AcF 2025 proposed plan

Proposal by
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INTC-P-615
15 shifts without protons and **14 with protons**

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The original proposal and experiment

Motivation

- The heavy octupole deformed nuclei ^{225,227}Ac and the strong internal of polar diatomic molecules makes AcF one of the most sensitives probes of the nuclear Schiff moment.
- The production of Ac ion beams (a non-volatile element) can be greatly enhanced using AcF, providing Ac beams to future experiments.
- Isotope shift measurements on AcF will allow a systematic comparison with its atomic counterpart.
- ^{225}Ac is one of the few promising radionuclides for α-therapy, being severely limited by its low production.

[1] Athanasakis-Kaklamanakis, M., et al. No. CERN-INTC-2021-053.

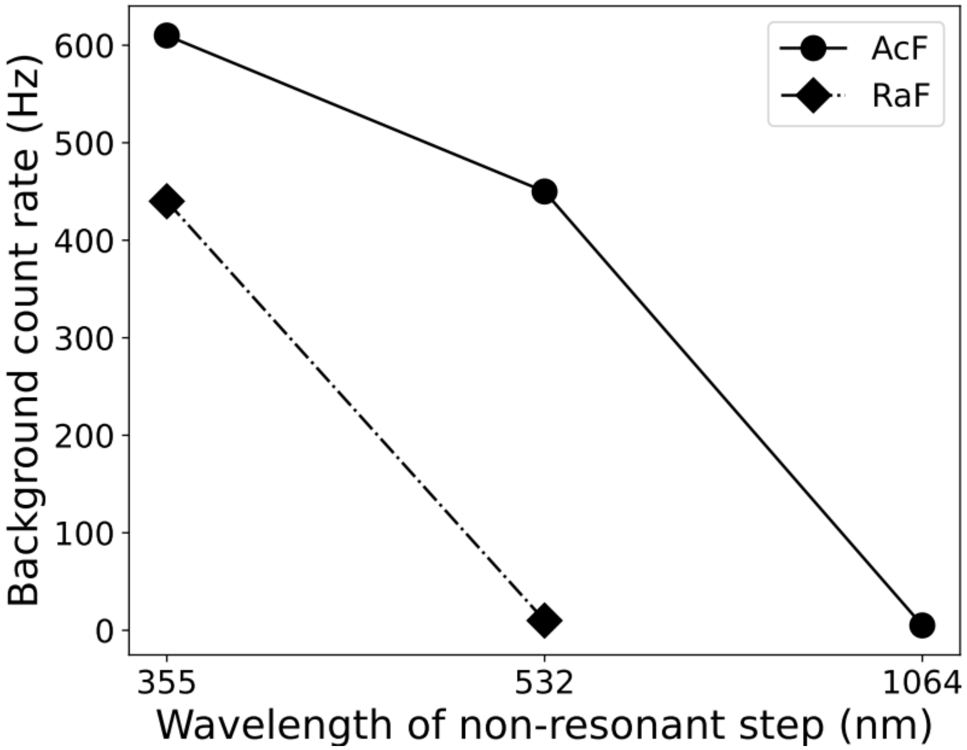
Goals of the experiment (as in 2021 proposal)

- First measurement of an electronic transition in AcF (as no electronic states were known).
- Isotope shift measurements in $^{225\text{-}230}$AcF.
- Ionization potential (IP) and dissociation energy measurements on AcF ➔ require to extract Ac from AcF.

[1] Athanasakis-Kaklamanakis, M., et al. No. CERN-INTC-2021-053.

Summary of the 2021 AcF campaign

- Measurement of the $(8)\Pi_1$ state using a two-step scheme.
- Lifetime measurement of the $(8)\Pi_1$ state.
- Presence of a large non-resonant background ➔ Implies existence of metastable states populated in charge exchange (<532 nm from the IP).



- To avoid the large non-resonant background a three-step scheme using 1064 nm was pursued (800 cm^{-1} already excluded).

[2] Athanasakis-Kaklamanakis, M. (2023). Doctoral dissertation, KU Leuven, Belgium.

Goals of the AcF 2025 campaign.

1. Find a three step-scheme on ^{227}AcF ➔ limiting factor for high resolution and IP search.

2. Measure the ionization potential of ^{227}AcF ➔ current most accurate observable for theory.

3. Measure the $(8)\Pi_1$ state using a three-scheme on ^{225}AcF ➔ viability of the scheme in masses where isobaric contamination is present.

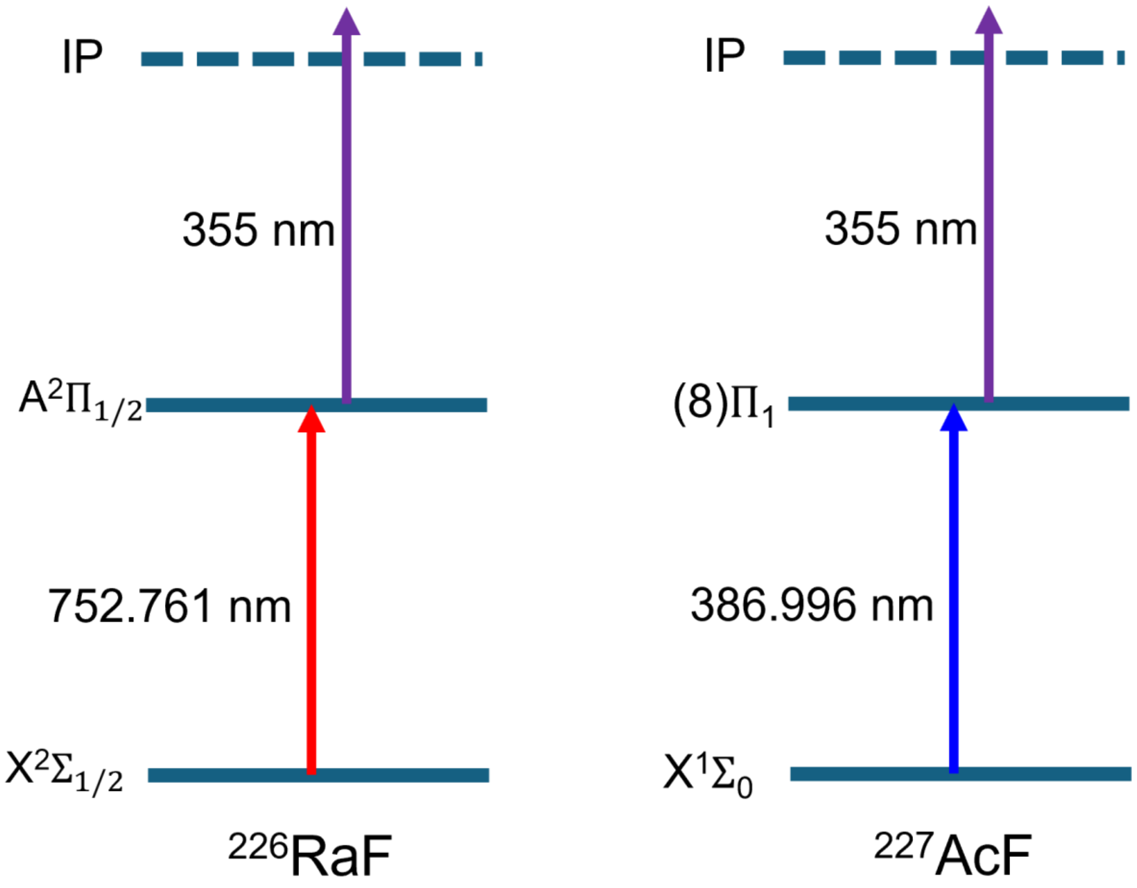
4. Isotope shift of $^{225\text{-}230}$AcF (assuming protons) ➔ comparison between atomic and molecular spectroscopy on Ac.

5. High resolution spectroscopy on AcF (if time allows) ➔ next step for high precision spectroscopy.

Proposed plan

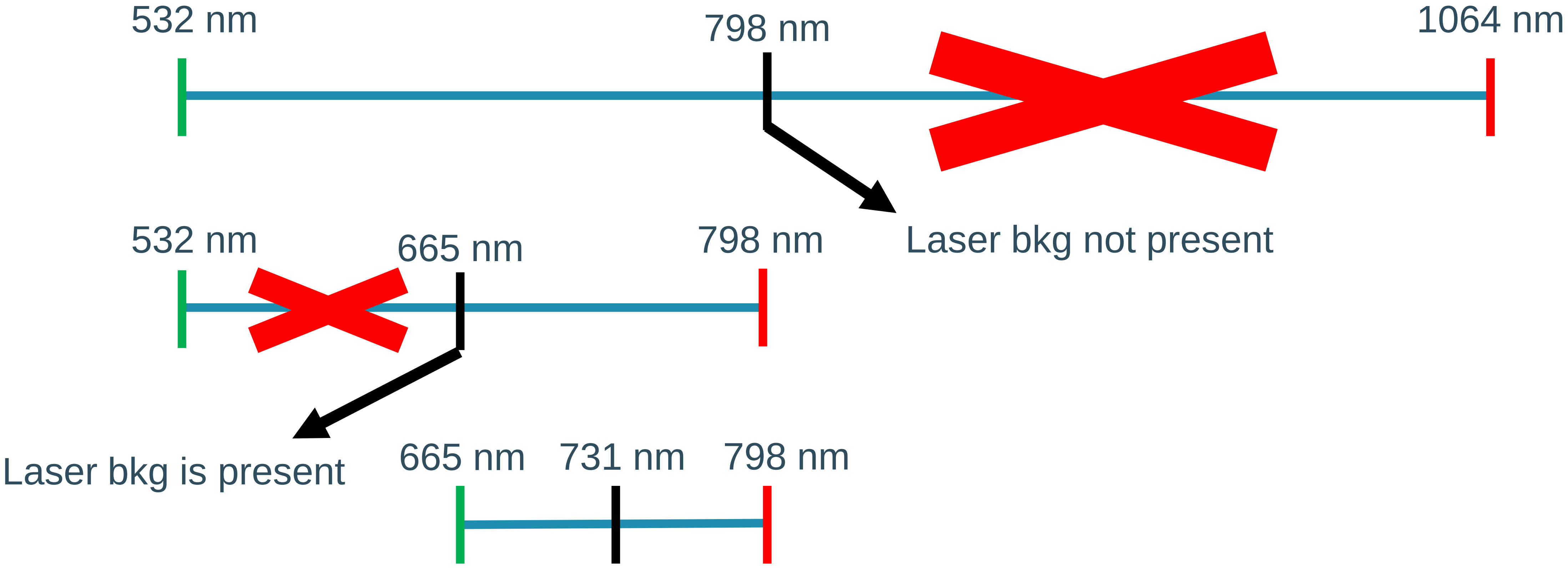
First RIS signal

1. Two step scheme on ^{226}RaF (“surface” and plasma mode) ➔ temperature distribution of the molecules and laser/ion overlap reference.
2. Two step scheme on ^{227}AcF (isobaric pure mass).



Metastable state search

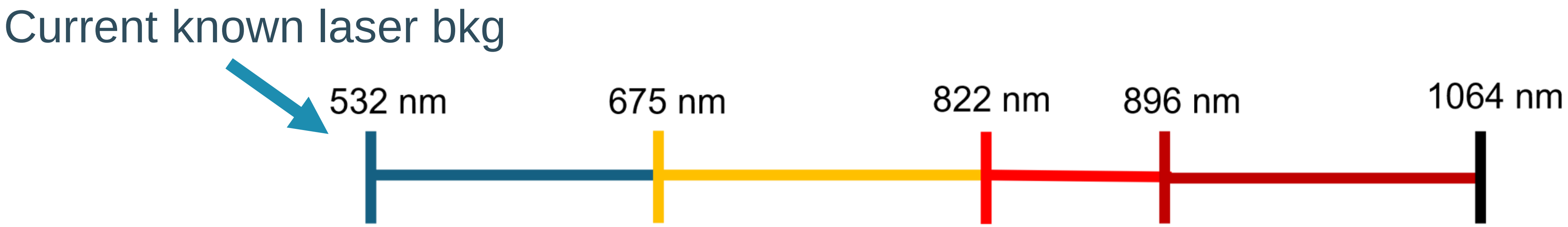
Use a binary search to find the metastable state (search based on eliminating regions where the laser-induced background is not present).



Metastable state search

Use a binary search to find the metastable state (search based on eliminating regions where the laser-induced background is not present).

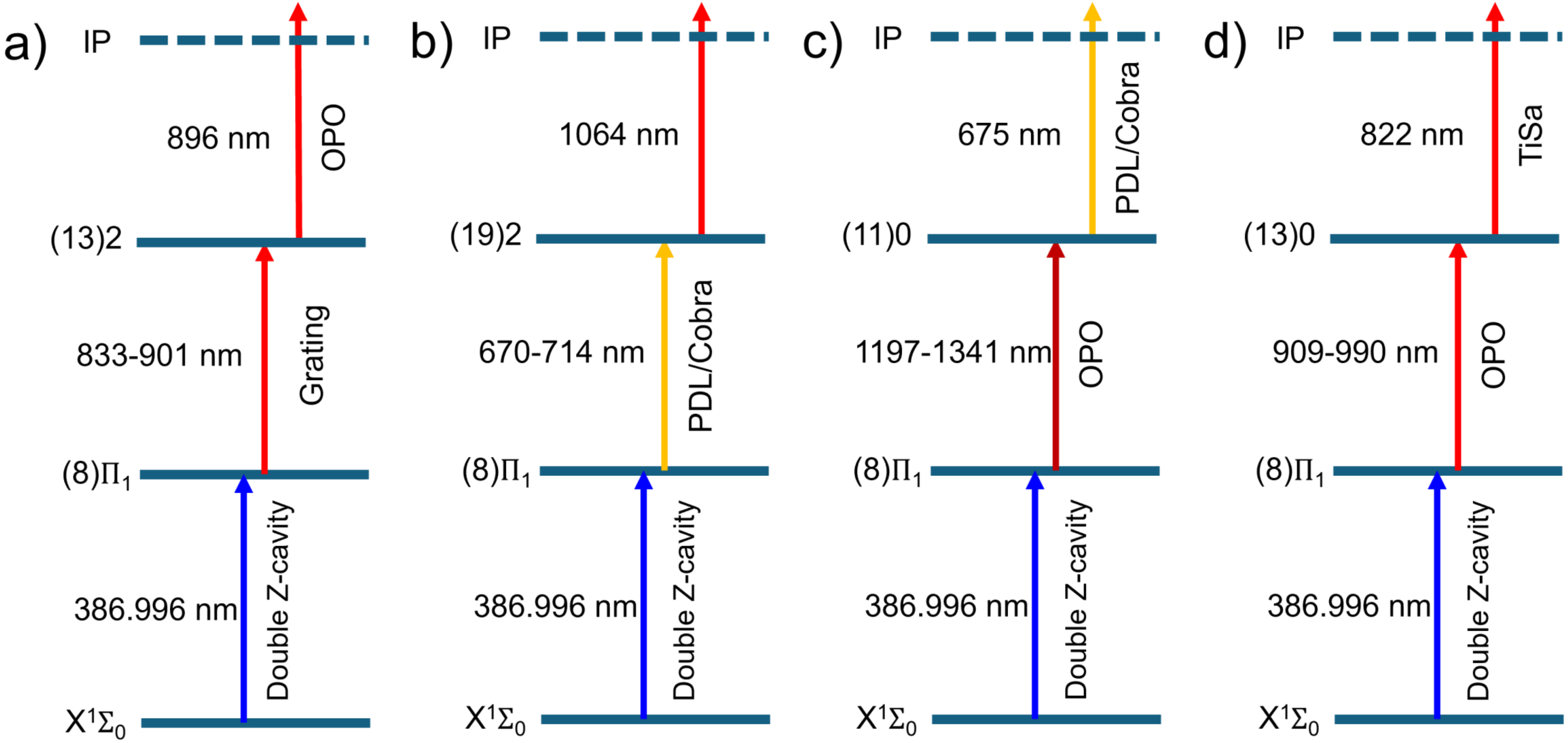
1. Gives an additional spectroscopical information.
2. The relative position of the metastable state would determine the feasibility of alternative schemes three-step schemes.


Current known laser bkg

Non-resonant wavelengths that could be use in a three-step scheme based on the binary search

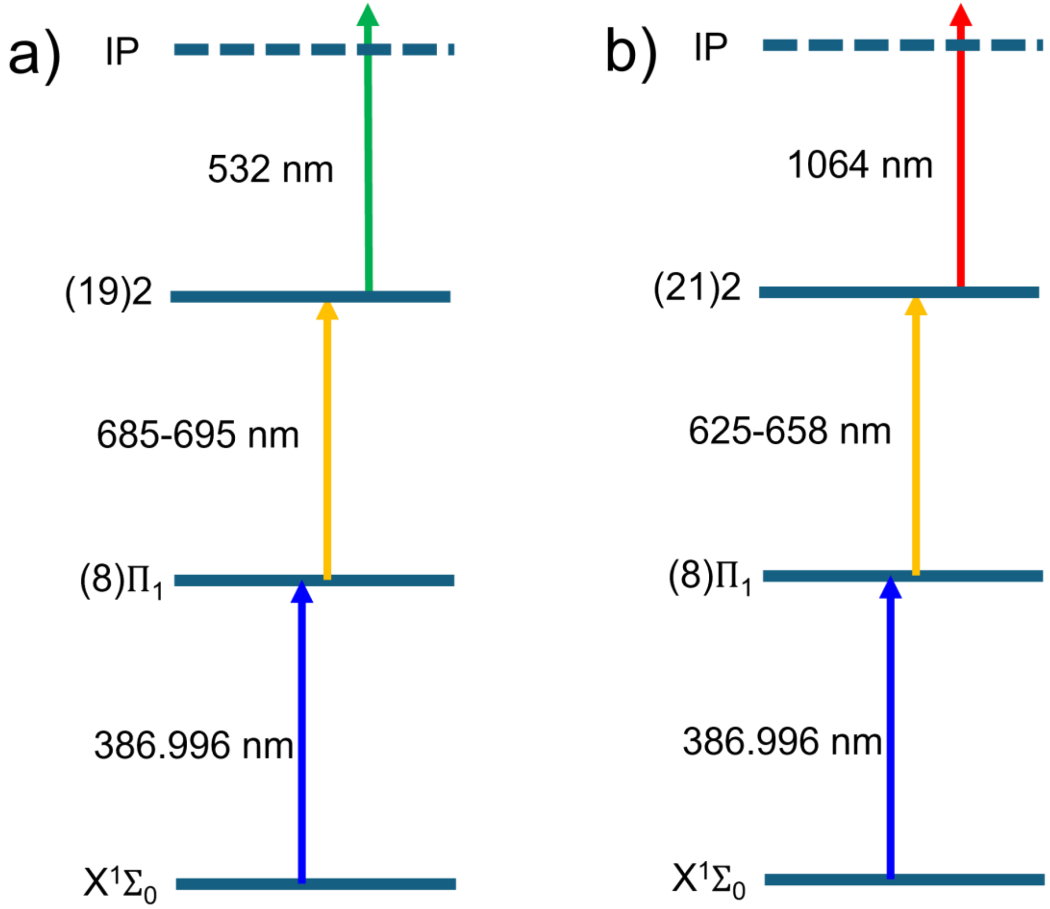
Proposed laser schemes

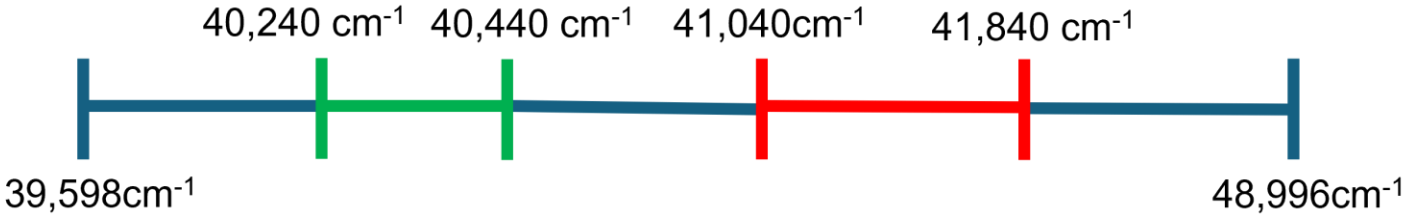
The predicted most intense three step scheme are the following:



Unmeasured region using a three-step

Two three-step scheme were already attempted during the 2022 campaign.

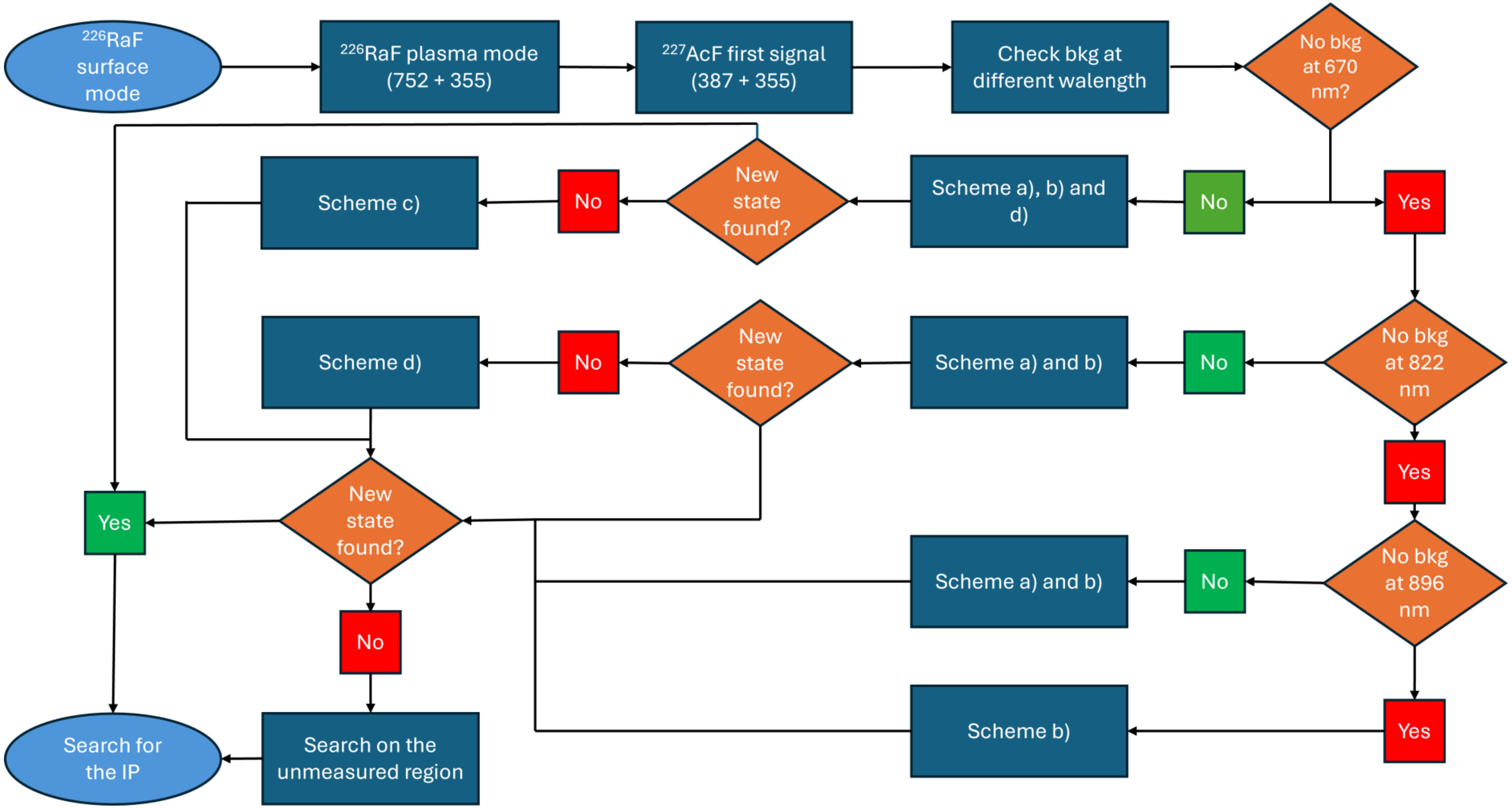




In case all the previous scheme fails, these are the unmeasured regions that would be compatible with a 1064 nm scheme

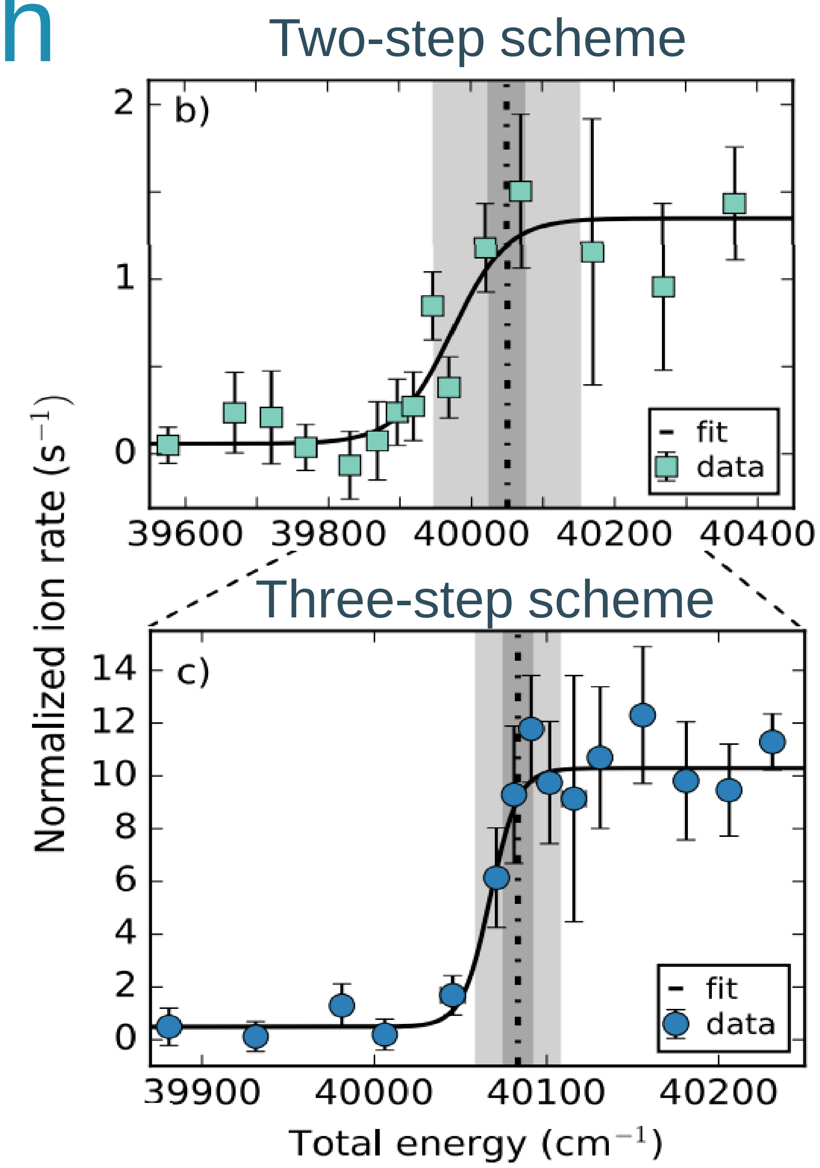
Flowchart for the three-step scheme search

Based on the energy of the metastable state, the search for a three-step scheme is the following.



AcF ionization potential search

- Once a three-step scheme is found, the IP of AcF can be obtained fitting a Sigmoid function of the count rate vs laser wavelength.
- The measurement of the IP has already been attempted with a two-step scheme with no success.
- The search of the IP using the FIU could be attempted, but given the congested Rydberg structure on molecules, its measurement is unlikely.


Two-step scheme

Three-step scheme

[3] Wilkins, S. G., et al. (2024). Ionization potential of radium monofluoride.

$^{224\text{-}231}$AcF measurements

1. Once the IP has been retrieved, re-measure the $(8)\Pi_1$ and newly found state using a three-scheme on ^{227}AcF ➔ comparison to a two-step scheme.

2. Measurement of the on ^{225}AcF (non-pure isobaric mass) ➔ viability of future experiments.

3. Isotope shift measurements on $^{224\text{-}231}$AcF ➔ comparison to the already measured atomic data (winter physics dependent).

4. High resolution spectroscopy on ^{224}AcF $(I = 0)$ or ^{227}AcF $(I = 3/2)$ (if time allows).

Requirements for the experiment.

1. Given the large scanning range required for each laser, position and power stabilization systems are needed.

2. In case scheme b) (using a 1064 non-resonant step) is successful, the measurement of the IP could only be performed using the OPO, meaning that a spectrometer to record the OPO wavelength would be needed.

3. Since some of the schemes would require having more than one broadband TiSa laser, a second scannable TiSa laser would be helpful (upgrade the Z-cavity?).

Thanks for your attention

Backup slides

Rydberg states in molecules

Molecular Rydberg series are divided based on the orbital angular momentum (like in atoms).

However, each member of a given series can be seen as a “normal” electronic state, composed by vibrational and rotational states, creating a considerably congested electronic structure.

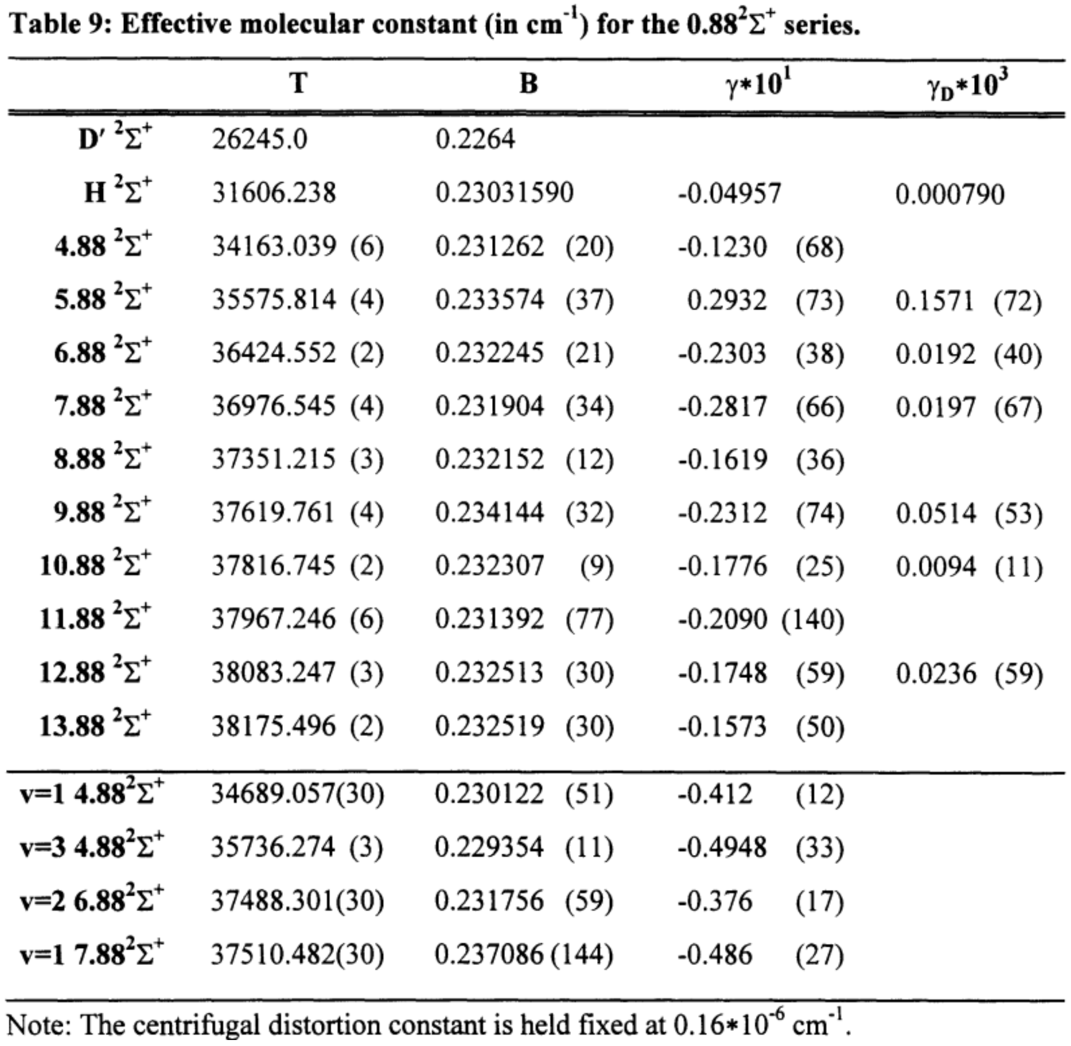


Table 9: Effective molecular constant (in cm^{-1}) for the 0.88$^2\Sigma^+$ series.

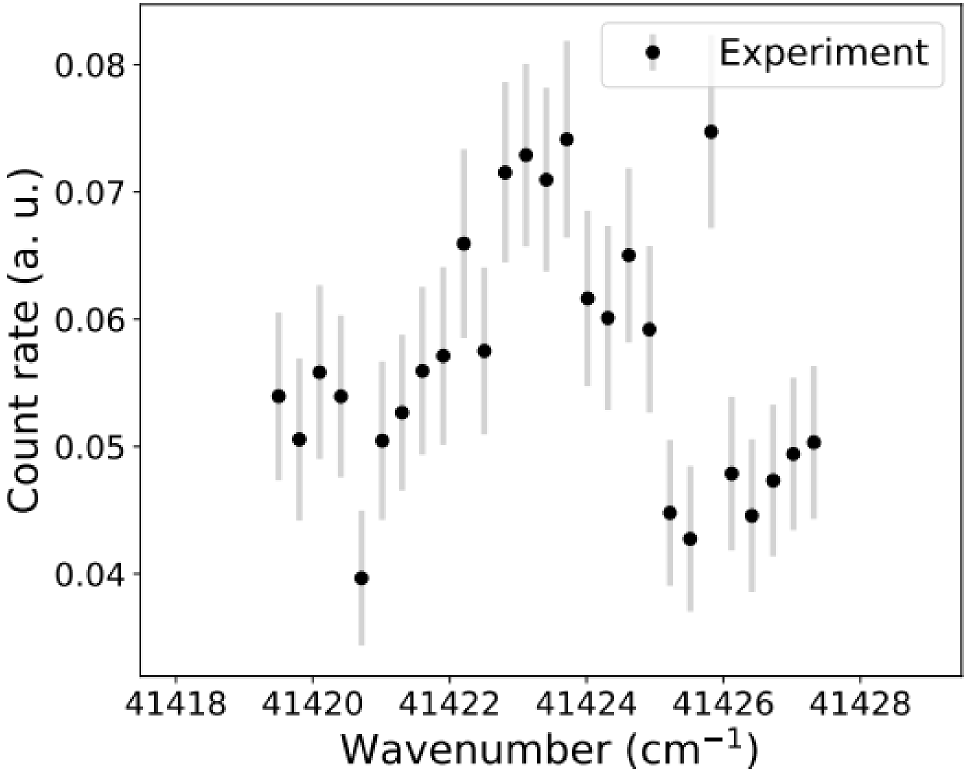
	T	B	$\gamma*10^1$	γ_D*10^3
D′ $^2\Sigma^+$	26245.0	0.2264		
H $^2\Sigma^+$	31606.238	0.23031590	-0.04957	0.000790
4.88 $^2\Sigma^+$	34163.039 (6)	0.231262 (20)	-0.1230 (68)	
5.88 $^2\Sigma^+$	35575.814 (4)	0.233574 (37)	0.2932 (73)	0.1571 (72)
6.88 $^2\Sigma^+$	36424.552 (2)	0.232245 (21)	-0.2303 (38)	0.0192 (40)
7.88 $^2\Sigma^+$	36976.545 (4)	0.231904 (34)	-0.2817 (66)	0.0197 (67)
8.88 $^2\Sigma^+$	37351.215 (3)	0.232152 (12)	-0.1619 (36)	
9.88 $^2\Sigma^+$	37619.761 (4)	0.234144 (32)	-0.2312 (74)	0.0514 (53)
10.88 $^2\Sigma^+$	37816.745 (2)	0.232307 (9)	-0.1776 (25)	0.0094 (11)
11.88 $^2\Sigma^+$	37967.246 (6)	0.231392 (77)	-0.2090 (140)	
12.88 $^2\Sigma^+$	38083.247 (3)	0.232513 (30)	-0.1748 (59)	0.0236 (59)
13.88 $^2\Sigma^+$	38175.496 (2)	0.232519 (30)	-0.1573 (50)	
v=1 4.88$^2\Sigma^+$	34689.057(30)	0.230122 (51)	-0.412 (12)	
v=3 4.88$^2\Sigma^+$	35736.274 (3)	0.229354 (11)	-0.4948 (33)	
v=2 6.88$^2\Sigma^+$	37488.301(30)	0.231756 (59)	-0.376 (17)	
v=1 7.88$^2\Sigma^+$	37510.482(30)	0.237086 (144)	-0.486 (27)	

Note: The centrifugal distortion constant is held fixed at 0.16$*10^{-6}$ cm^{-1}.

[4] Jakubek, Z. J. (1995). Doctoral dissertation, MIT, USA.

A suspect peak from 2022

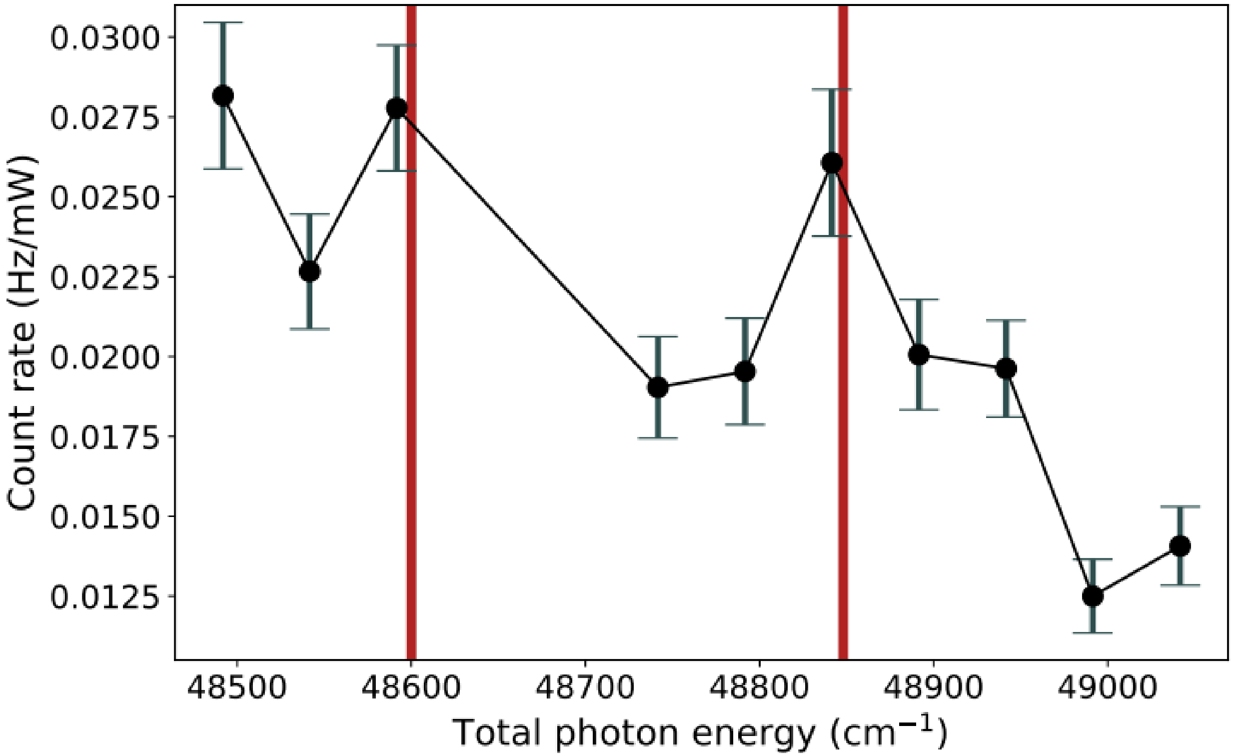
From the data set taken on 2022, a small RIS seem to have been overserved at around 41,423 cm-1. However, the recorded data is not enough to clearly resolve a peak. The remeasurement of this peak would be attempted.



[2] Athanasakis-Kaklamanakis, M. (2023). Doctoral dissertation, KU Leuven, Belgium.

Two-step scheme search in 2022

The measurement of AcF IP was attempted using a double TiSa scheme with no success.



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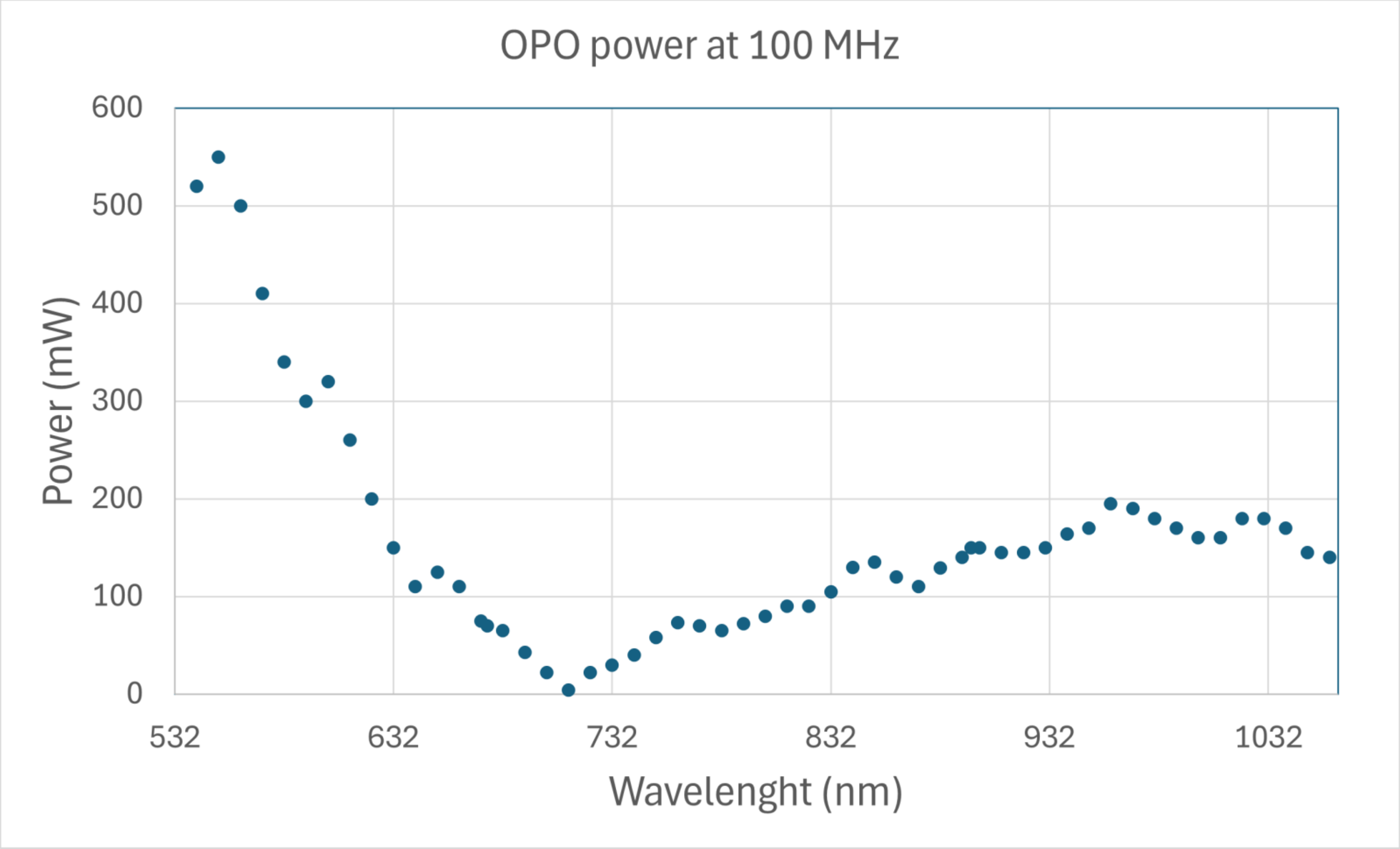
OPO laser power at 100Hz



Wavelength (nm)	Power (mW)
672	75
682	65
692	43
702	22
712	4
722	22
732	30
742	40
752	58
762	73
772	70