

# Precision Measurement of the Ionization Energy of the $GK\ ^1\Sigma_g^+$ ( $v = 1, N = 1$ ) State of Molecular Hydrogen.

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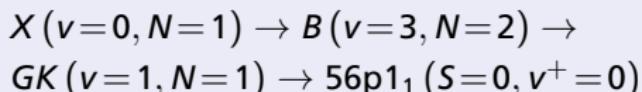
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D. Sprecher, M. Beyer, and F. Merkt, *Mol. Phys.*, in press.

# Ionization Energy of Molecular Hydrogen: Step by Step

## Divide And Measure

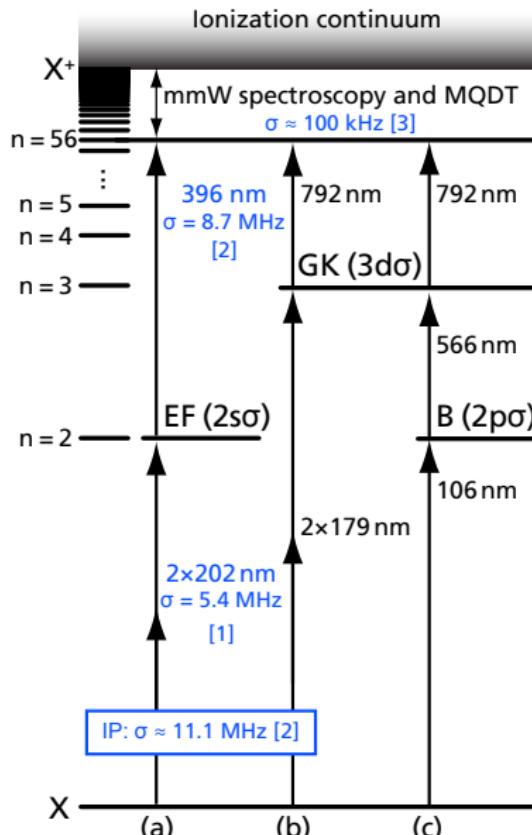
- ▶  $X \rightarrow \text{low-}n$  interval
- ▶  $\text{low-}n \rightarrow \text{high-}n$  interval
  - efficient population of the low- $n$  state
  - transition frequency accessible with Ti:Sa system
- ▶  $\text{high-}n \rightarrow X^+$  interval
  - least perturbed Rydberg series to facilitate highly accurate MQDT calculations



[1] S. Hannemann et al., Phys. Rev. A, **74**, 062514 (2006).

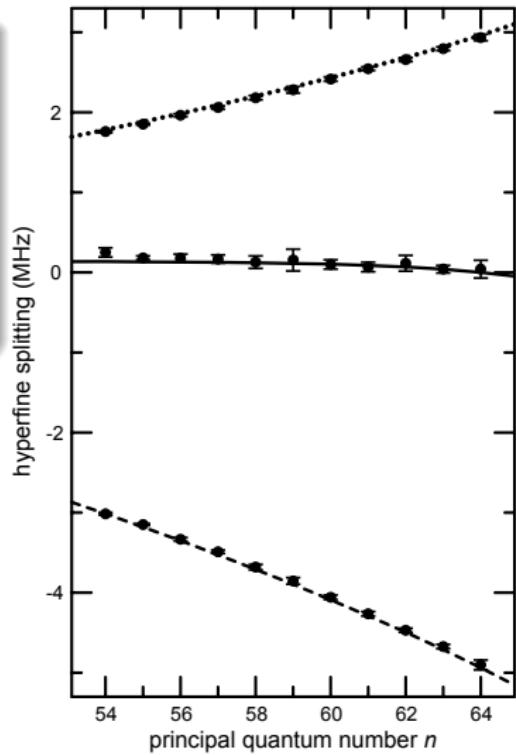
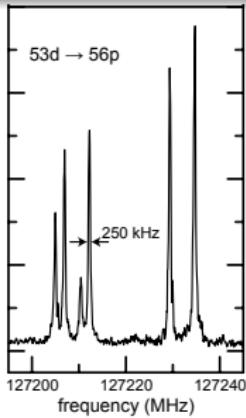
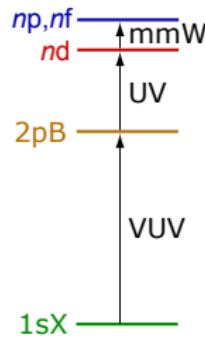
[2] J. Liu et al., J. Chem. Phys. **130**, 174306 (2009).

[3] D. Sprecher et al., Faraday Discuss. **150**, 51 (2011).



# Multichannel quantum defect theory (MQDT) treatment

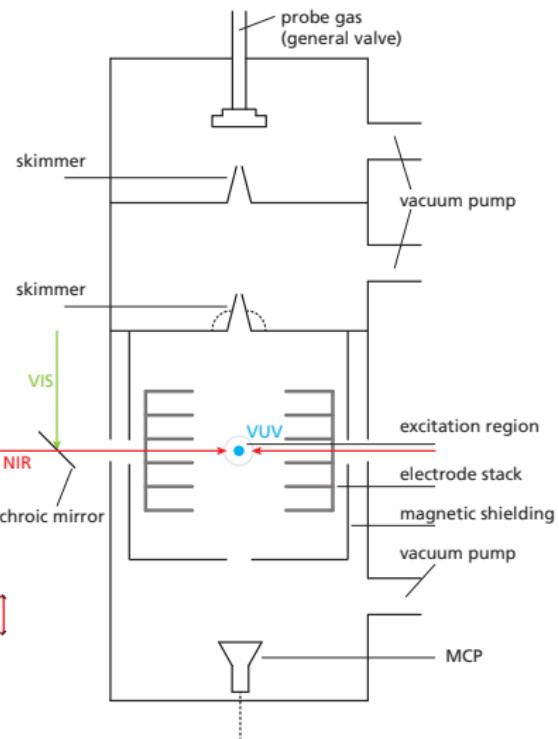
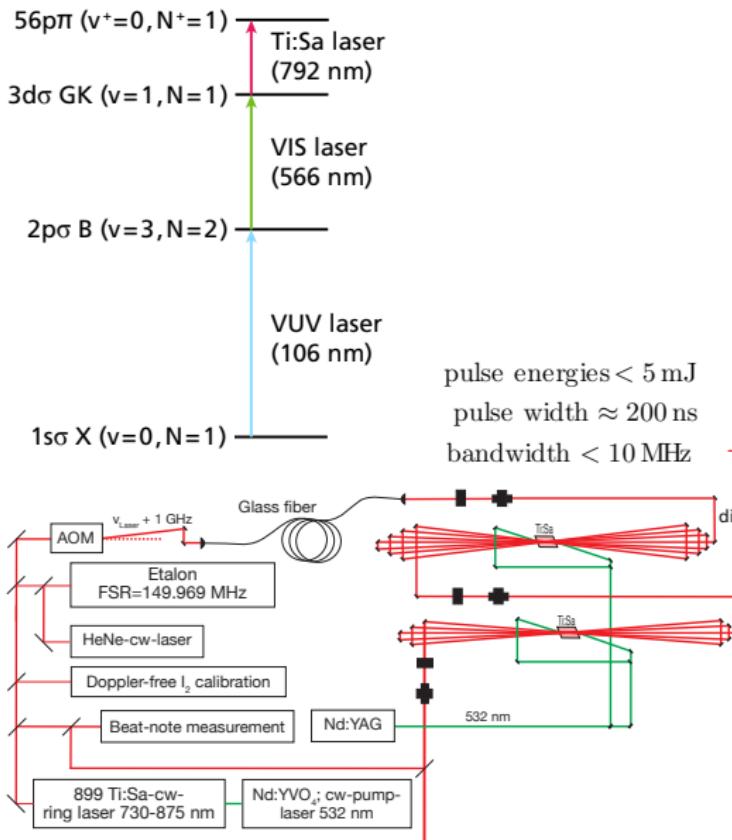
- ▶ "Least perturbed" Rydberg series in o-H<sub>2</sub>:  $np1_1(S=0, v^+=0)$ .
- ▶ Use mmW-Spectra to refine *ab initio* quantum defects [1].
- ▶ Prediction uncertainties for binding energies (54–64p1<sub>1</sub>):  $\approx 100$  kHz [2].



[1] A. Osterwalder et al., J. Chem. Phys. **121**, 11810 (2004).

[2] D. Sprecher et al., Faraday Discuss. **150**, 51 (2011).

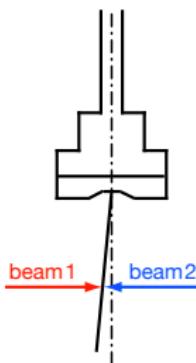
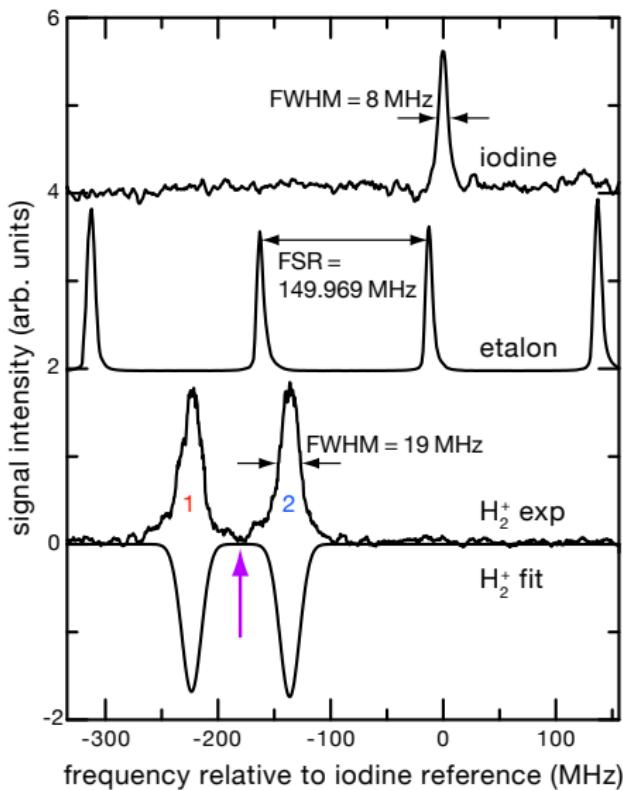
# Experimental Setup



R. Seiler, Th. Paul, M. Andrist and F. Merkt, *Rev. Sci. Instr.* **76**, 103103 (2005).

# Results

Observed Spectra:  $GK (v=1, N=1) \rightarrow 56p1_1 (S=0, v^+=0)$



## Quantification of Systematic Errors

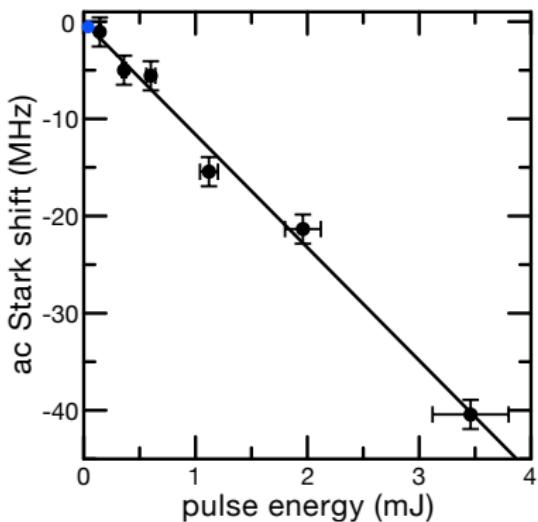
- ▶ ac Stark shift (Ti:Sa laser)
- ▶ dc Stark shift (stray fields)
- ▶ Frequency shift (Ti:Sa laser)

# Results

## Quantification of Systematic Errors: ac and dc Stark Shifts

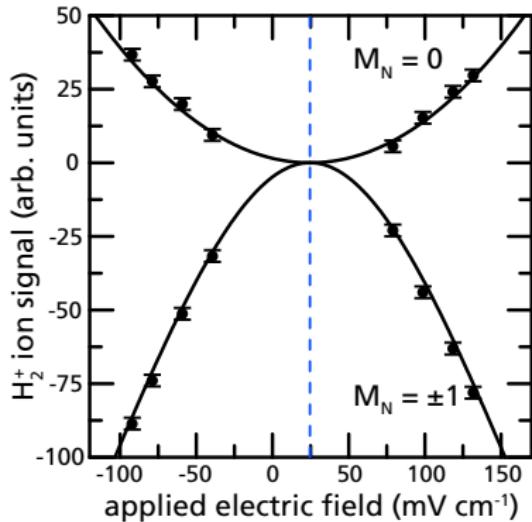
### ac Stark Shift

Using  $\approx 40 \mu\text{J} \Rightarrow -0.4(6) \text{ MHz}$



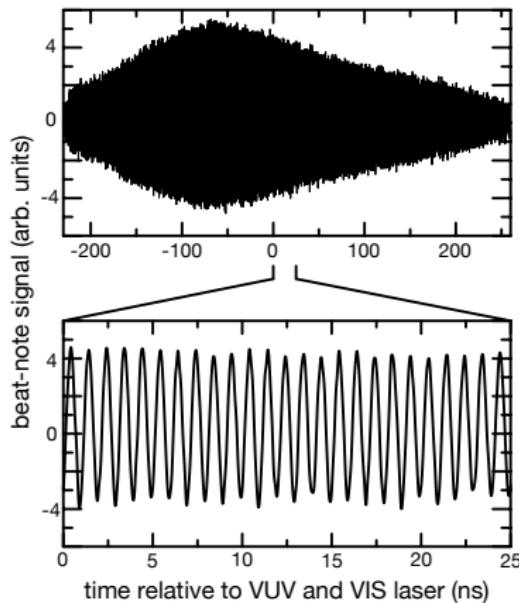
### dc Stark Shift

Compensate electric stray fields to less than  $0.6 \text{ mV/cm} \Rightarrow 0.0(1) \text{ MHz}$



# Results

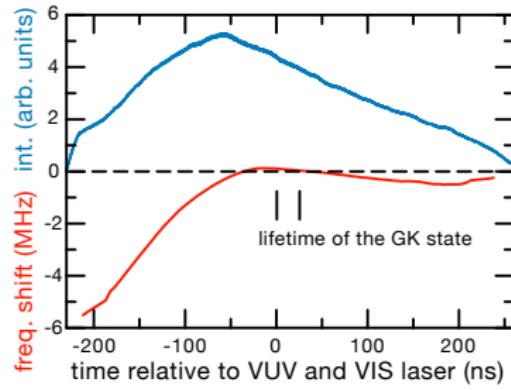
## Quantification of Systematic Errors: Frequency Shift and Chirp Resulting From the Pulsed Amplification in Ti:Sa



### Frequency shift and chirp

Caused by time-dependent changes of the refractive index of the Ti:Sa crystals during amplification

$$\Rightarrow 0.0(5) \text{ MHz}$$



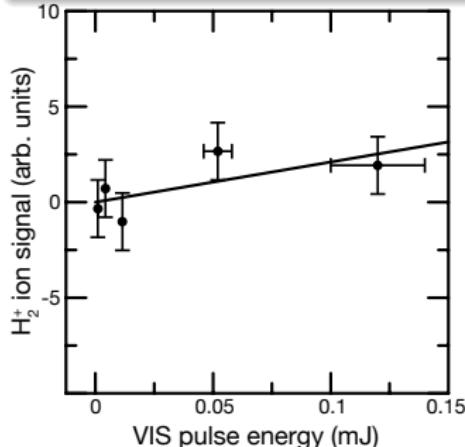
# Results

## Quantification of Systematic Errors: Ion Induced Frequency Shift | Statistics

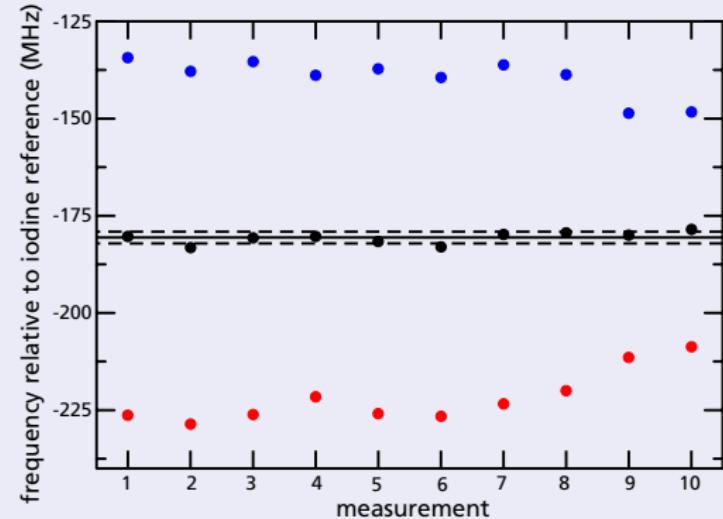
Stark shift caused by ions in the excitation volume

Ions produced by photoionization of the *GK* state.

Using  $\approx 8 \mu\text{J} \Rightarrow 0.0(5) \text{ MHz}$



## Statistics



# Results

Transition Frequency:  $GK(v=1, N=1) \rightarrow 56p1_1(S=0, v^+=0)$

	Shift (MHz)	Uncertainty (MHz)
Transition frequency relative to the $I_2$ reference line	-180.8	0.6
Position of the $I_2$ reference line [1]	378808699.1	< 0.3
Shift by systematic errors	0.4	0.9
Shift by AOM's	-960	< 0.1
Total	378809478.7	1.2

[1] H. Knöckel, B. Bodermann and E. Tiemann, *Software IodineSpec 5* (2008).

# Results

## Term Value and Ionization Energy of the $GK(v=1, N=1)$ State

Label	Energy interval	Frequency / MHz	Wave number / $\text{cm}^{-1}$	Reference
(1)	$GK(v=1, N=1) - 56p_1(v^+=0, S=0)$	378809478.7(12)	12635.72410(4)	This work
(2)	$56p_1(v^+=0, S=0) - X^+(v^+=0, N^+=1)$	1045709.62(10)	34.881118(3)	[1]
(3)*	$GK(v=1, N=1) - X^+(v^+=0, N^+=1)$	379855188.3(12)	12670.60522(4)	This work
(4)	$X(v=0, N=0) - X(v=0, N=1)$	3552146(3)	118.48684(10)	[2]
(5)	$X(v=0, N=1) - X^+(v^+=0, N^+=1)$	3728136204(11)	124357.23797(36)	[3]
(6)†	$X(v=0, N=0) - GK(v=1, N=1)$	3351833162(12)	111805.1196(4) 111805.1101(10) 111805.139(17)	This work [4] [5]

\* Ionization energy of the  $GK(v=1, N=1)$  state, determined as (1) + (2).

† Term value of the  $GK(v=1, N=1)$  state, determined as (4) + (5) - (3).

[1] D. Sprecher, Ch. Jungen, W. Ubachs and F. Merkt, Faraday Discuss. **150**, 51 (2011).

[2] D.E. Jennings, A. Weber and J.W. Brault, J. Mol. Spectrosc. **126**, 19 (1987).

[3] J. Liu, E.J. Salumbides, U. Hollenstein, J.C.J. Koelemeij, K.S.E. Eikema, W. Ubachs and F. Merkt, J. Chem. Phys. **130**, 174306 (2009).

[4] D. Bailly, E.J. Salumbides, M. Vervloet and W. Ubachs, Mol. Phys. **108**, 827 (2010).

[5] Ch. Jungen, I. Dabrowski, G. Herzberg and M. Vervloet, J. Chem. Phys. **93**, 2289 (1990).

# Conclusions and Outlook

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- ▶ Measure  $GK$  term value
- ▶ New measurement: EF → high- $n$  interval by stimulated emission

## Acknowledgements

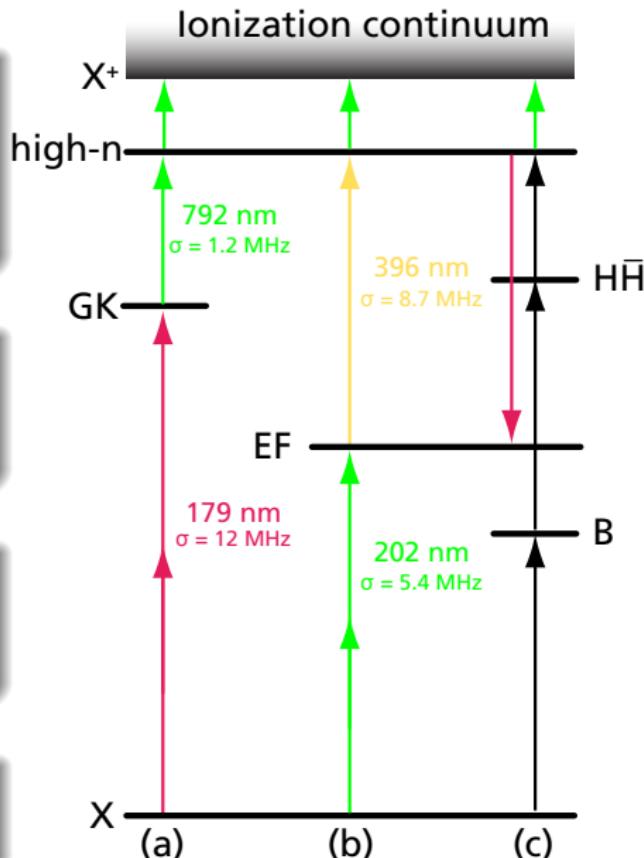
- ▶ Hansjürg Schmutz
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## Collaborators

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- ▶ Christian Jungen

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