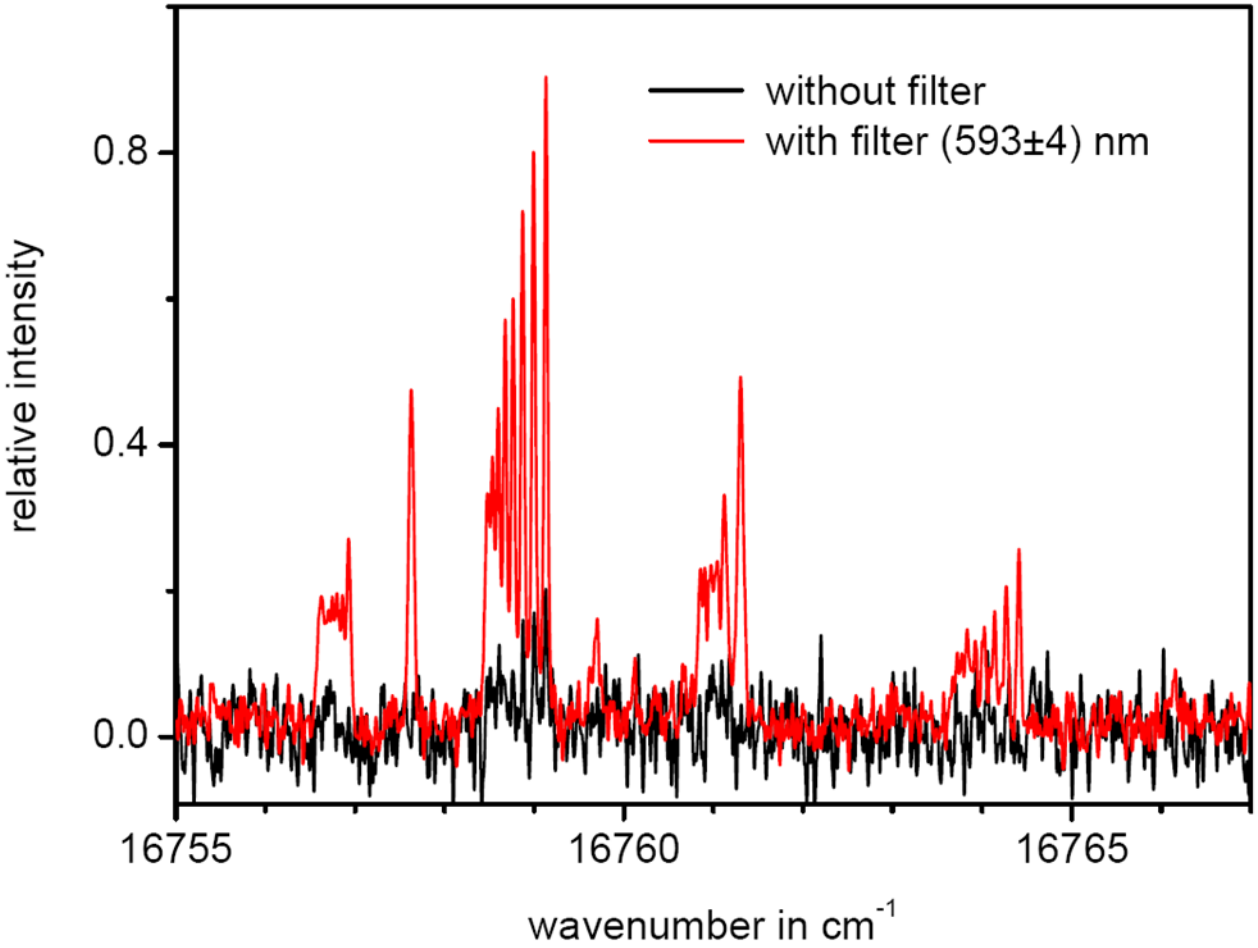
disadvantage:

small wavelength range

Experimental methods

FT spectroscopy:

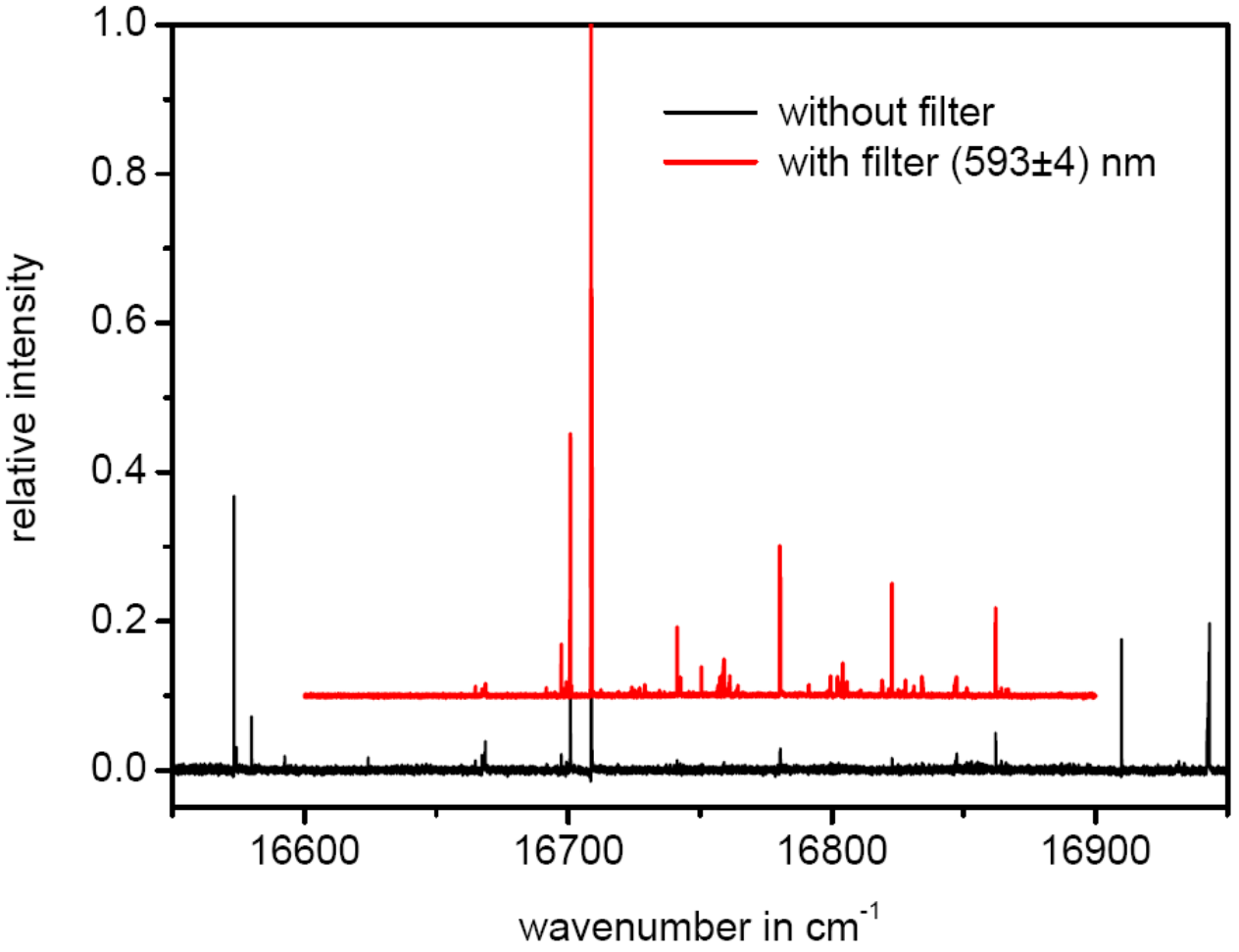
increasing the sensitivity by installing an optical band-pass filter



reference.: A Er et al, 2011, J. Phys. B: At. Mol. Opt. Phys. 44, 205001 (DOI 10.1088/0953-4075/44/20/205001)

FT spectroscopy:

increasing the sensitivity by installing an optical band-pass filter

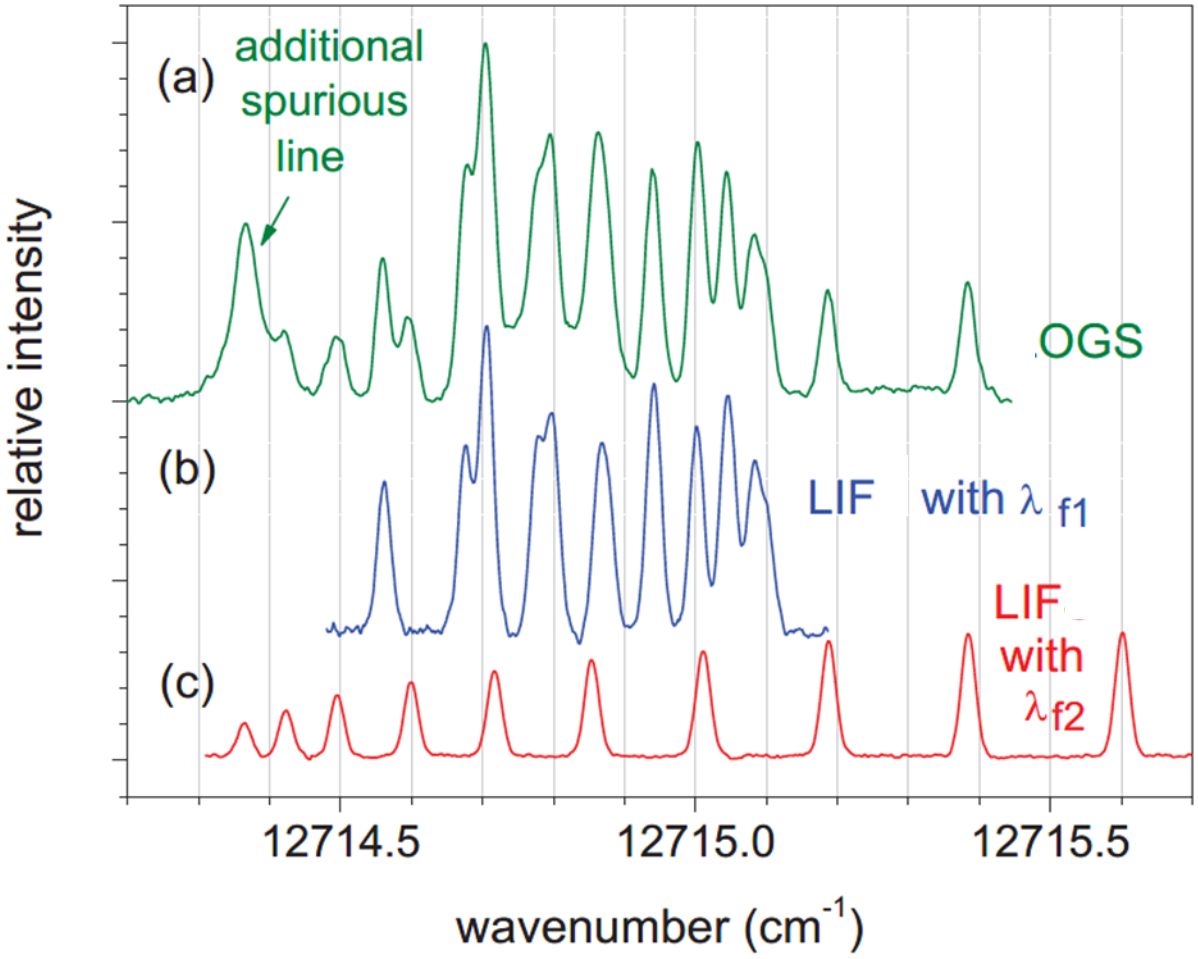


reference.: A Er et al, 2011, J. Phys. B: At. Mol. Opt. Phys. 44, 205001 (DOI 10.1088/0953-4075/44/20/205001)

Experimental methods

laser spectroscopy

optogalvanic sp. (OGS) versus **laser induced sp. (LIF)**

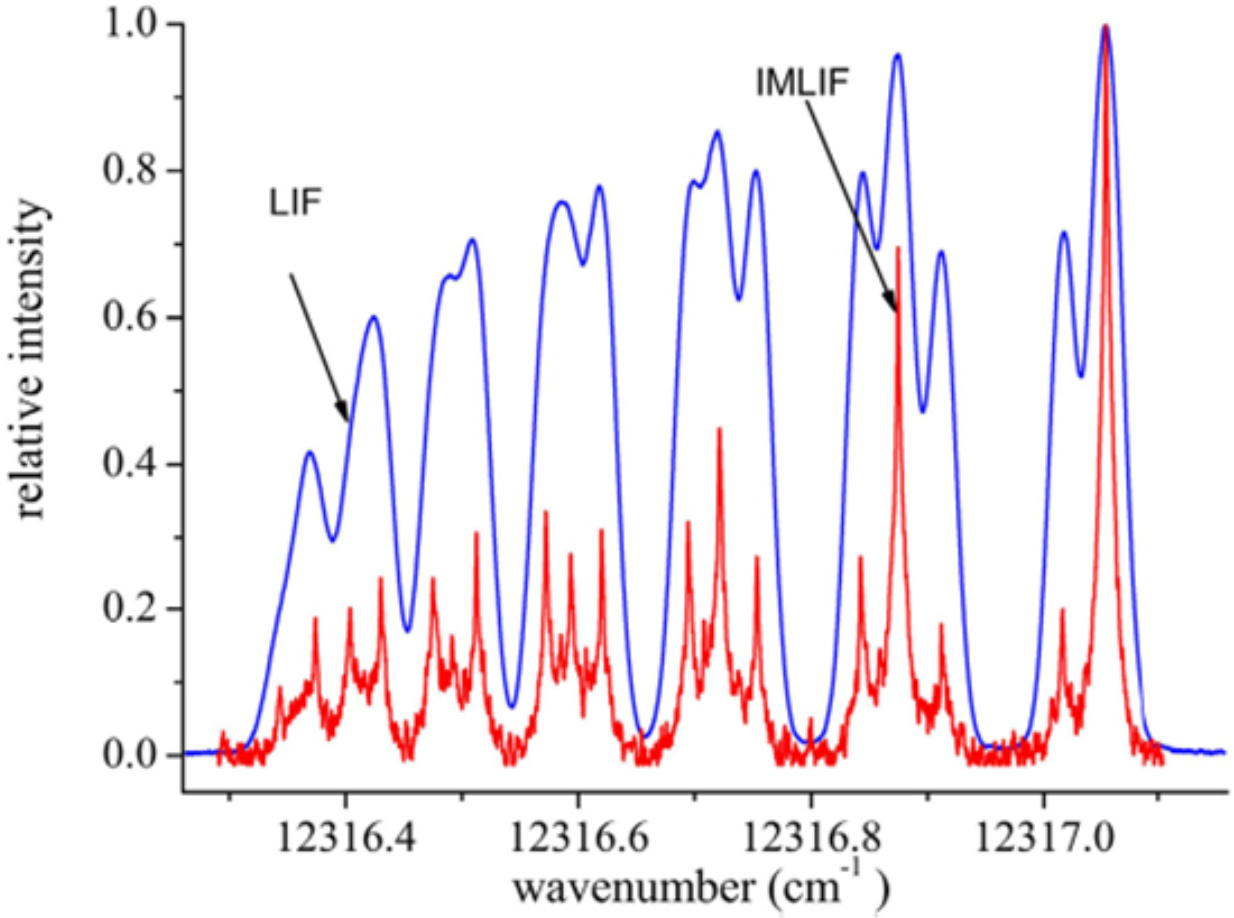


reference.: Gö. Başar et al, 2013, A&A 556, A103 (doi: 10.1051/0004-6361/201321919)

Experimental methods

laser spectroscopy

Doppler-limited versus **Doppler-reduced**



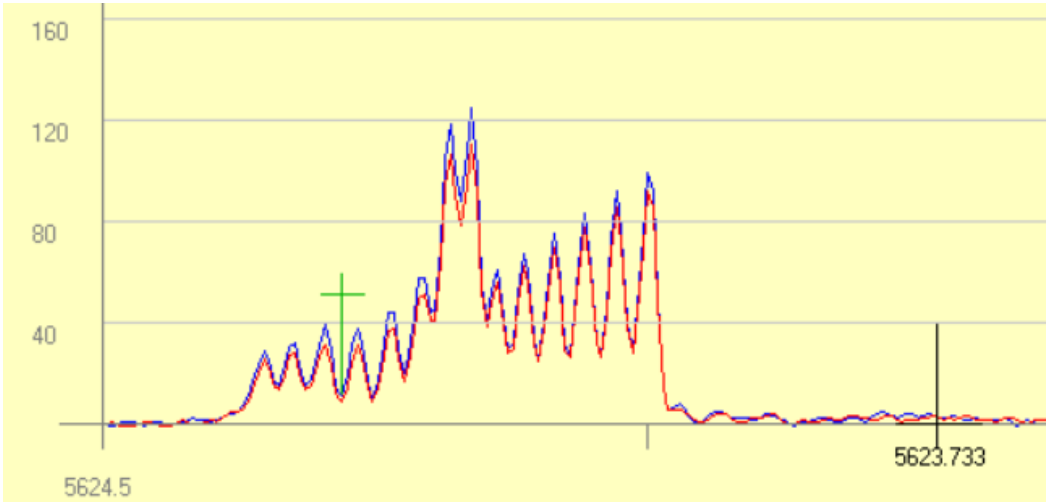
reference.: Gü. Başar et al, 2018, JQSRT 219, 1 (https://doi.org/10.1016/j.jqsrt.2018.07.018)

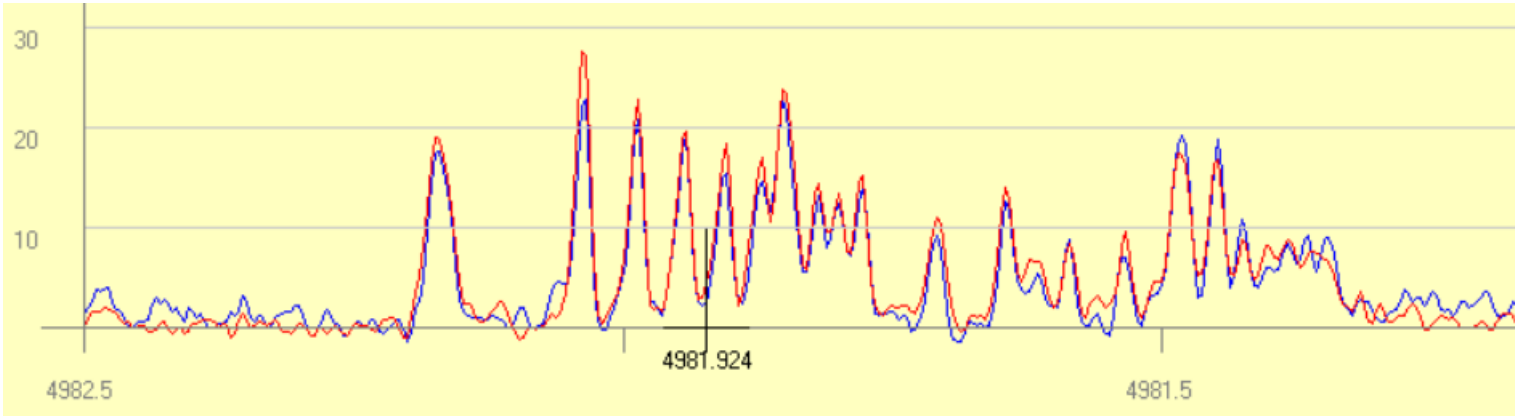
Challenges, effects, special problems

- blends
- self absorption
- asymmetry
- saturation
- second order effect on the hyperfine structure

Challenges, effects, special problems

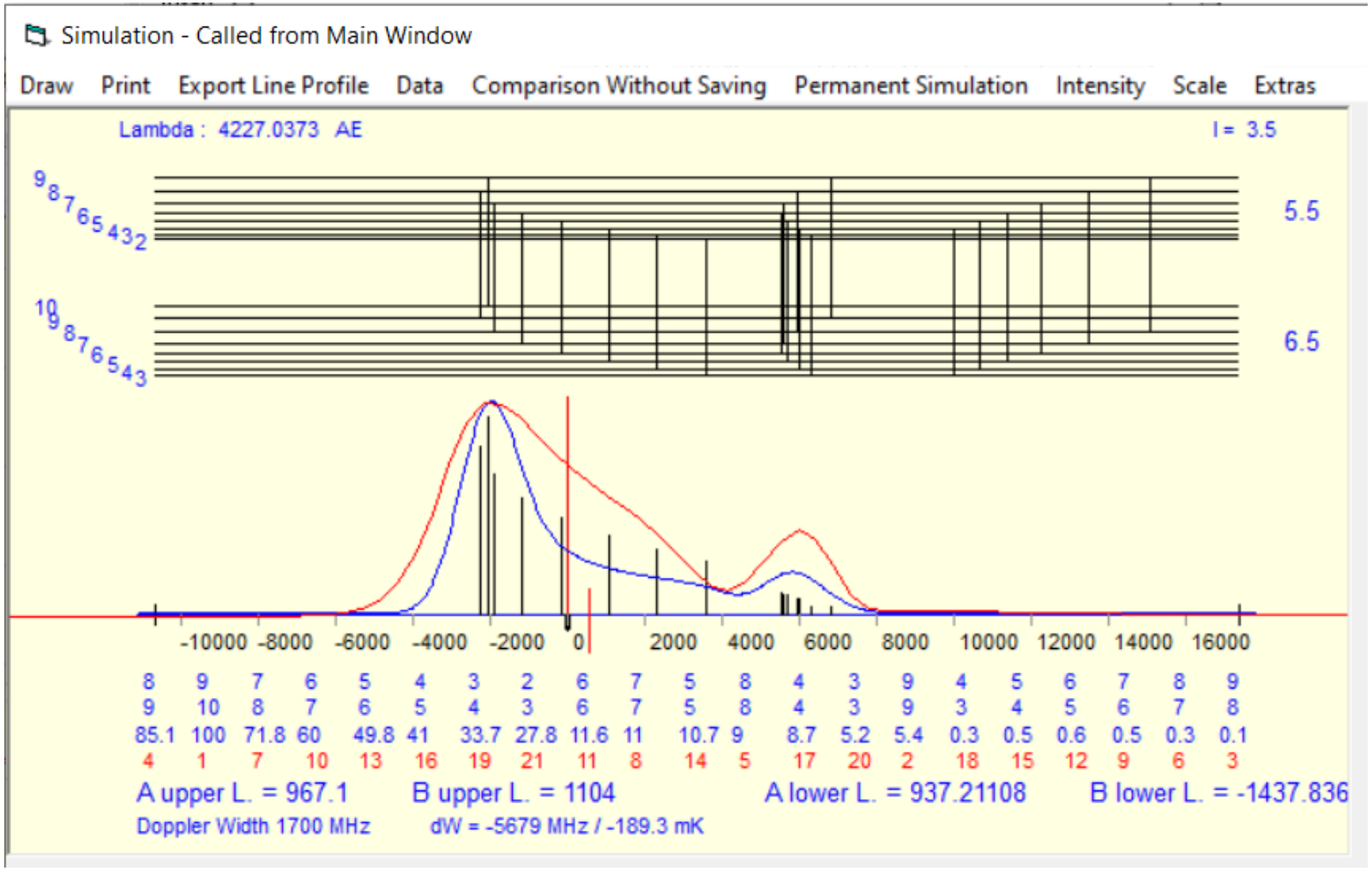
- **blends** example: **FT-measurements**, Ho-Ar + Ho-Ne





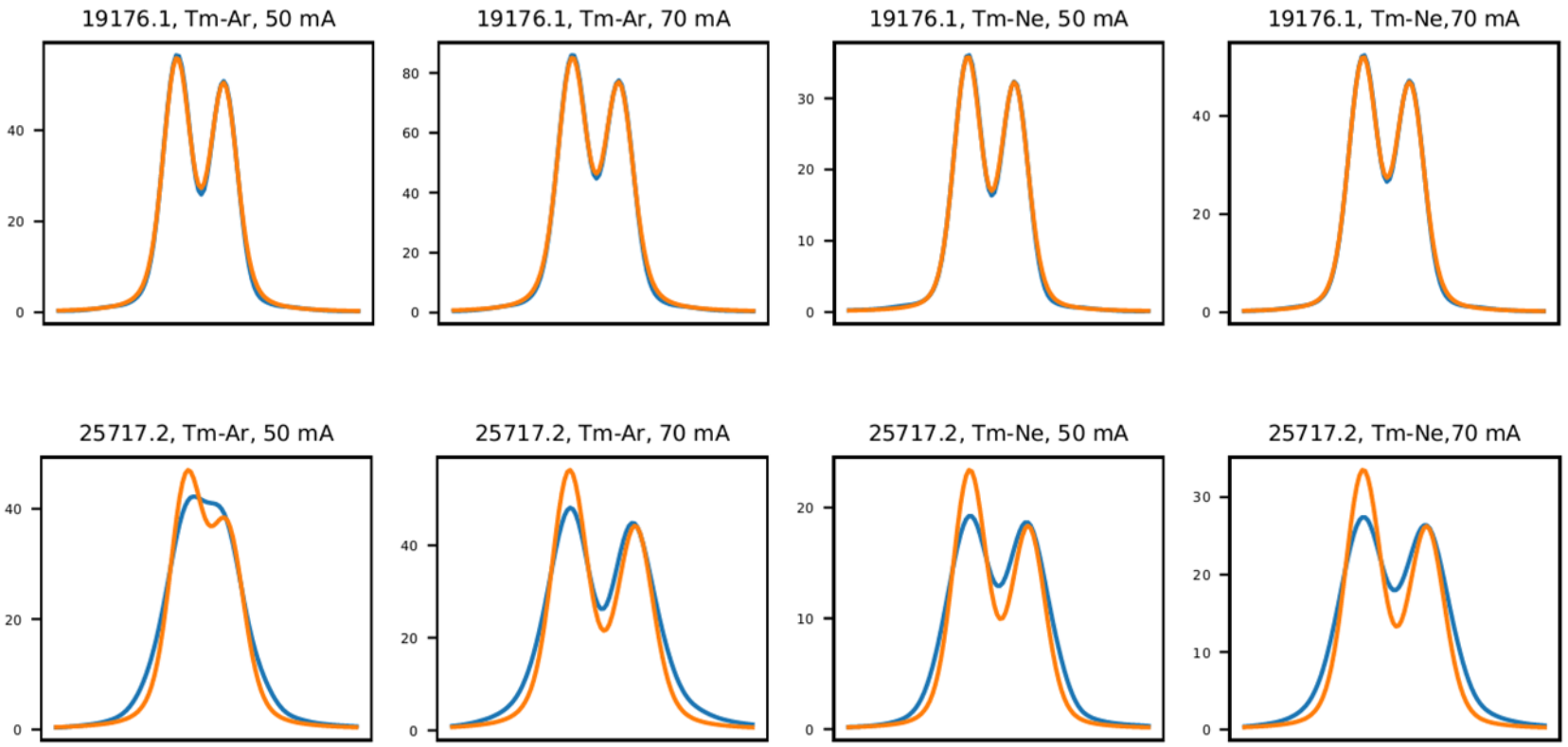
Challenges, effects, special problems

- **self absorption** example: **FT-measurements**, Ho I, S/N > 5000



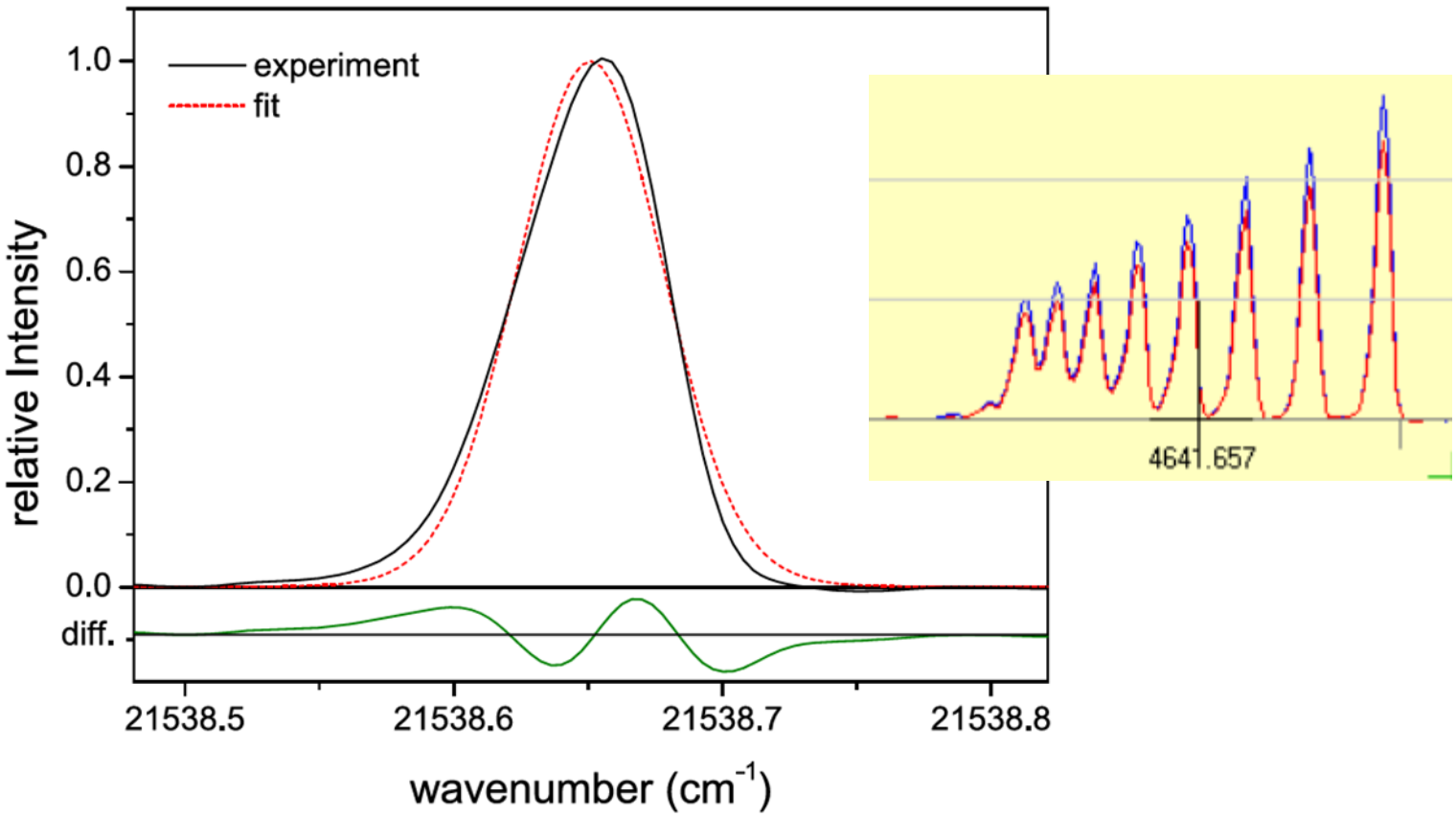
Challenges, effects, special problems

- **self absorption** example: **FT-measurements**, Tm I,



Challenges, effects, special problems

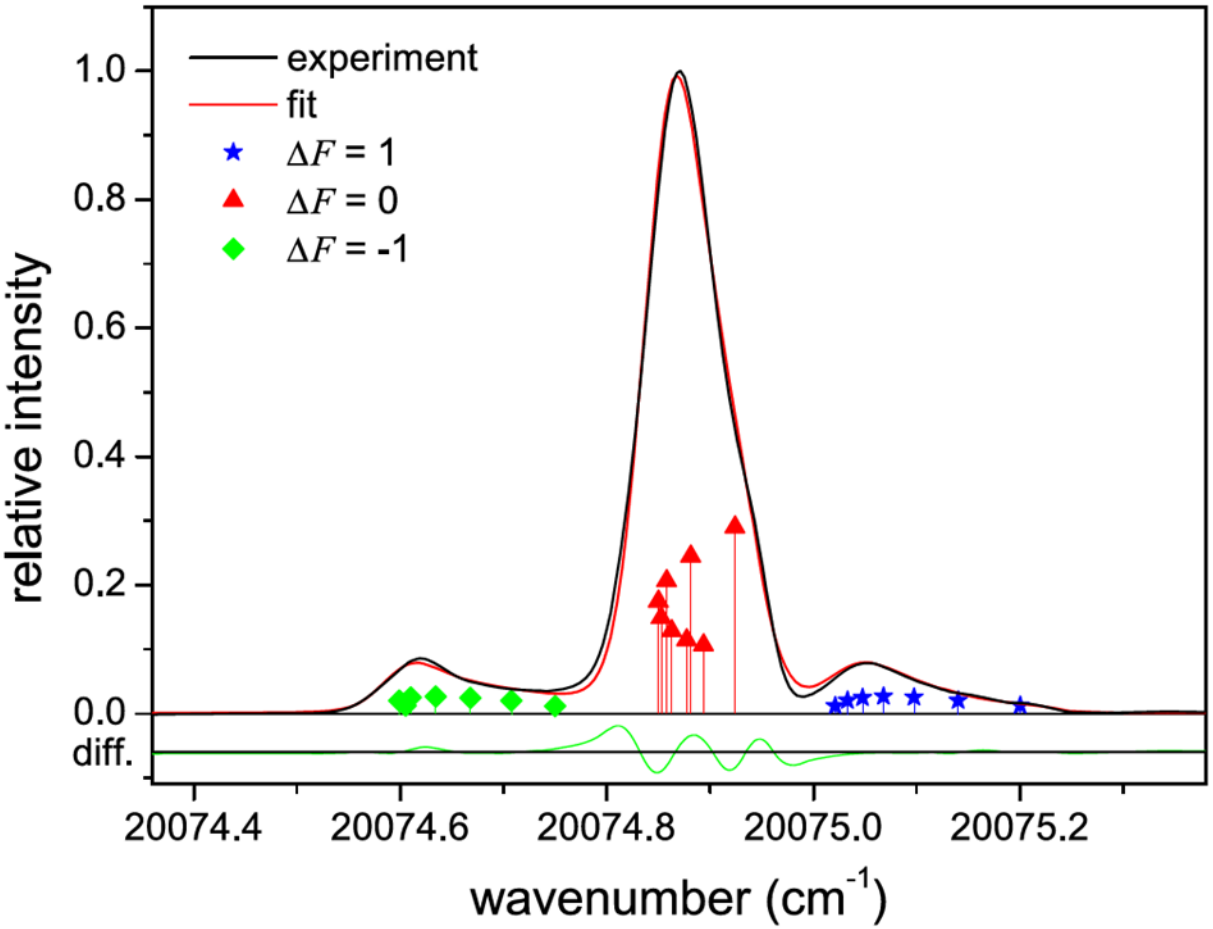
- **asymmetry:** example: **FT-measurements**, Ho I,



reference.: B. Özdalgiç et al, 2019, ApJS 244, 41 (DOI 10.3847/1538-4365/ab4262)

Challenges, effects, special problems

- **asymmetry:** example: **FT-measurements**, Ho I,



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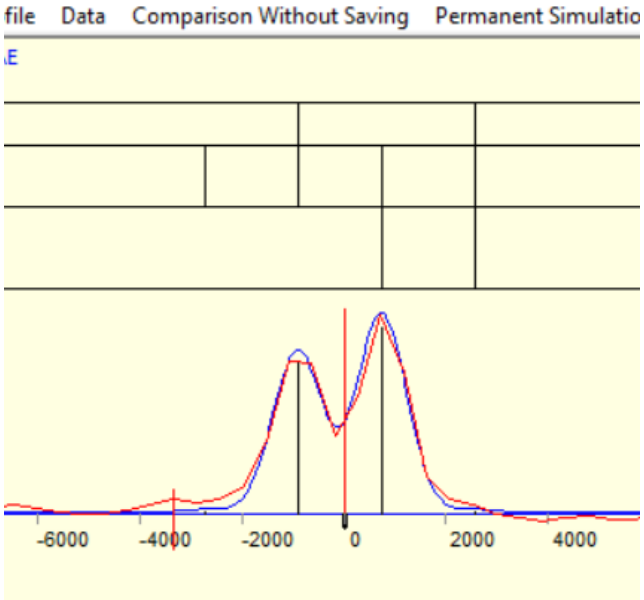
Challenges, effects, special problems

- **saturation**: advantage or disadvantage

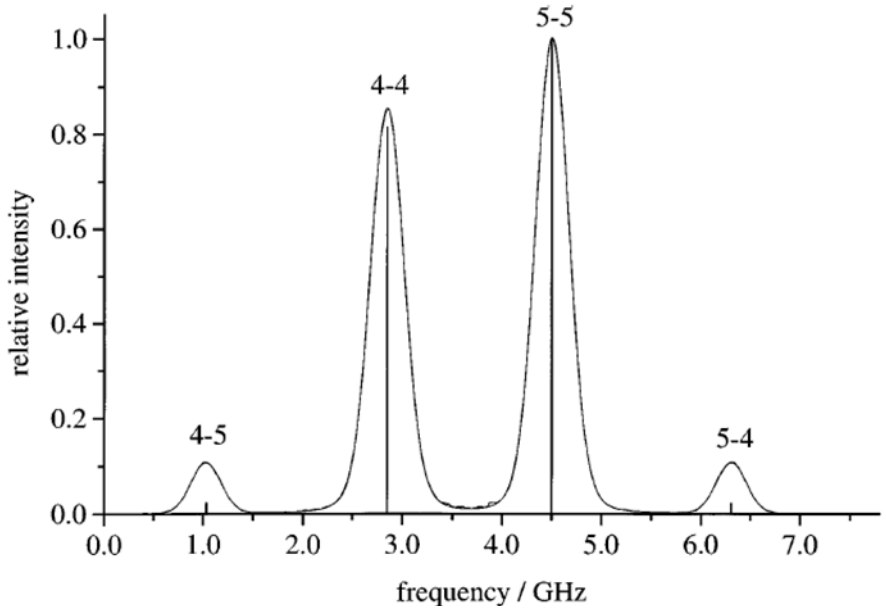
Challenges, effects, special problems

- **saturation**: **advantage**

FT-measurements, Tm I:
without saturation



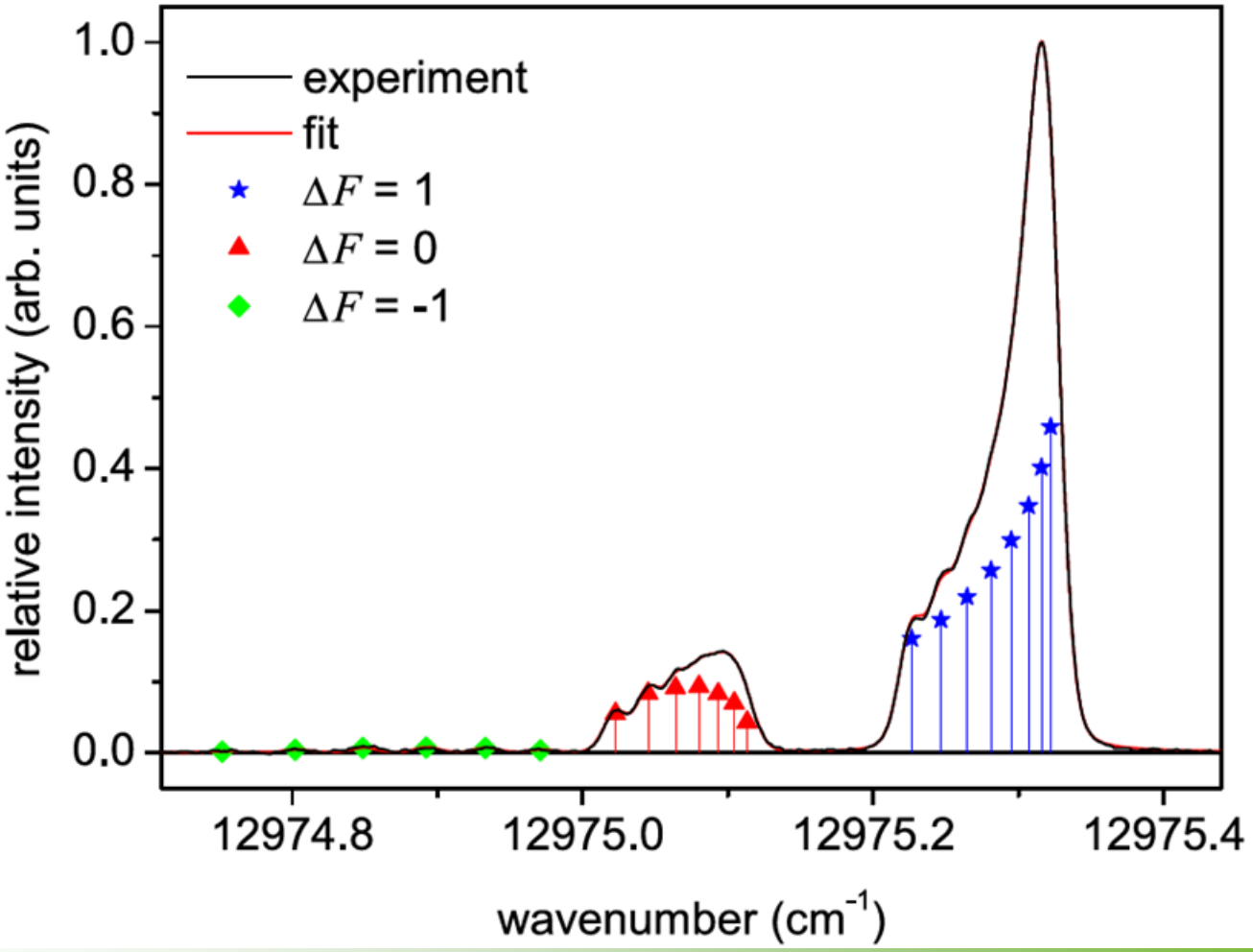
Laser-measurements, Tm I:
with saturation



reference.: S. Kröger et al, 1997, Z. Phys. D 41, 181 (doi.org/10.1007/s004600050309)

Challenges, effects, special problems

- **saturation**: **advantage** and disadvantage **laser-measurements**, Ho I:

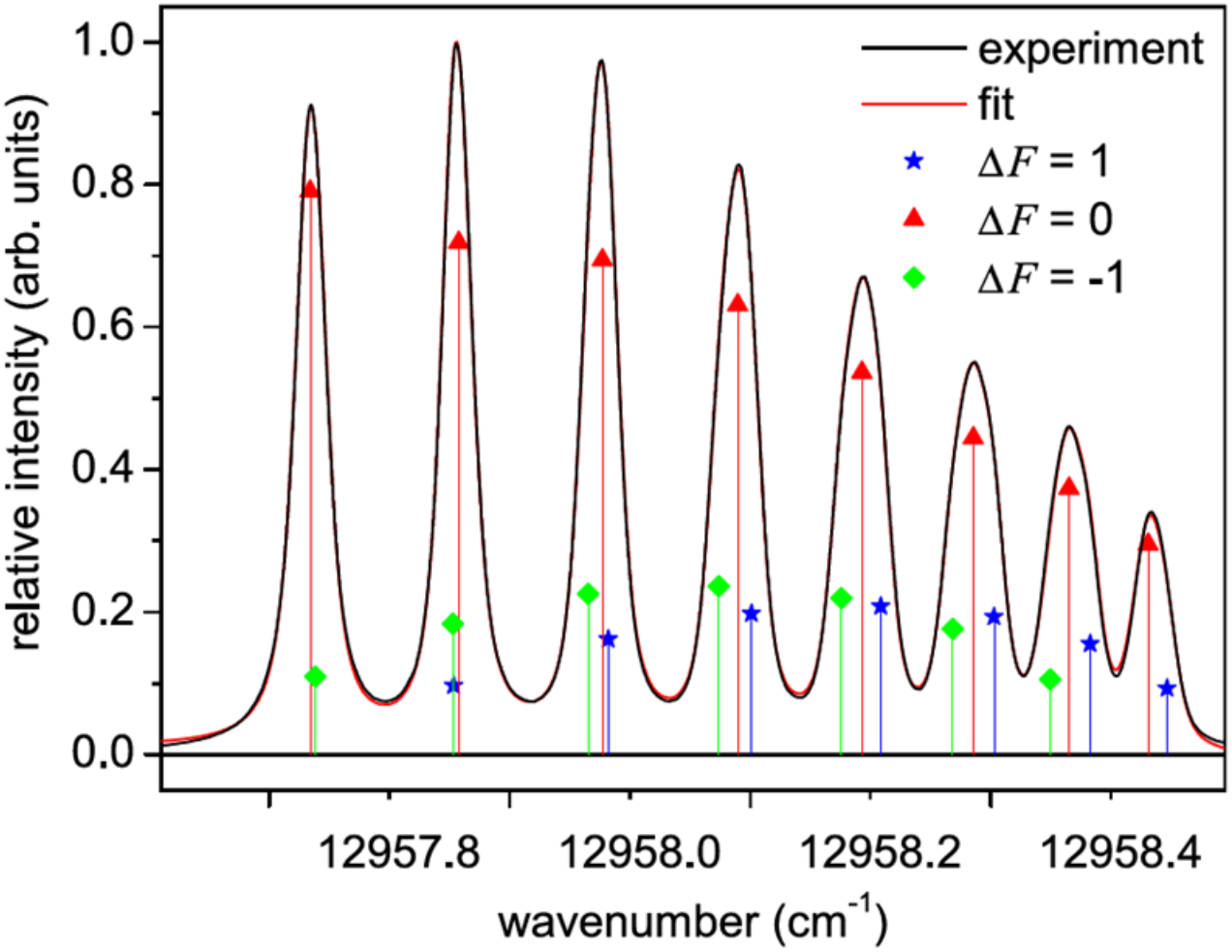


reference.: Gö. Başar et al, 2020, JQSRT 243, 106809 (doi.org/10.1016/j.jqsrt.2019.106809)

Challenges, effects, special problems

- **saturation**: advantage or **disadvantage**

  laser-measurements, Ho I:

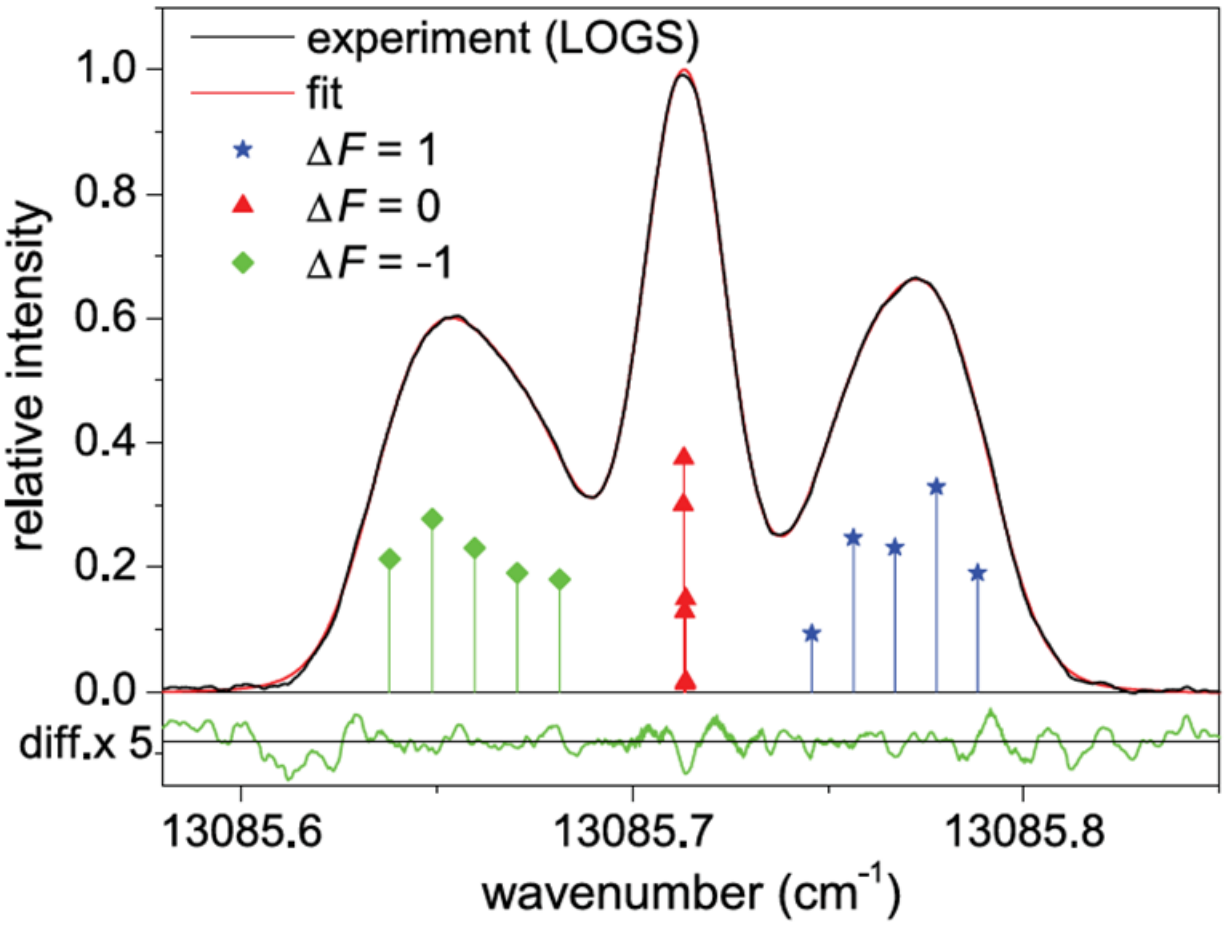


reference.: Gö. Başar et al, 2020, JQSRT 243, 106809 (doi.org/10.1016/j.jqsrt.2019.106809)

Challenges, effects, special problems

- **saturation**: advantage or **disadvantage**

  laser-measurements, Nb I:



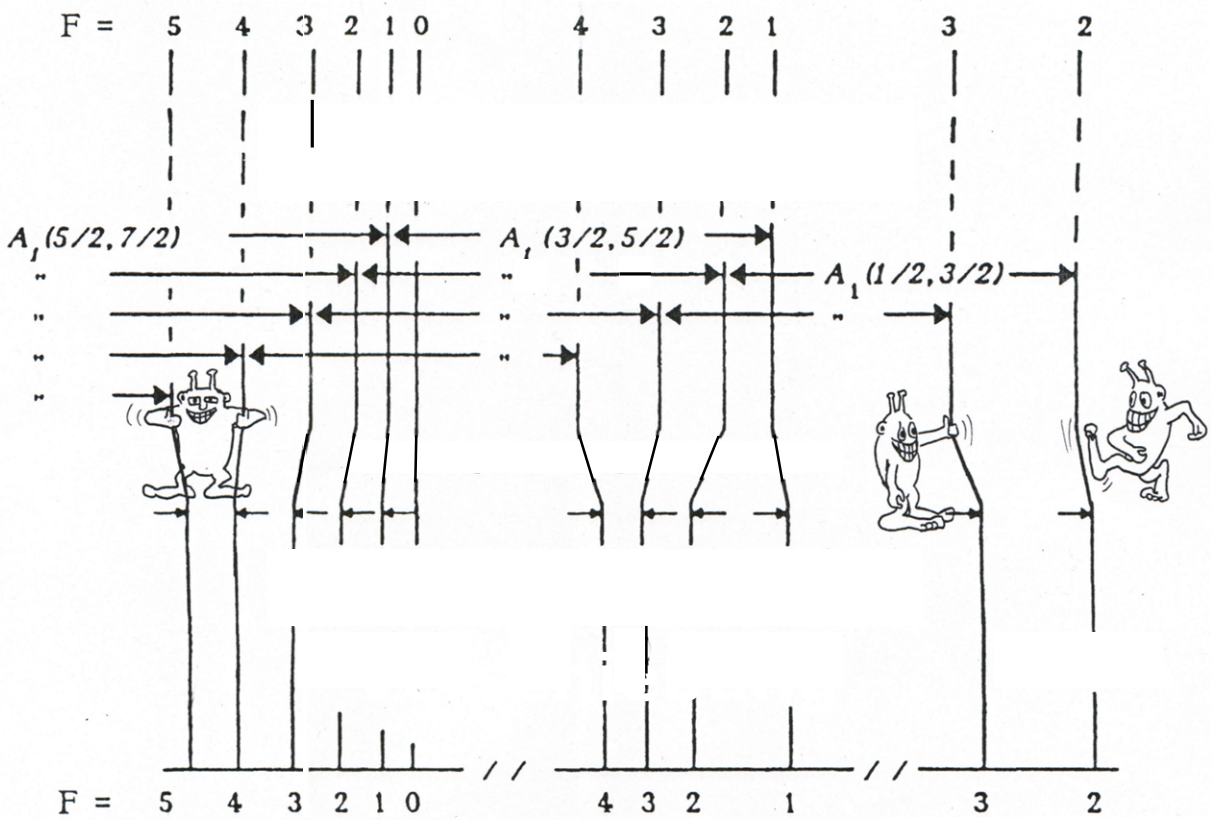
reference.: Gö. Başar et al, 2013, A&A 556, A103 (doi: 10.1051/0004-6361/201321919)

Challenges, effects, special problems

- **second order effect** on the hyperfine structure

close lying neighboring fine structure energy levels, that disturb each other => J is not any more a good quantum number

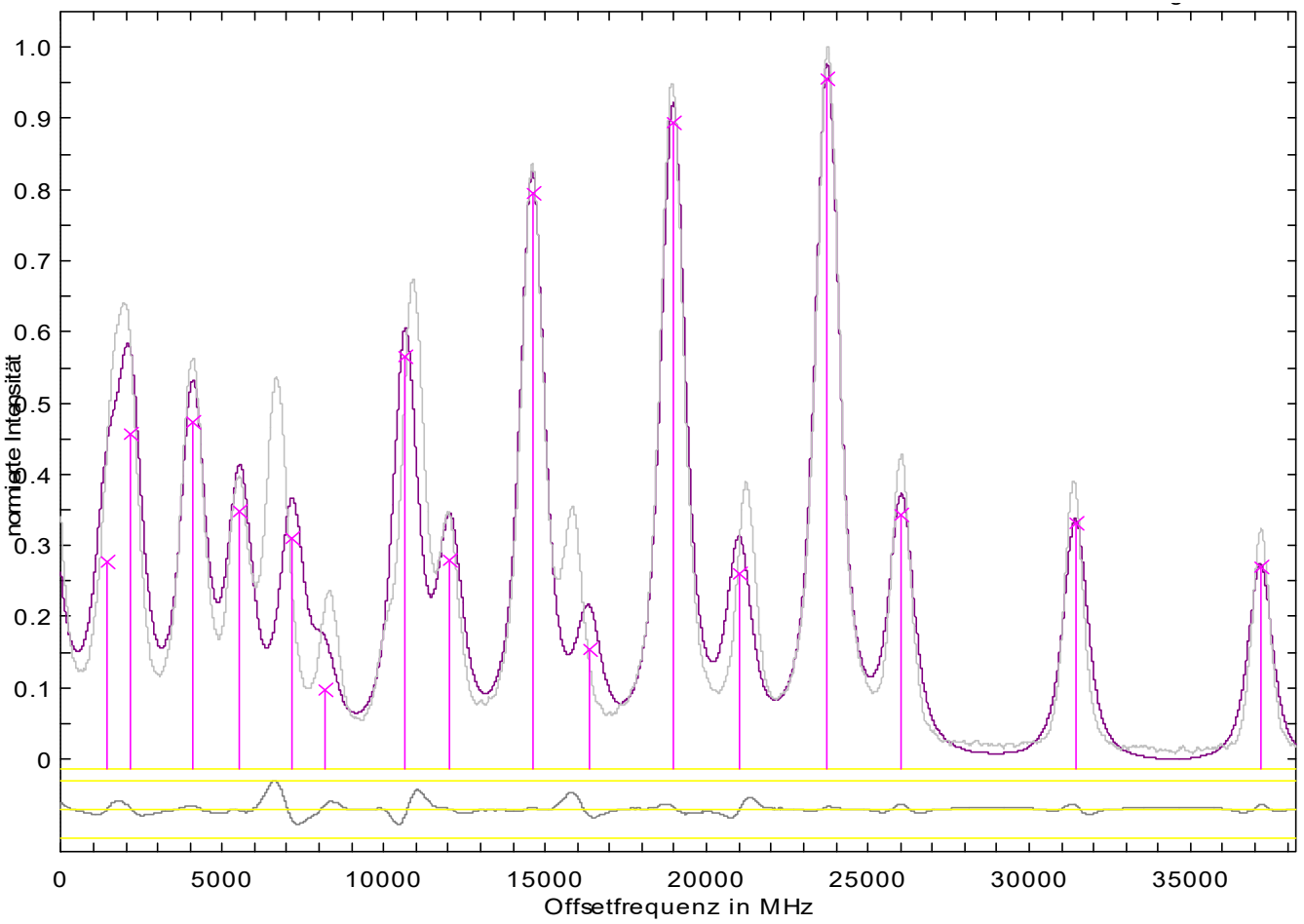
example:
Er I



Challenges, effects, special problems

- **second order effect** on the hyperfine structure

  example: laser measurements Ho I



Summery and outlook

- 15 elements investigated
- barrel without bottom
- time passes too quickly
  and always too much else to do
- up to now: picked out the sultanas

- Cooperation and exchange of data between different research groups is very important!

Always stated as reason for existence of our experiments: needed from astrophysics

What is really needed from astrophysics?

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