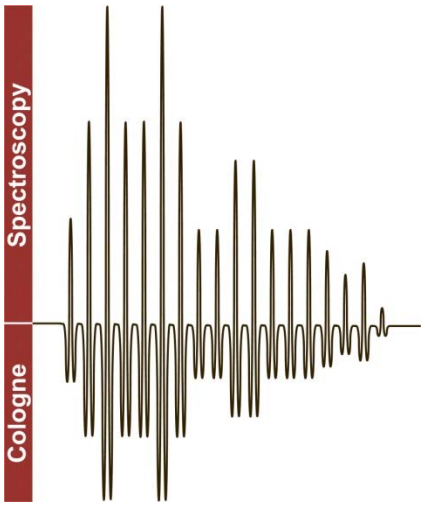
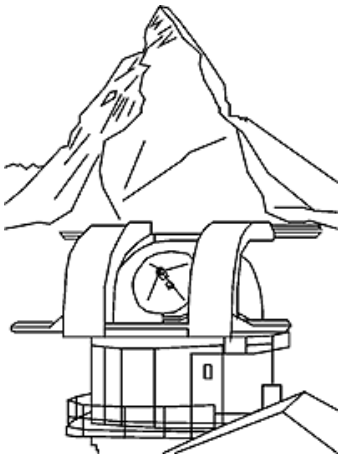


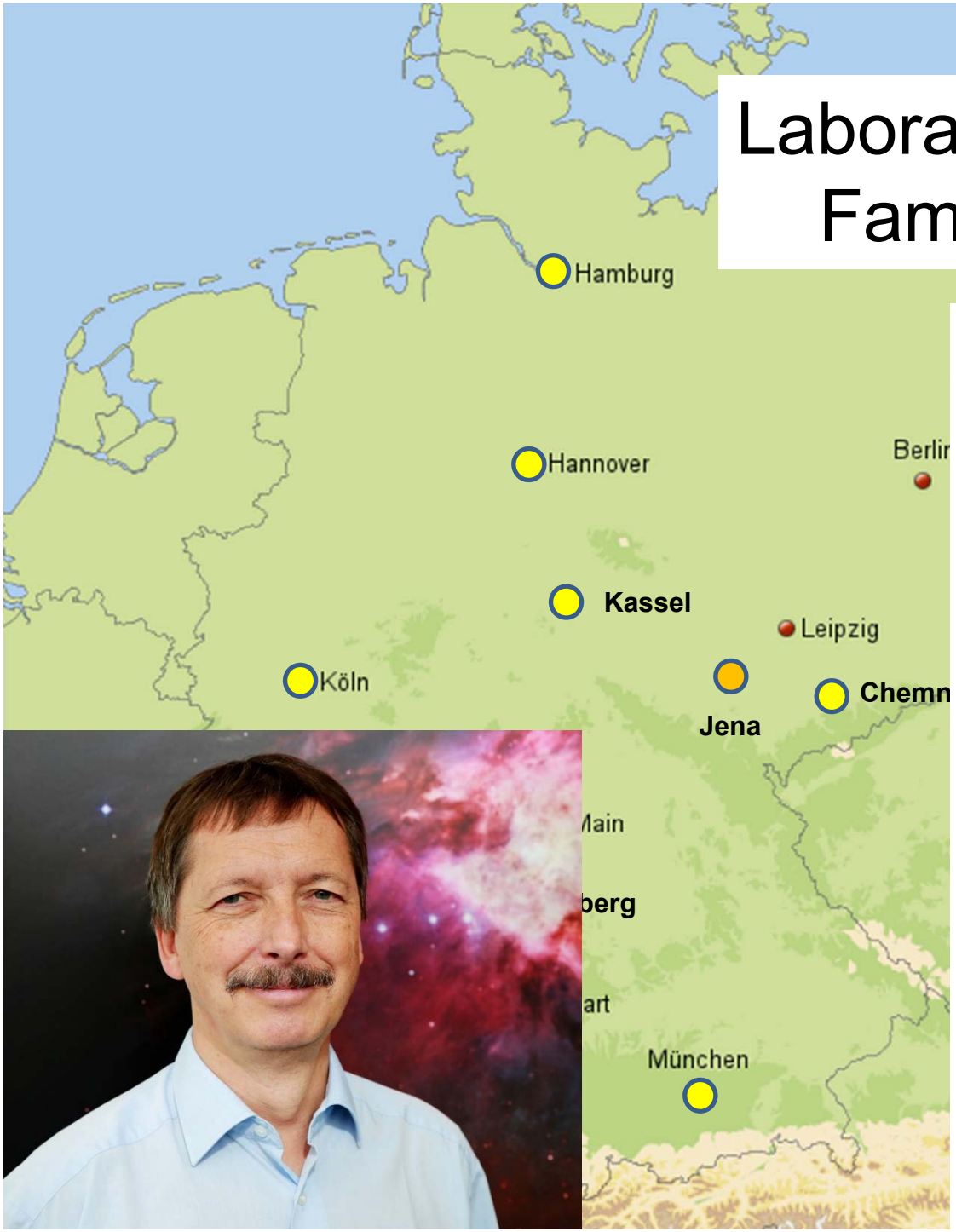
Missing Ions in Laboratory and Space

Stephan Schlemmer
I. Physikalisches Institut,
Universität zu Köln



- Laborastrophysics in Germany & Thomas Henning
- Ion Chemistry in Space & Dieter Gerlich
- Ion Spectroscopy & Cologne

Laboratory Astrophysics Family in Germany



DFG:

1995 - 2001
Priority Program:
Physics of Star Formation

1999-2005 FGLA
(Chemnitz – Jena)

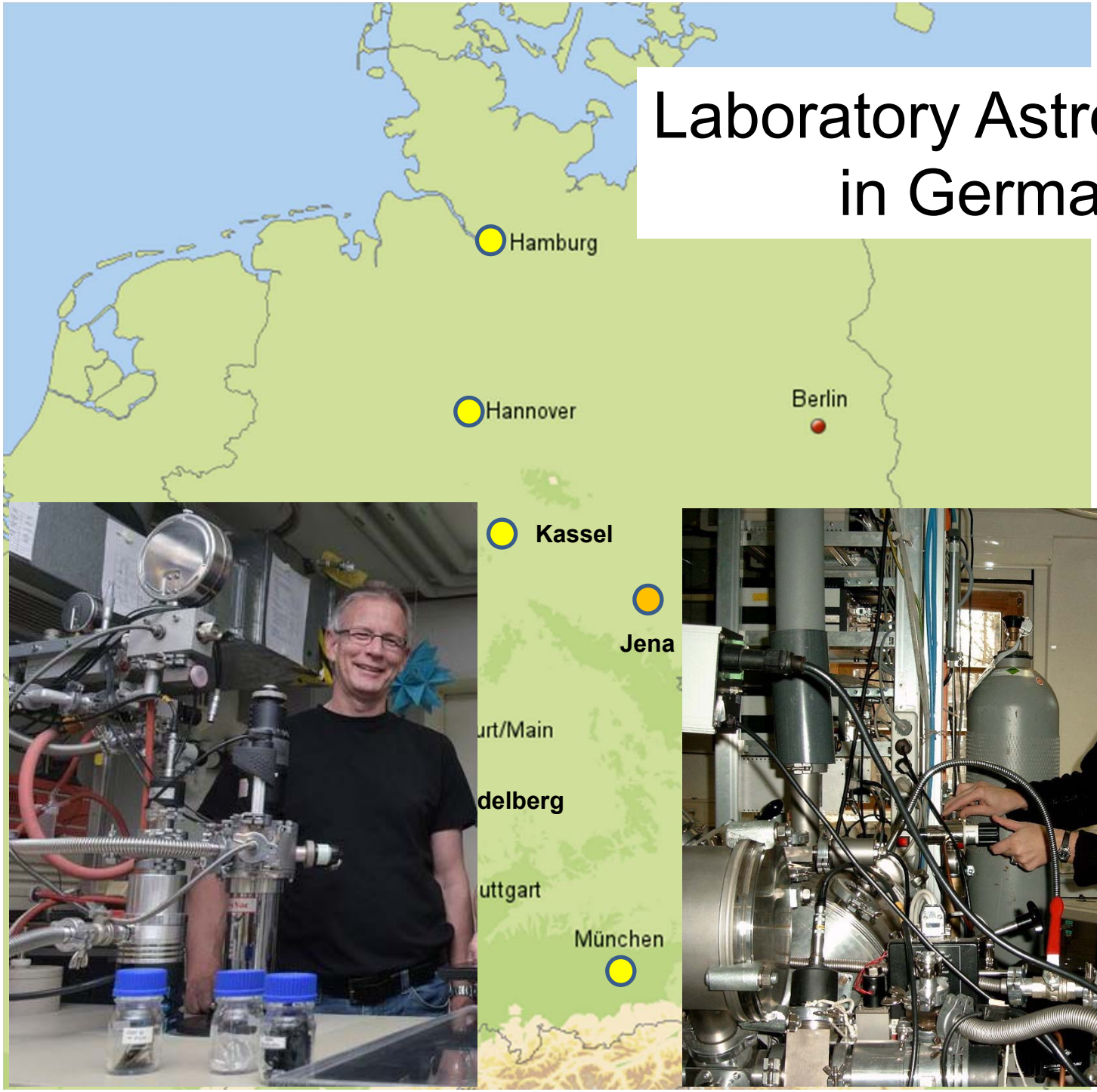
2011- SFB956 (Cologne)

2012-2017
Priority Program:
Physics of the ISM

2023- SFB1601 (Cologne)

Laboratory Astrophysics in Germany

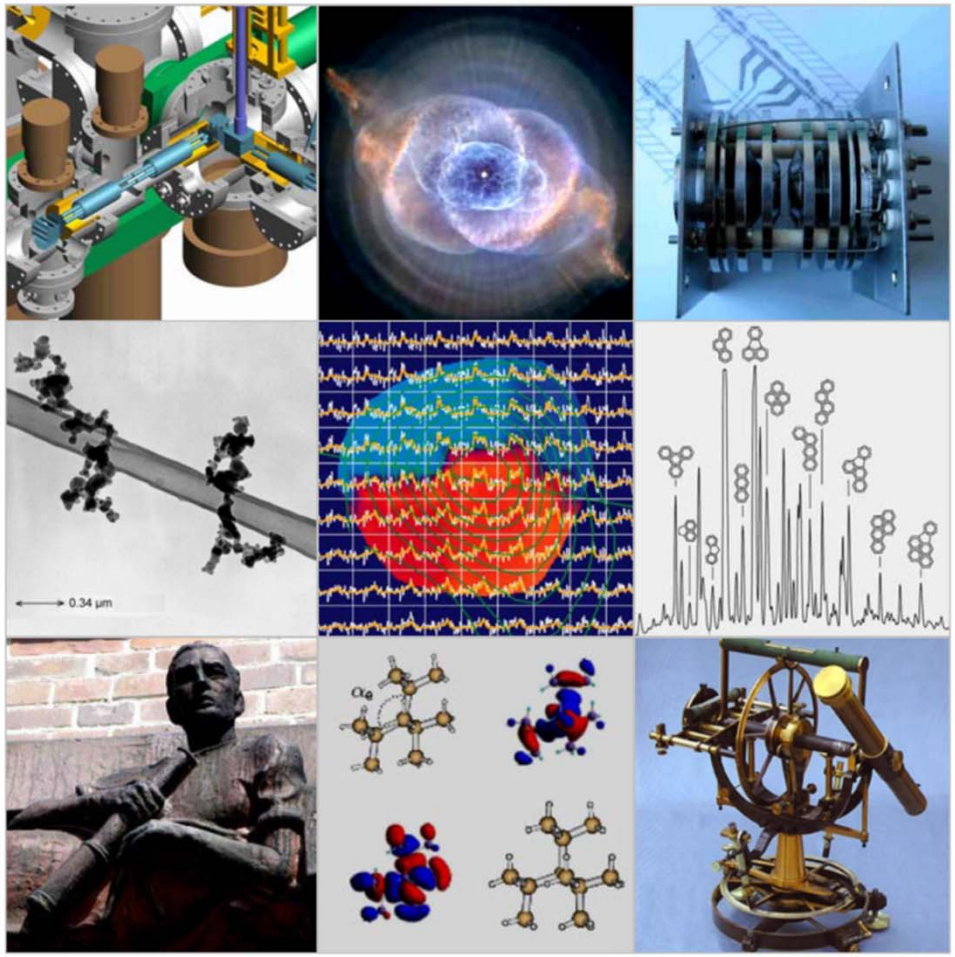
Laboratory Astrophysics in Germany



TU Chemnitz

Laboratory Astrophysics

FSU Jena



DFG-Forschergruppe 388, Report 2003 - 2006

Dieter Gerlich and Thomas Henning

TU Chemnitz

FSU Jena

Structure, Dynamics and Properties of Molecules and Grains in Space

FOR 388
Report 2003 - 2006

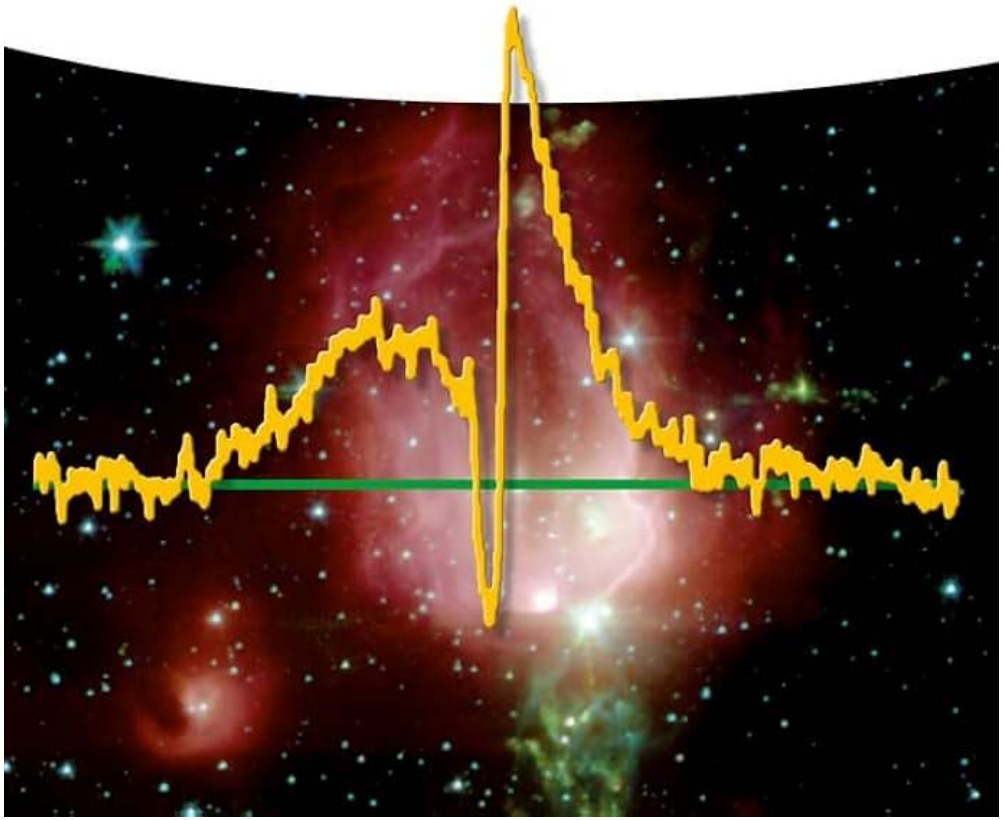
Dieter Gerlich and Thomas Henning

WILEY-VCH

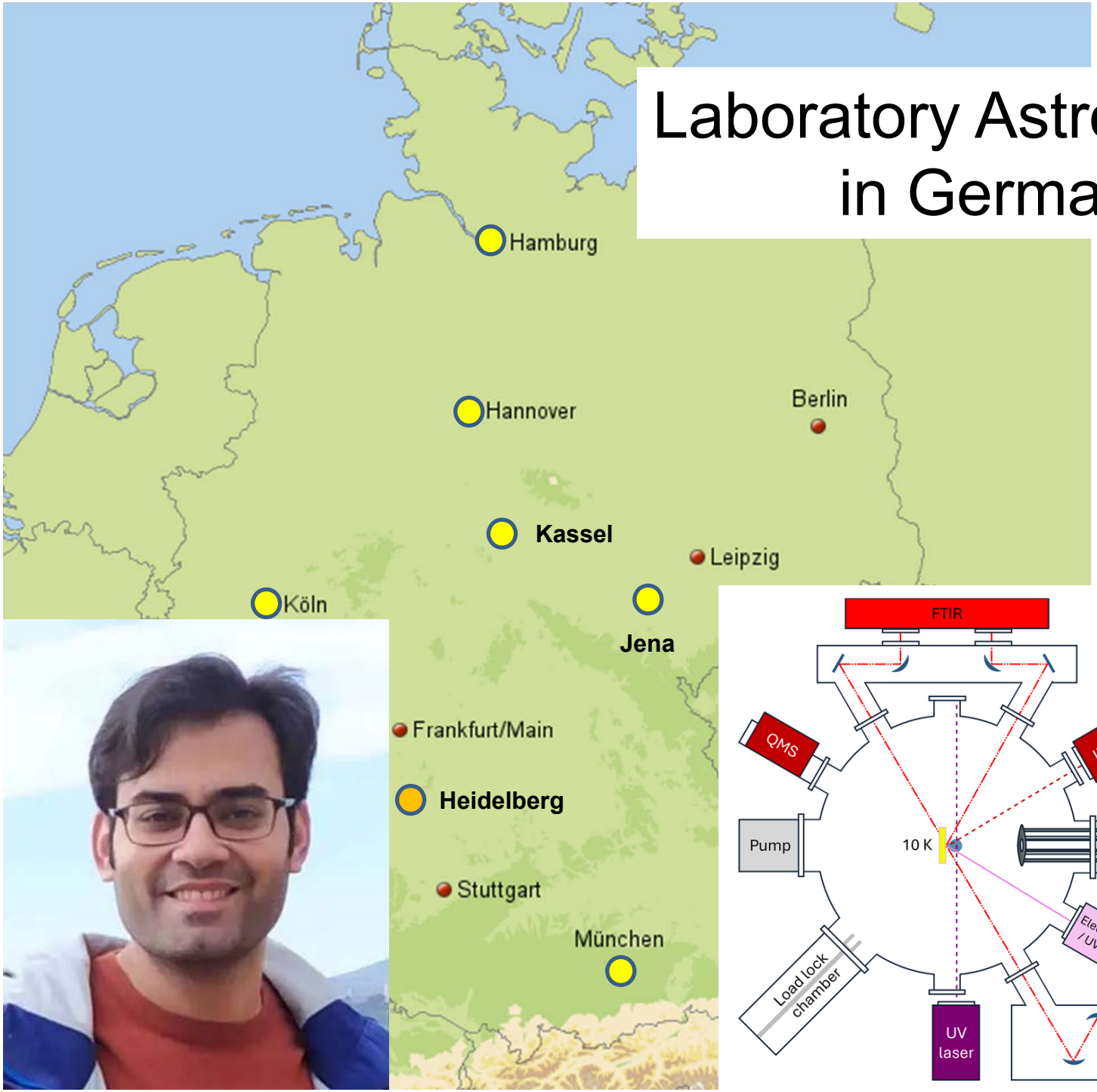
Edited by
S. Schlemmer, T. Giesen, H. Mutschke, and C. Jäger

Laboratory Astrochemistry

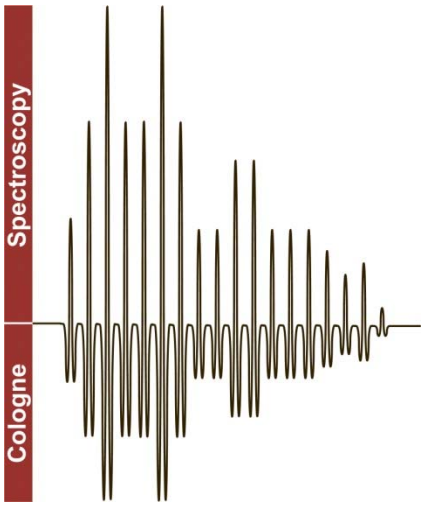
From Molecules through Nanoparticles to Grains



Laboratory Astrophysics in Germany



Spectroscopy Lab



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I. Physikalisches Institut,
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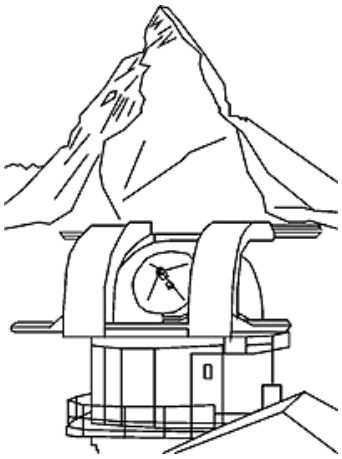
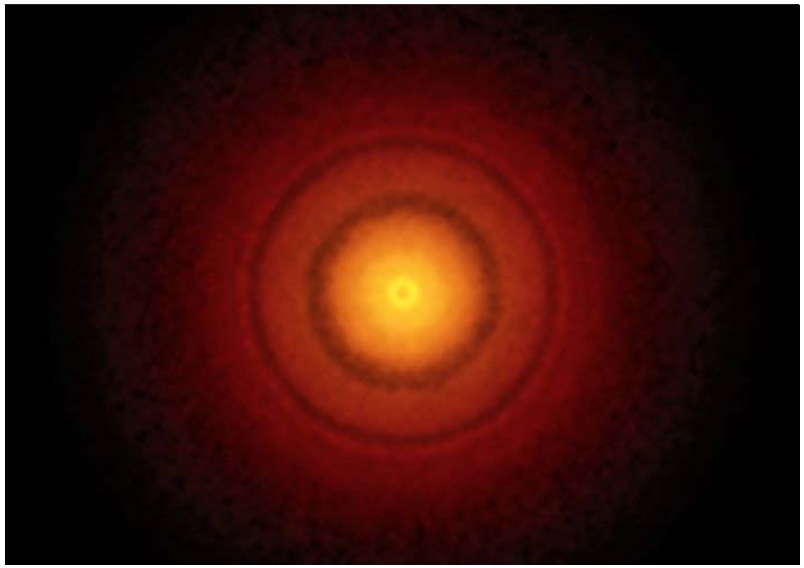
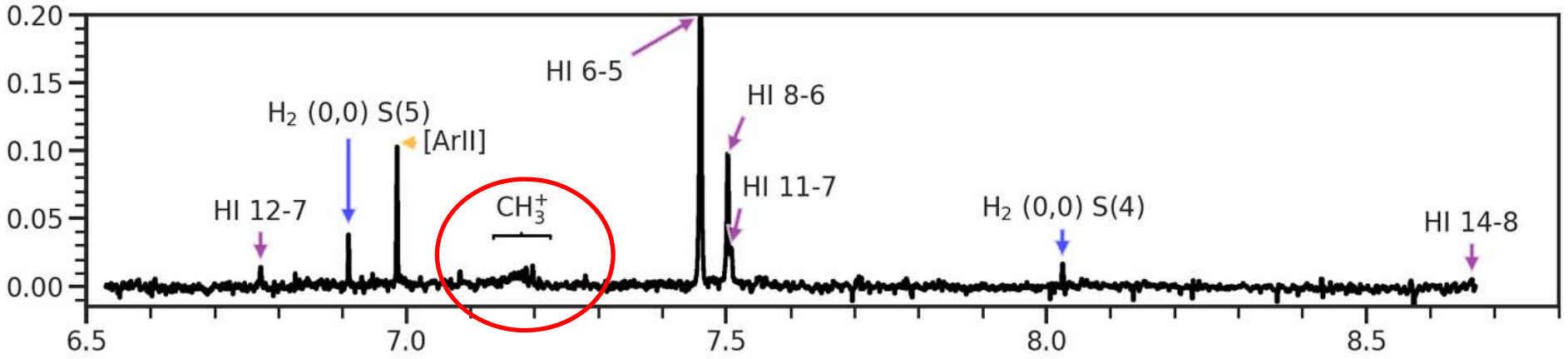


- Laborastrophysics in Germany & Thomas Henning
- Ion Chemistry in Space & Dieter Gerlich
- Ion Spectroscopy & Cologne

Publications of the Astronomical Society of the Pacific, 136:054302 (19pp), 2024 May

MINDS: The JWST MIRI Mid-INfrared Disk Survey

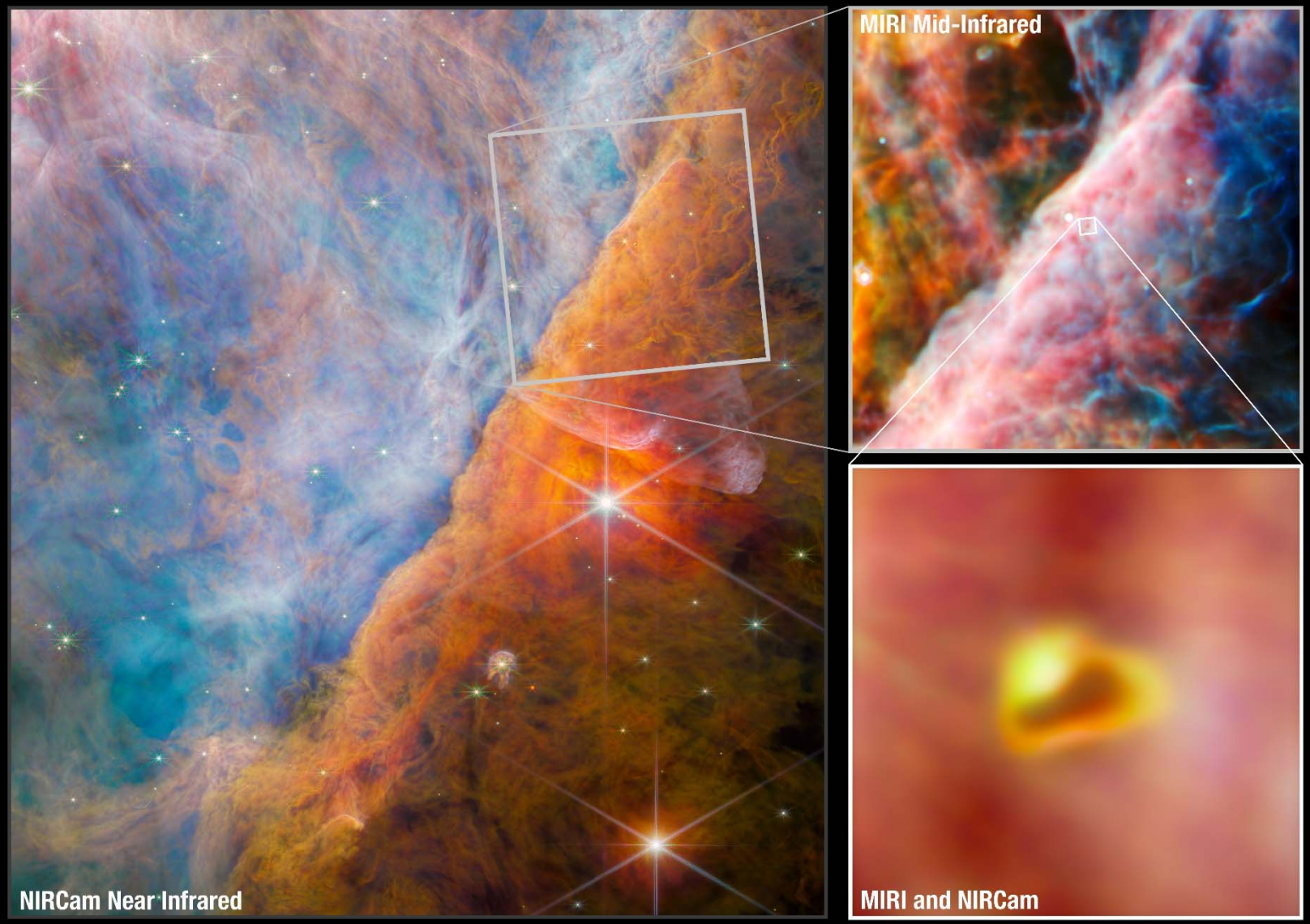




TW Hya MIRI spectrum: Ions appear like in PDRs…

James Webb Space Telescope (JWST): Orion bar Photon Dominated Region (PDR)

Formation of the Methyl Cation by Photochemistry in a Protoplanetary Disk
O. Berne, M.A. Martin Drumel, I. Schroetter, et al., Nature, , **621**, 56–59 (2023)



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Olivier Berne, Marie-Aline Martin Drumel et al.,
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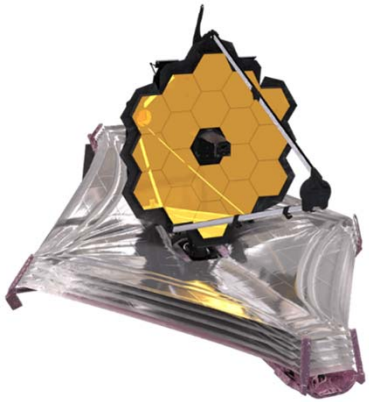
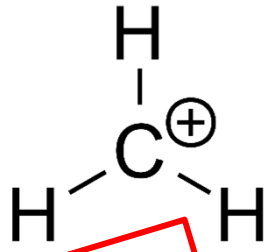
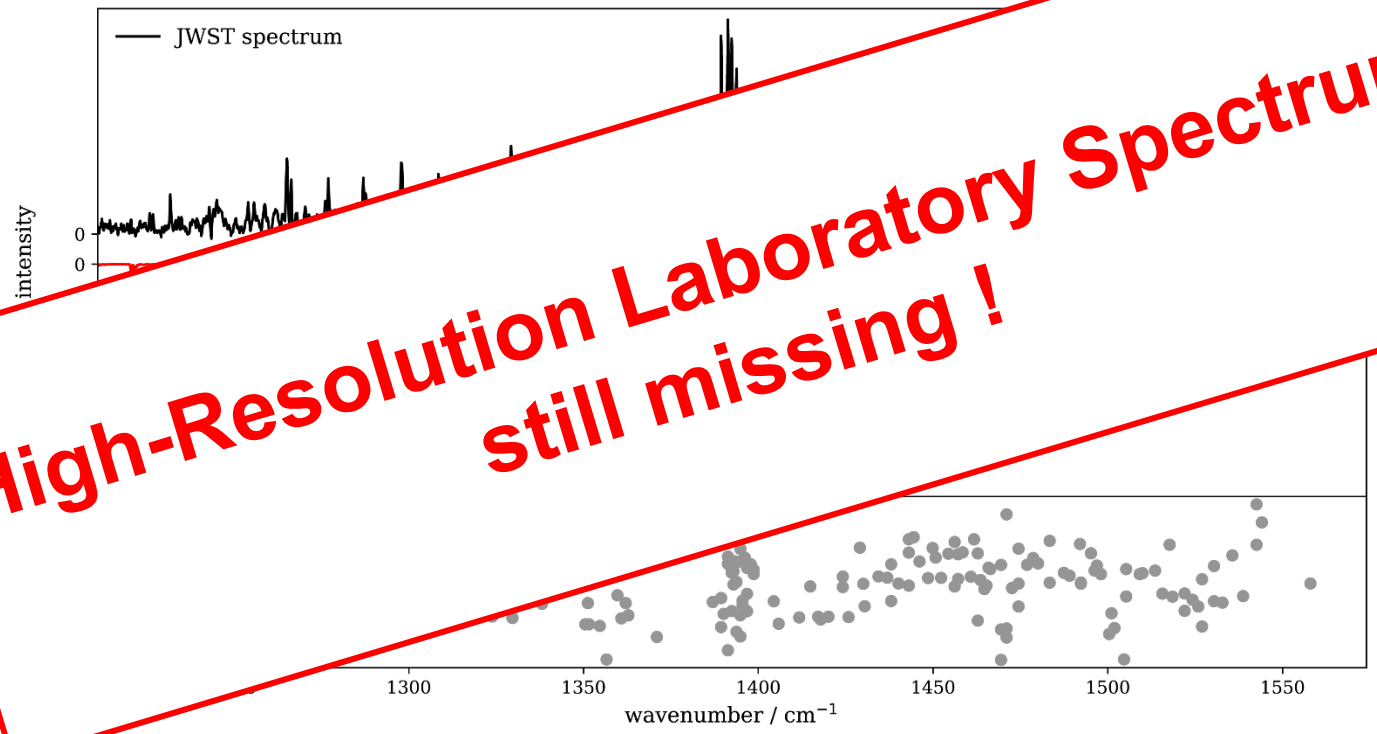


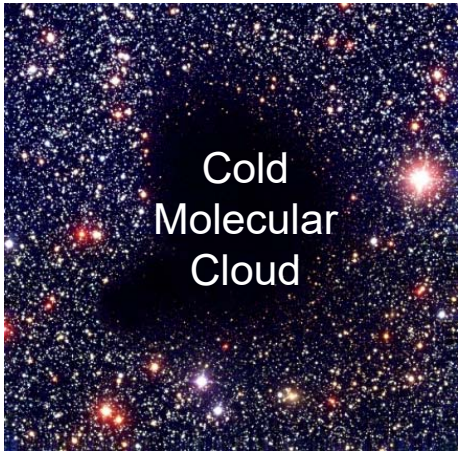


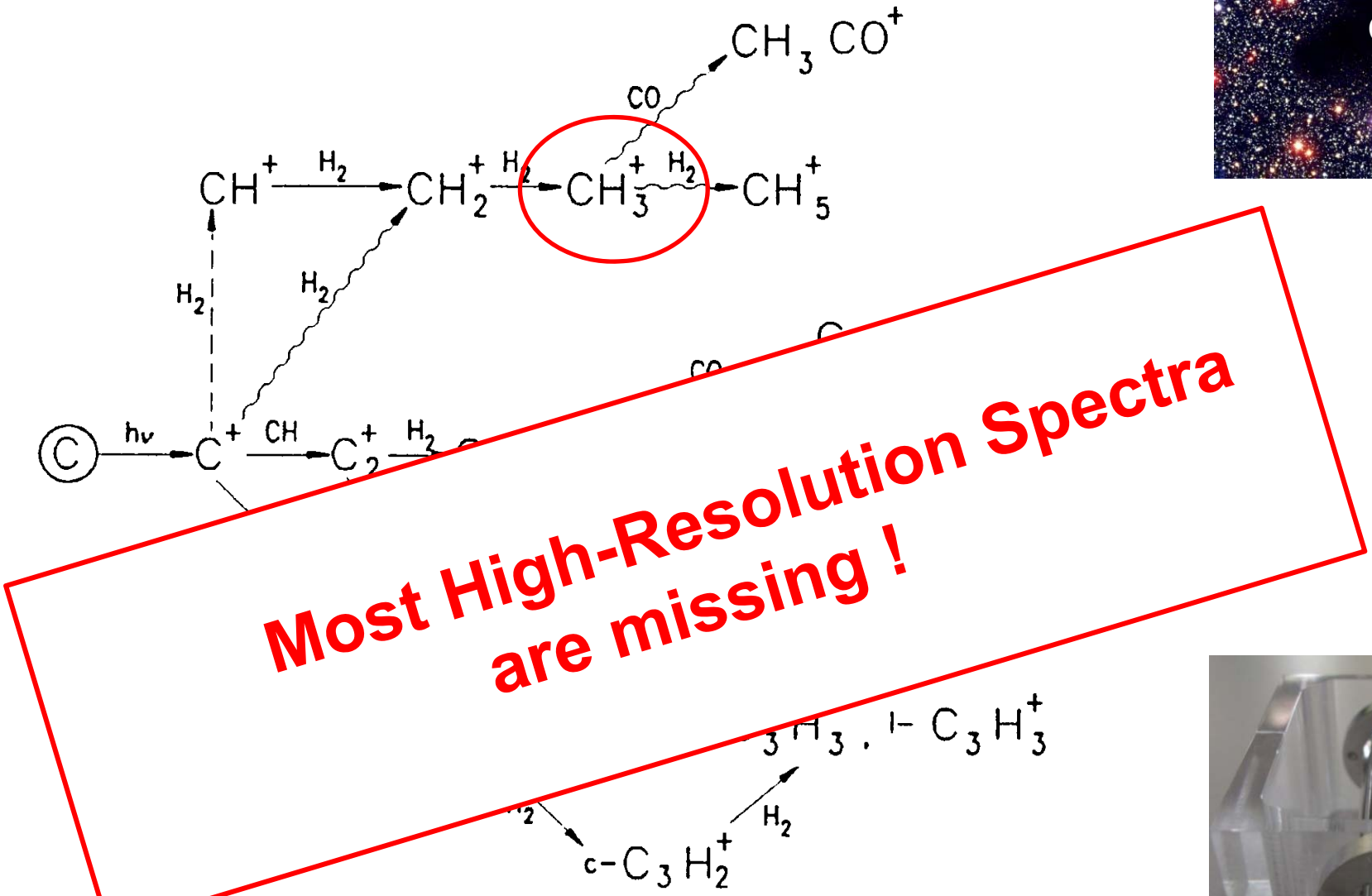


High-Resolution Laboratory Spectrum still missing !

B. Changala, N. Chen, H.L. Le, B. Gans, et al. A&A, **680**, Art. No. A19 (2023)

Formation of Small Hydrocarbons under Interstellar Conditions



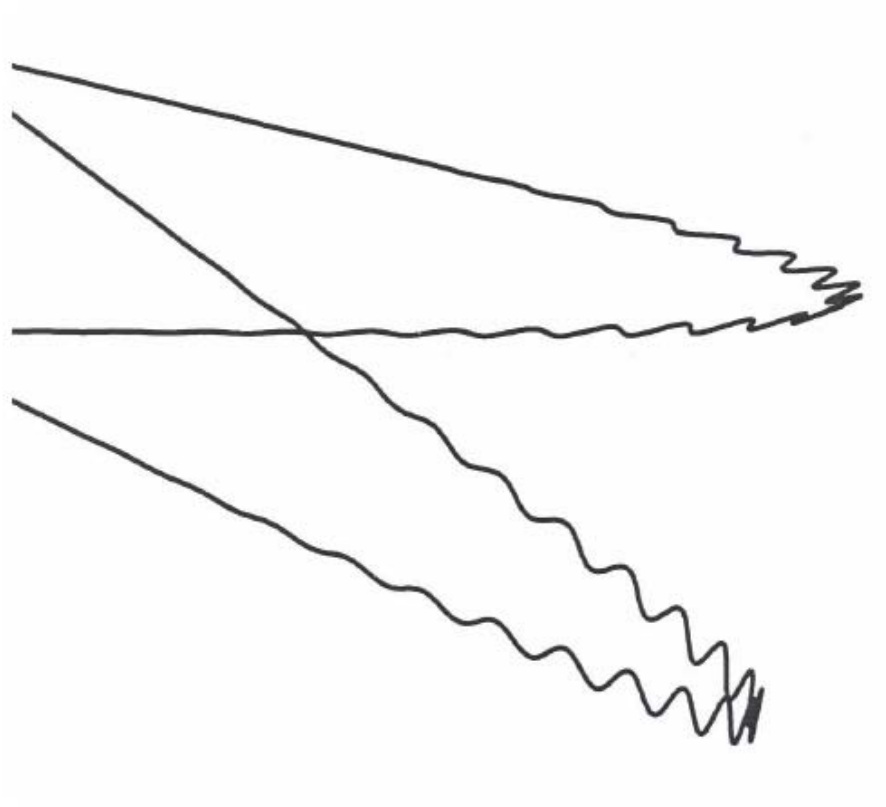


Most High-Resolution Spectra are missing !

D. Gerlich and S. Horning, Chem. Rev. 92, (1992) 1509

INHOMOGENEOUS RF FIELDS: A VERSATILE TOOL FOR THE STUDY OF PROCESSES WITH SLOW IONS

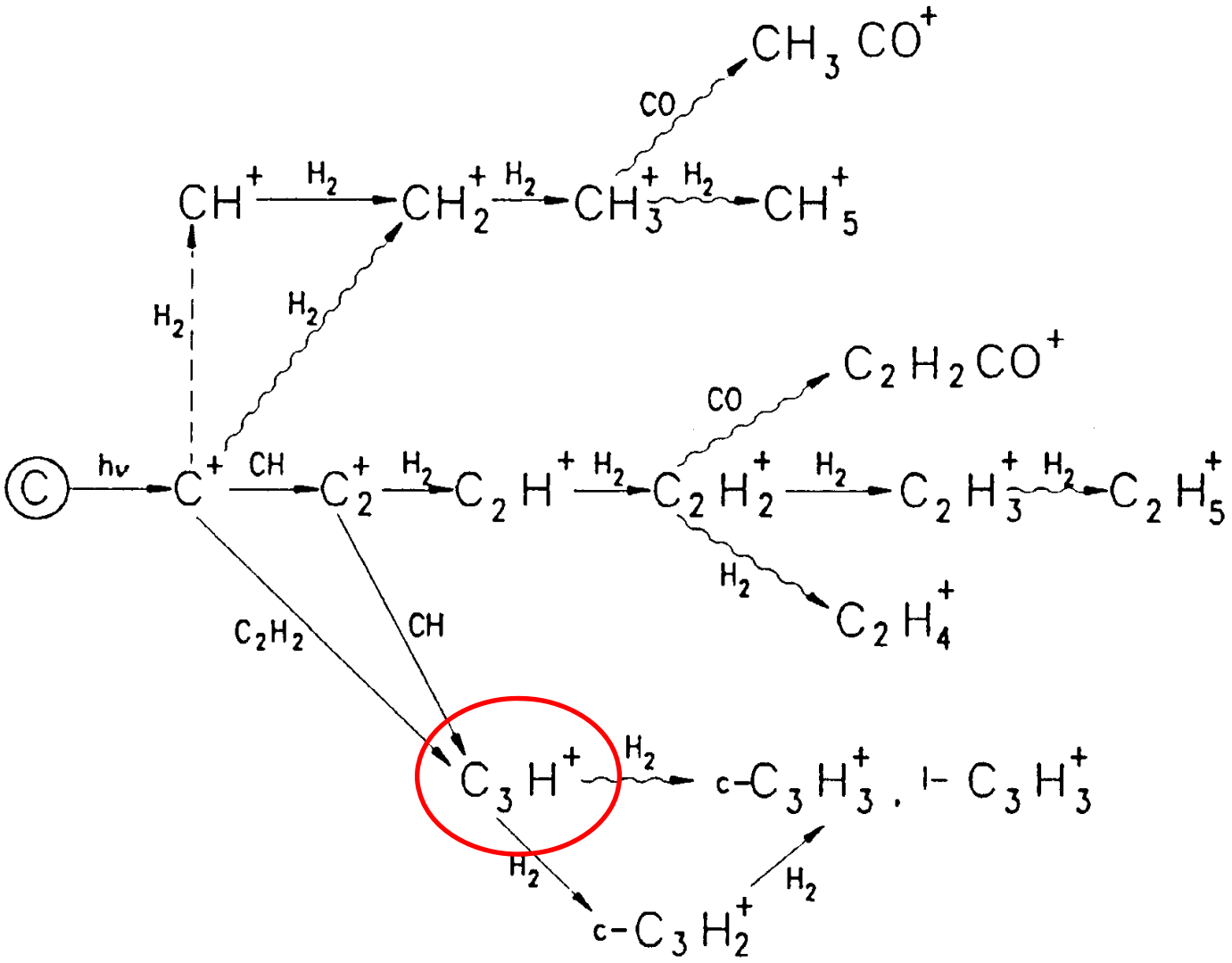
DIETER GERLICH



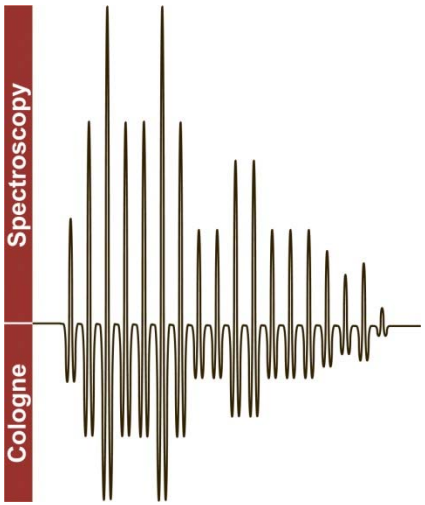
in: State-Selected and State-to-State Ion-Molecule Reaction Dynamics, C.Y. Ng and M. Baer (eds.), Advances in Chemical Physics Series, LXXXII, (1992)

Dieter Gerlich
1944 - 2020

Formation of Small Hydrocarbons under Interstellar Conditions



D. Gerlich and S. Horning, Chem. Rev. 92, (1992) 1509



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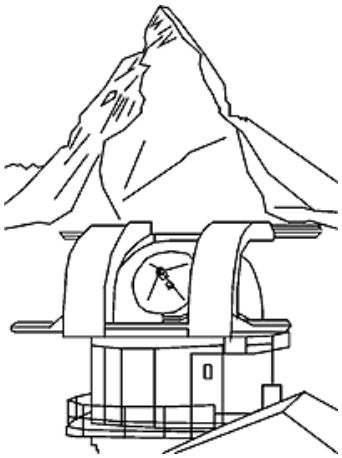
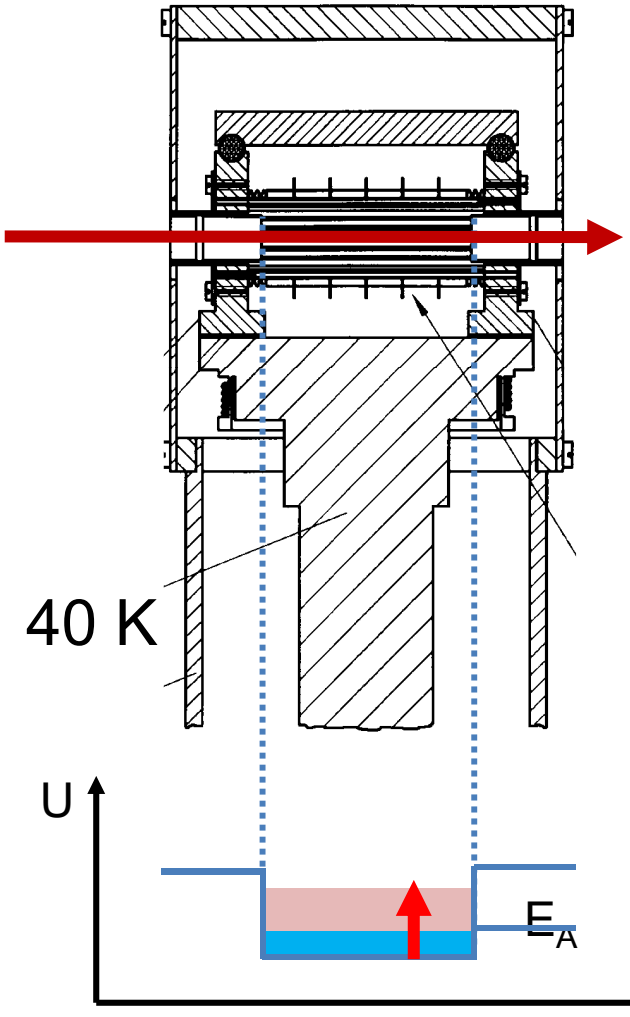


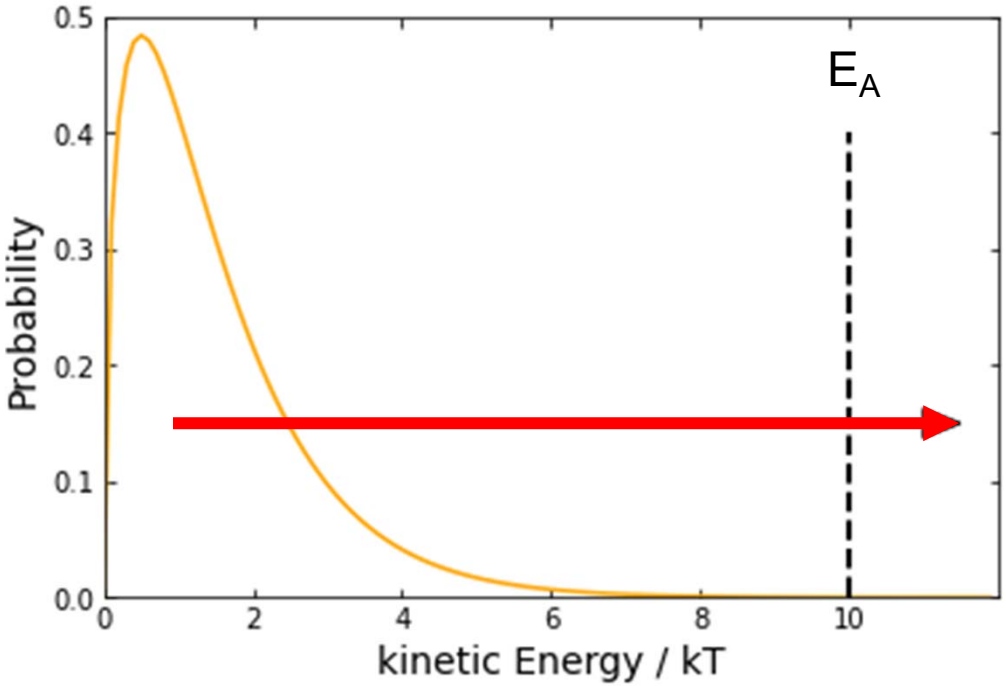
- Laborastrophysics in Germany & Thomas Henning
- Ion Chemistry in Space & Dieter Gerlich
- Ion Spectroscopy & Cologne

Leak-out Spectroscopy

Vibration to Translation Transfer



1. $(AB^+)^* + He \rightarrow AB^+(\text{low J}) + He$



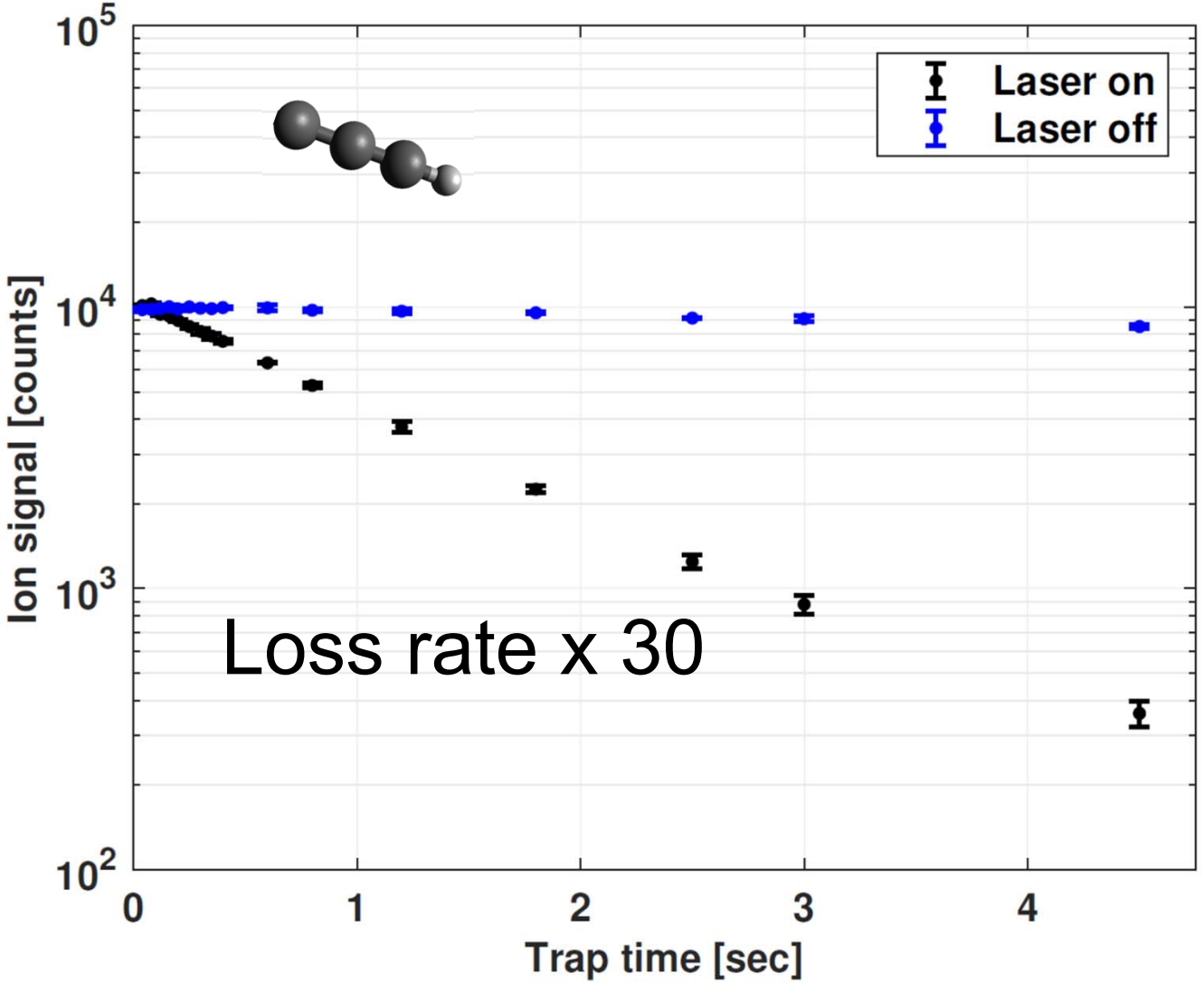
2. $AB^+ + h\nu \rightarrow AB^+(v=1)$

3. $AB^+(v=1)^* + M \rightarrow AB^+(v=0) + M + E_{kin}$

P. Schmid, O. Asvany, T. Salomon, S. Thorwirth, and S. Schlemmer, J. Phys. Chem. A 2022, 126, 43, 8111–8117

Principle of Leak-Out Spectroscopy

Cooling: Pulsed He, Leak-out: N_2 buffer gas

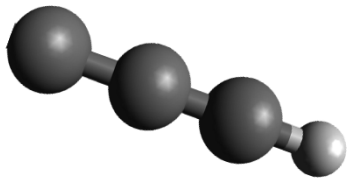


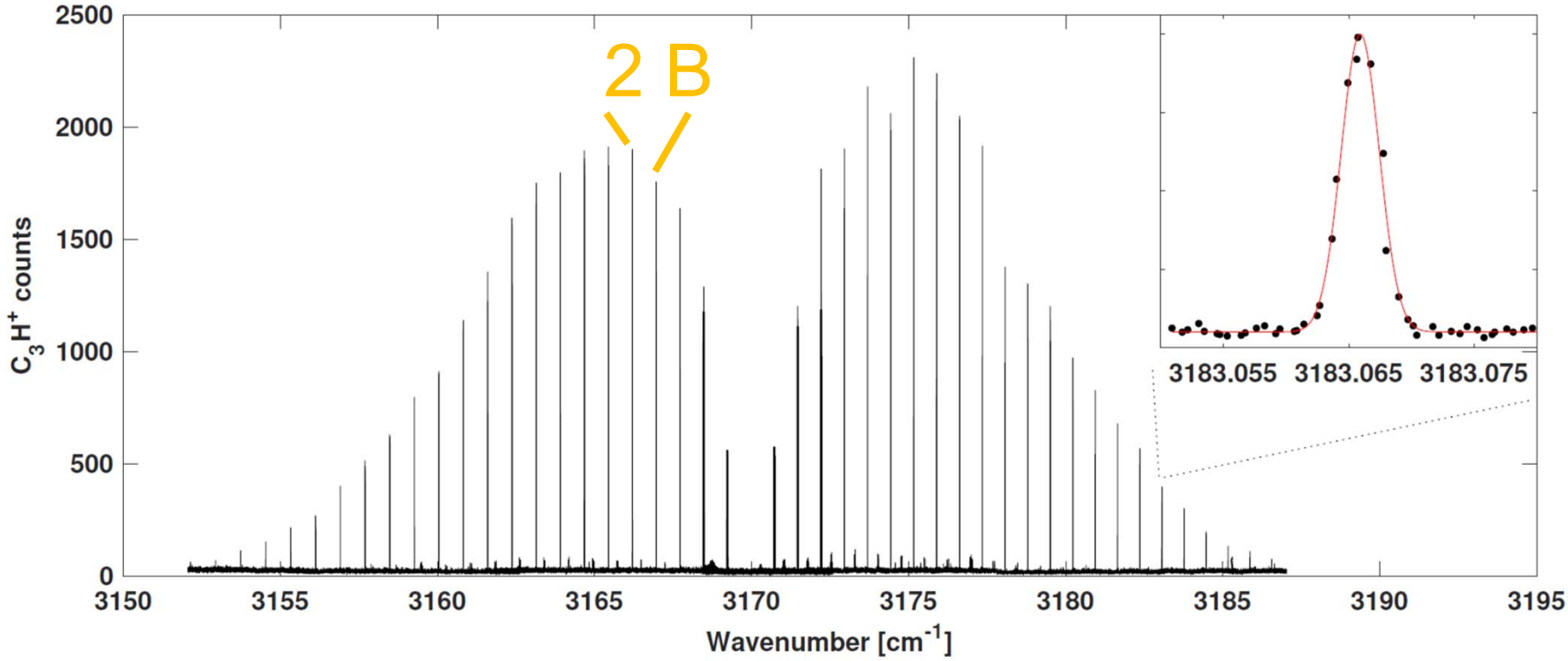
P. Schmid, O. Asvany, T. Salomon, S. Thorwirth, and S. Schlemmer, J. Phys. Chem. A 2022, 126, 43, 8111–8117

Ro-vibrational Spectrum of l-C_3H^+

Cooling: Pulsed He, Leak-out: N_2 buffer gas

$T_{trap} = T_{buffer} = 40$ K





Philipp Schmid, O. Asvany, T. Salomon, S. Thorwirth, and St. S., J. Phys. Chem. A 2022, 126, 43, 8111–8117

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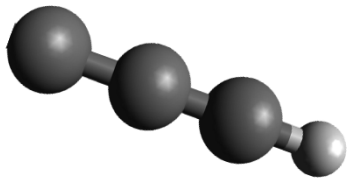
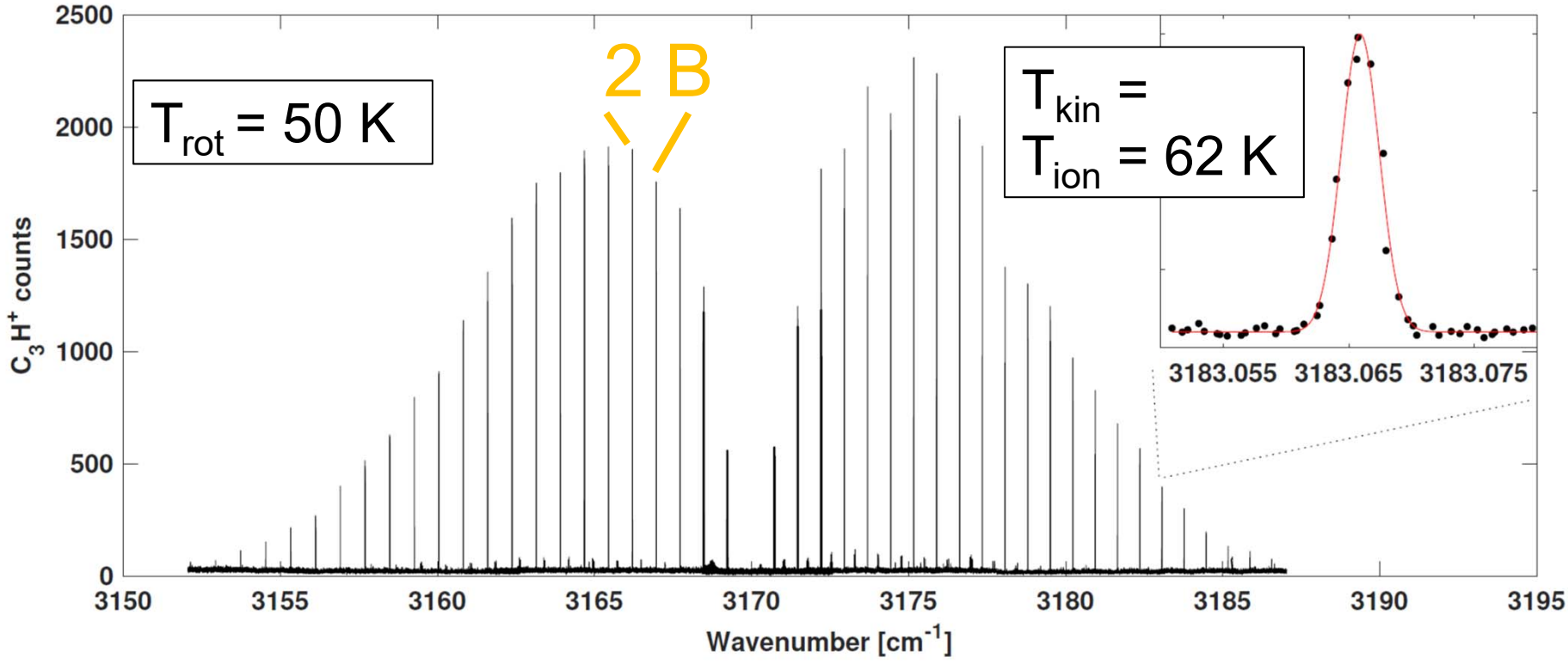
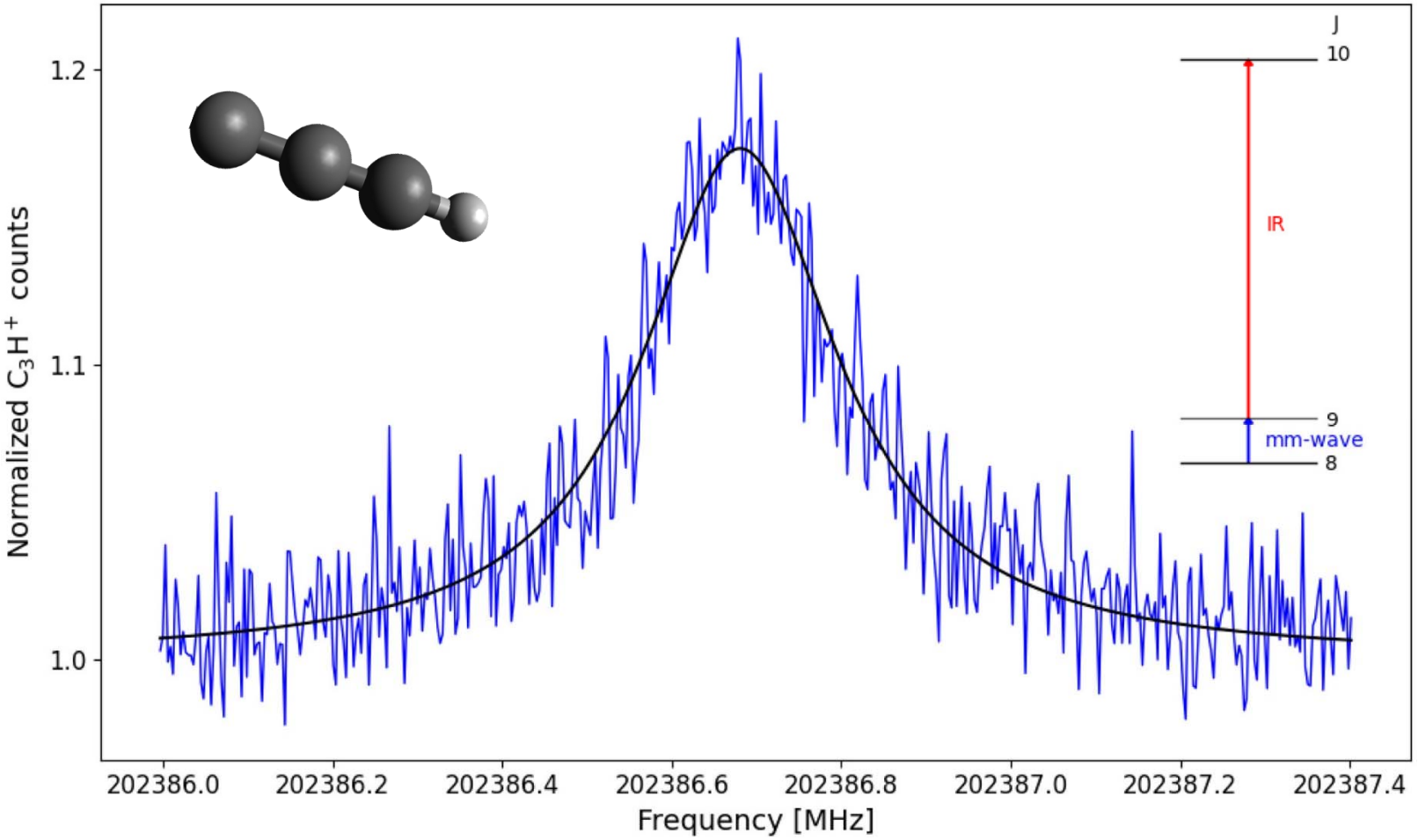


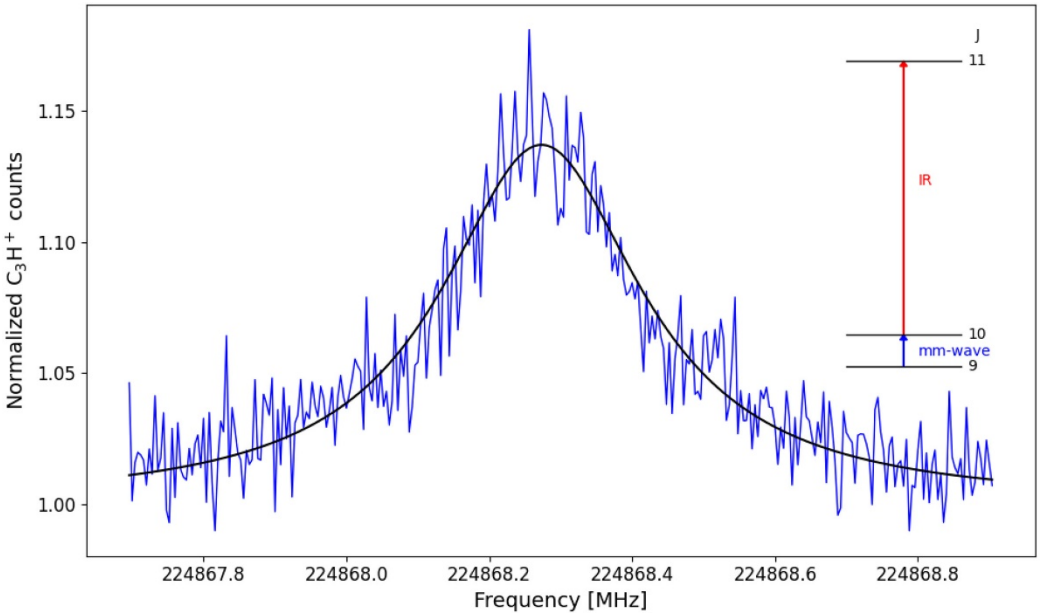


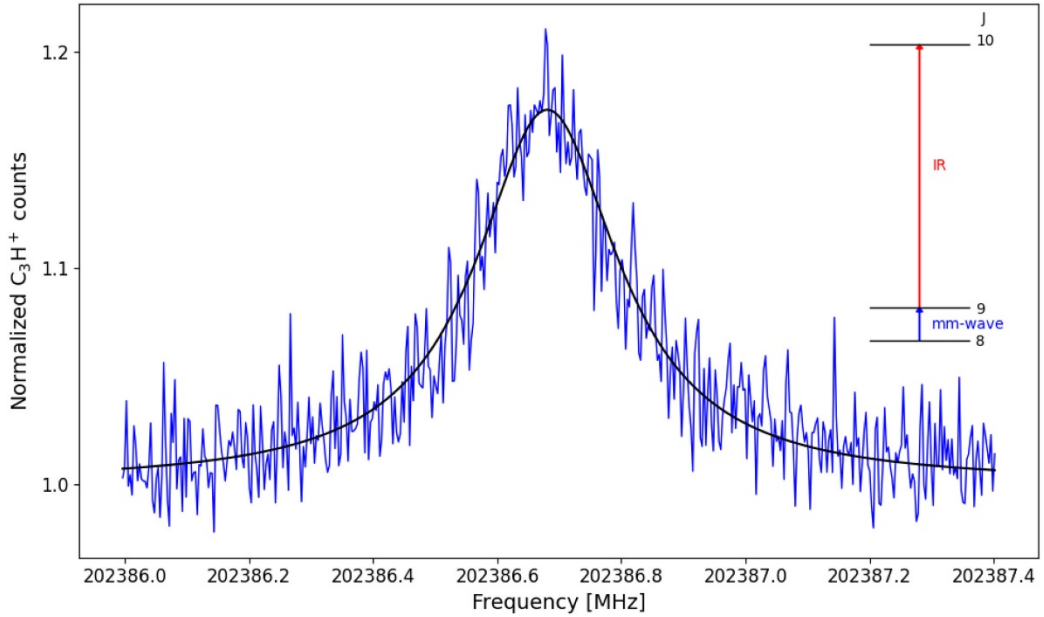
Philipp Schmid, O. Asvany, T. Salomon, S. Thorwirth, and St. S., J. Phys. Chem. A 2022, 126, 43, 8111–8117

Millimeter-IR Double Resonance Rotational Spectrum of l-C_3H^+

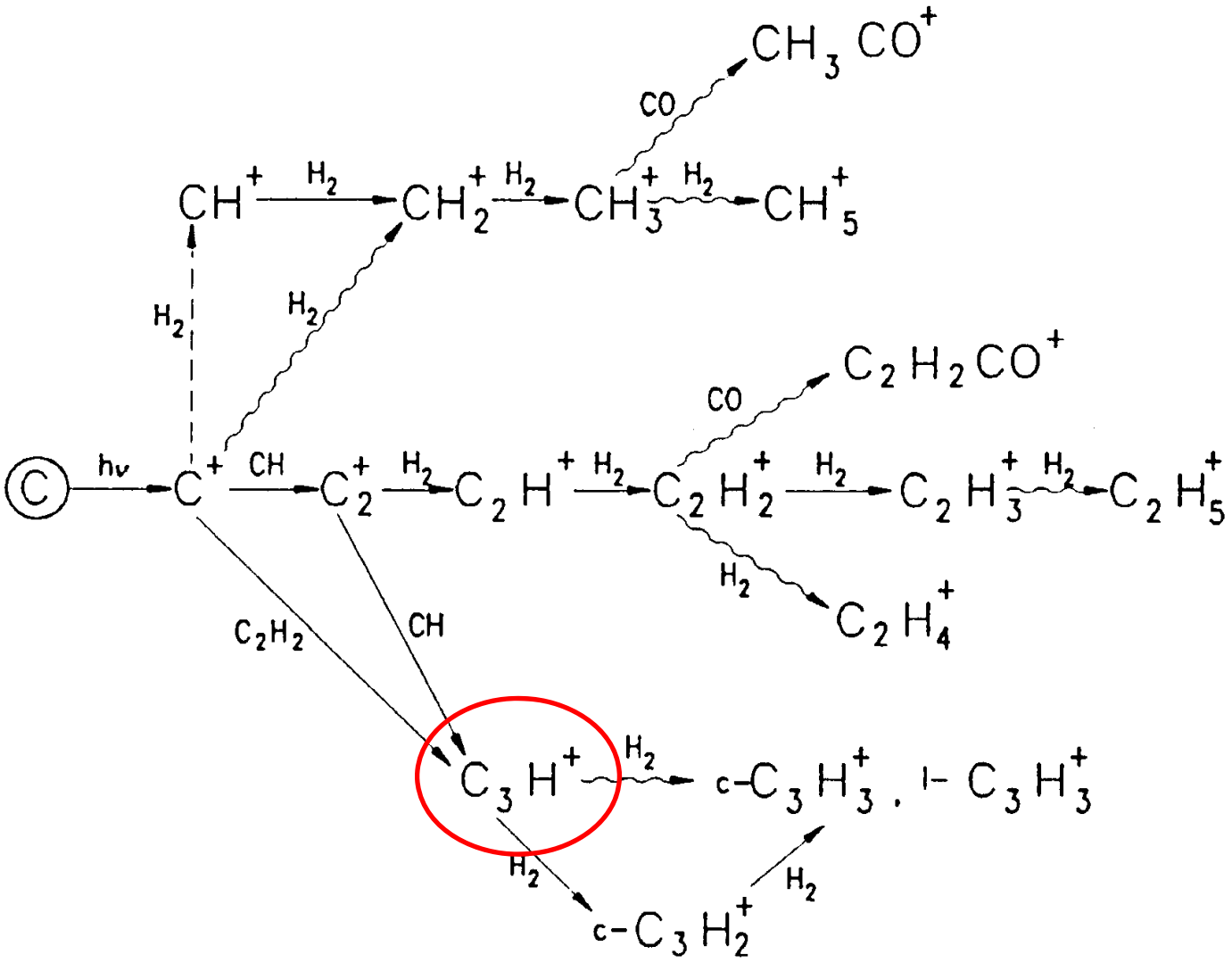


C. Baddeliyanage et al. Journal of Molecular Spectroscopy, **407** (2025), 111978

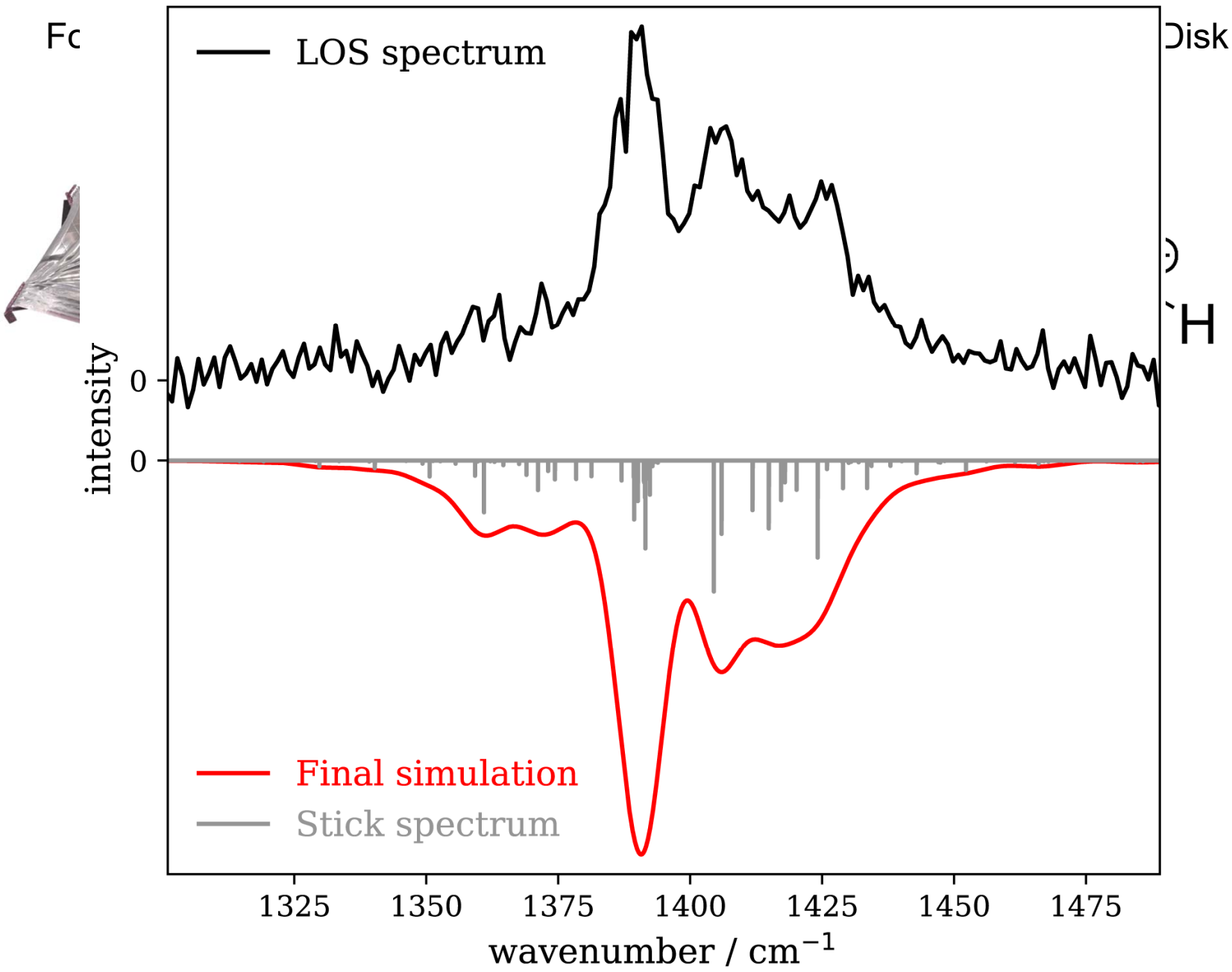

J
11
IR
10
mm-wave
9
1.15
1.10
1.05
1.00
Normalized C_3H^+ counts
224867.8
224868.0
224868.2
224868.4
224868.6
224868.8
Frequency [MHz]


J
10
IR
9
mm-wave
8
1.2
1.1
1.0
Normalized C_3H^+ counts
202386.0
202386.2
202386.4
202386.6
202386.8
202387.0
202387.2
202387.4
Frequency [MHz]

Formation of Small Hydrocarbons under Interstellar Conditions



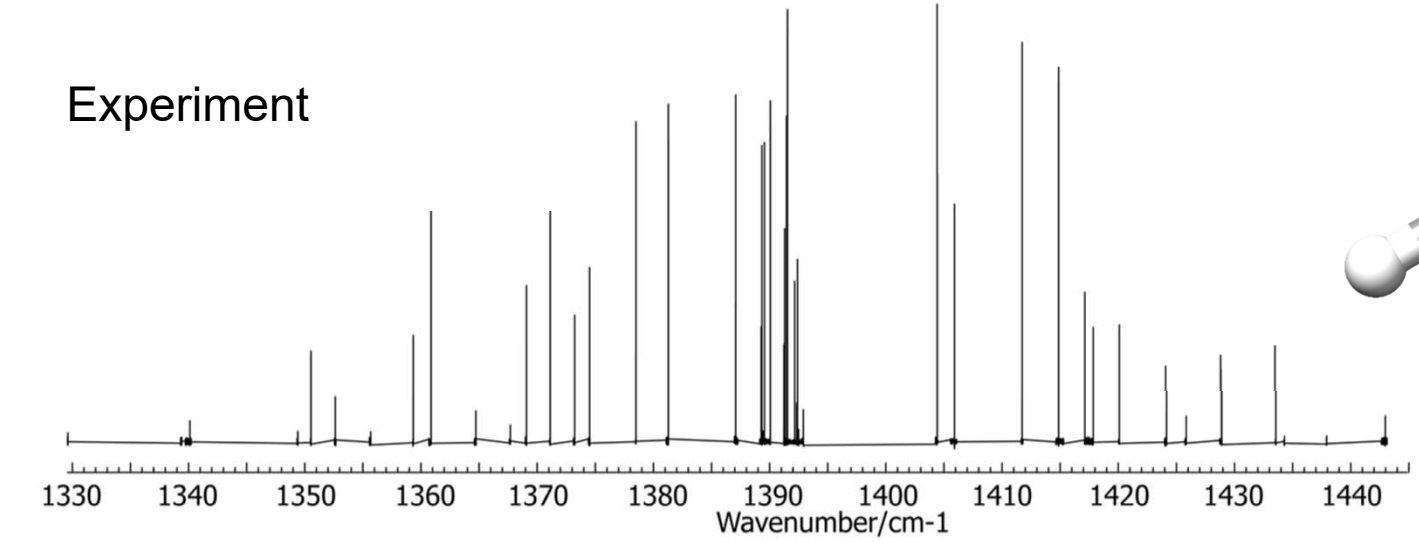
D. Gerlich and S. Horning, Chem. Rev. 92, (1992) 1509

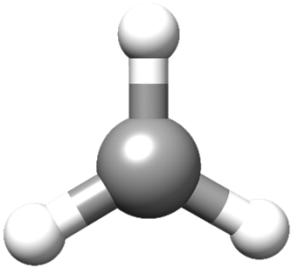


B. Changala, N. Chen, H.L. Le, B. Gans, et al. A&A, **680**, Art. No. A19 (2023)

High-Resoution Laboratory Spectrum

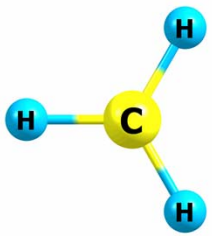
Experiment

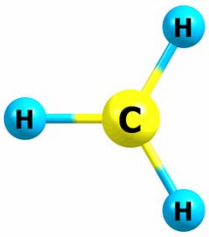




Simulation

ν_4 (E‘)

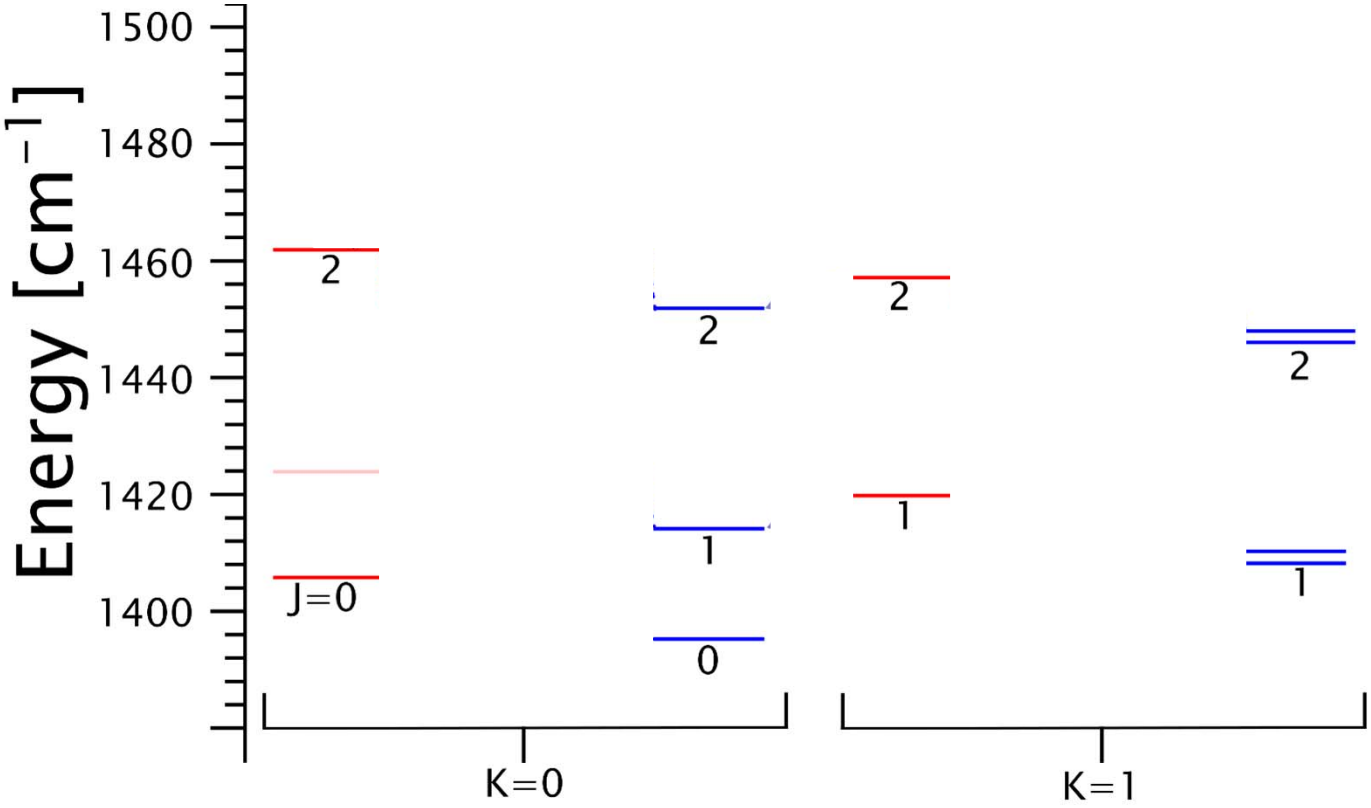




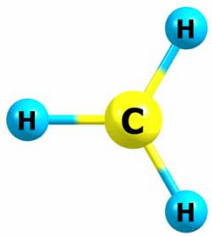
ν_2 (A_2“)

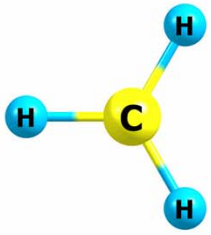
A&A accepted

CH_3^+: Coriolis – Interaction



ν_4 (E‘)





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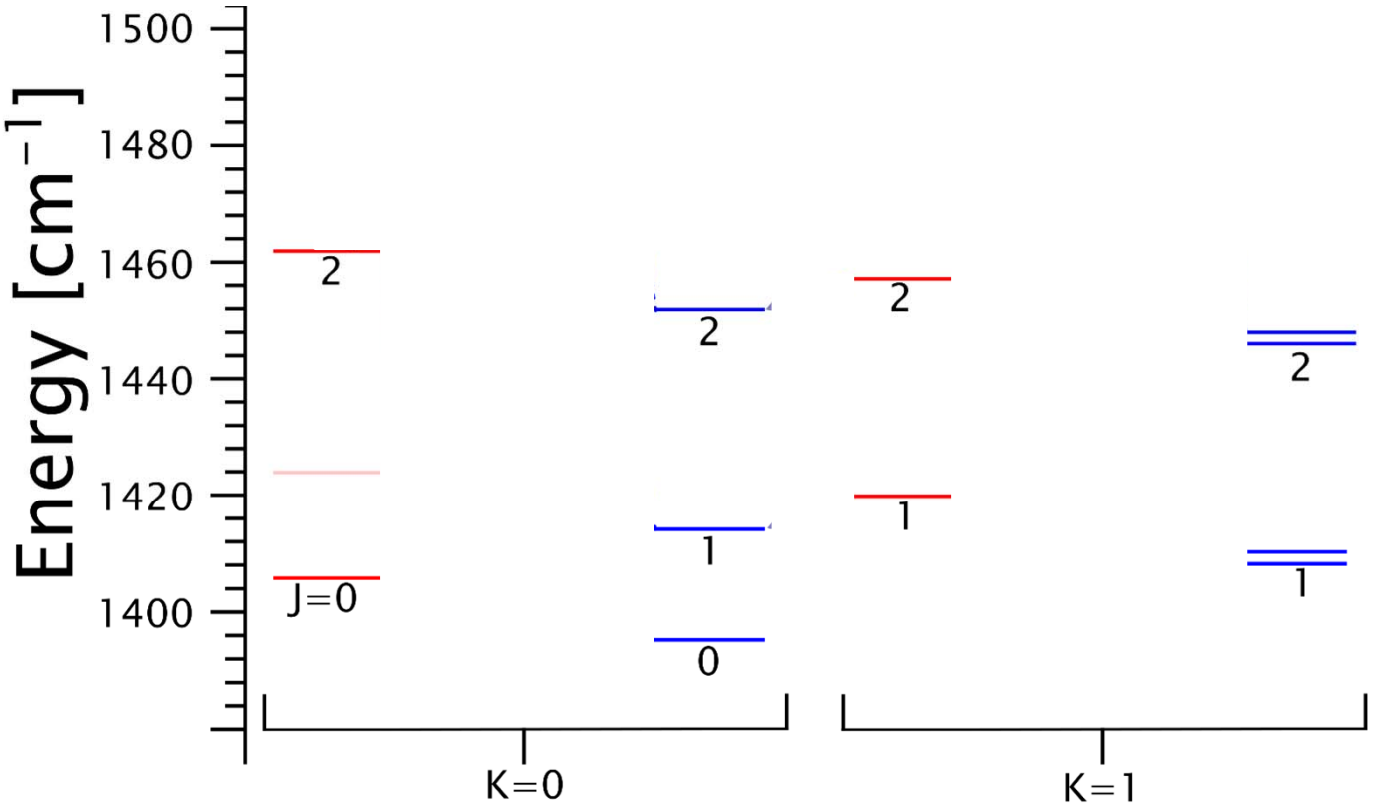

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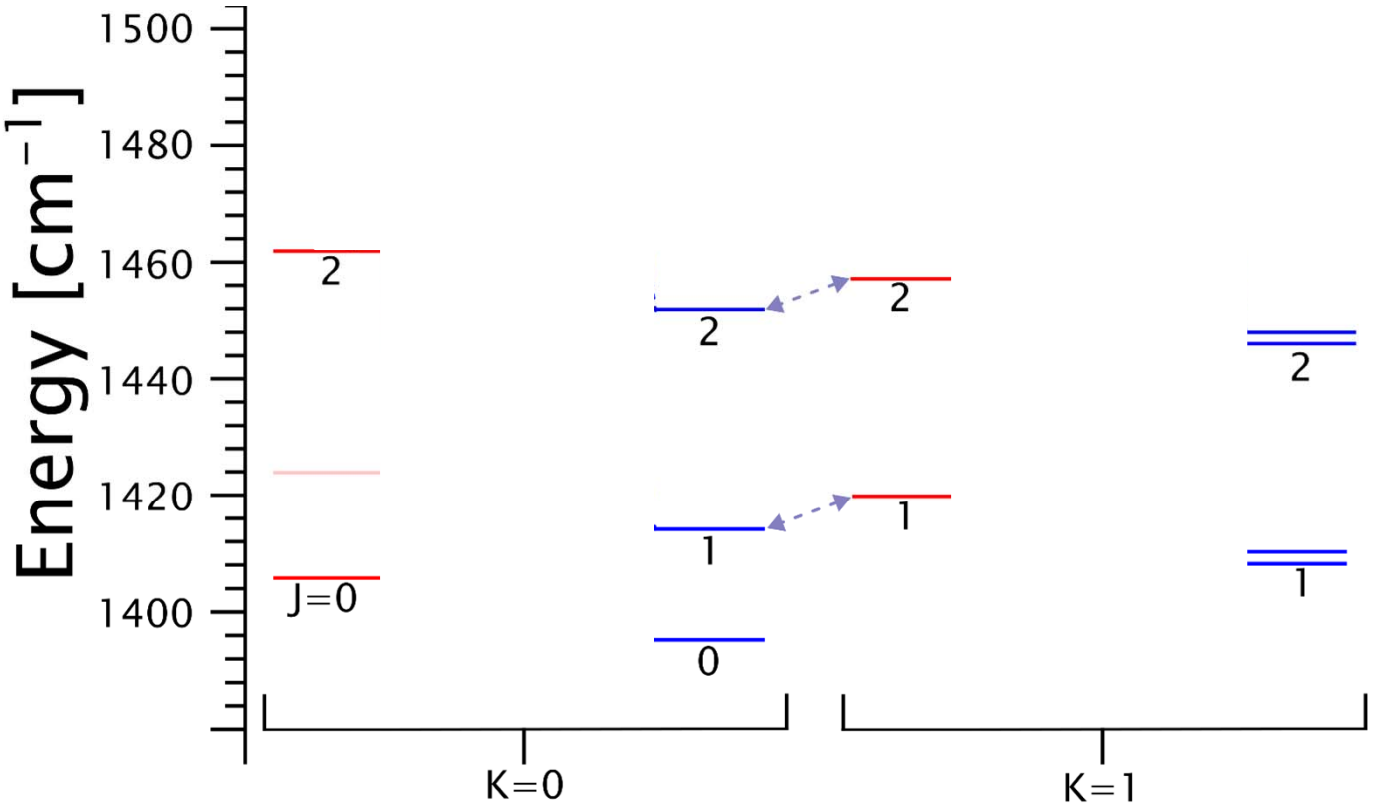

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ν_2 (A_2“)

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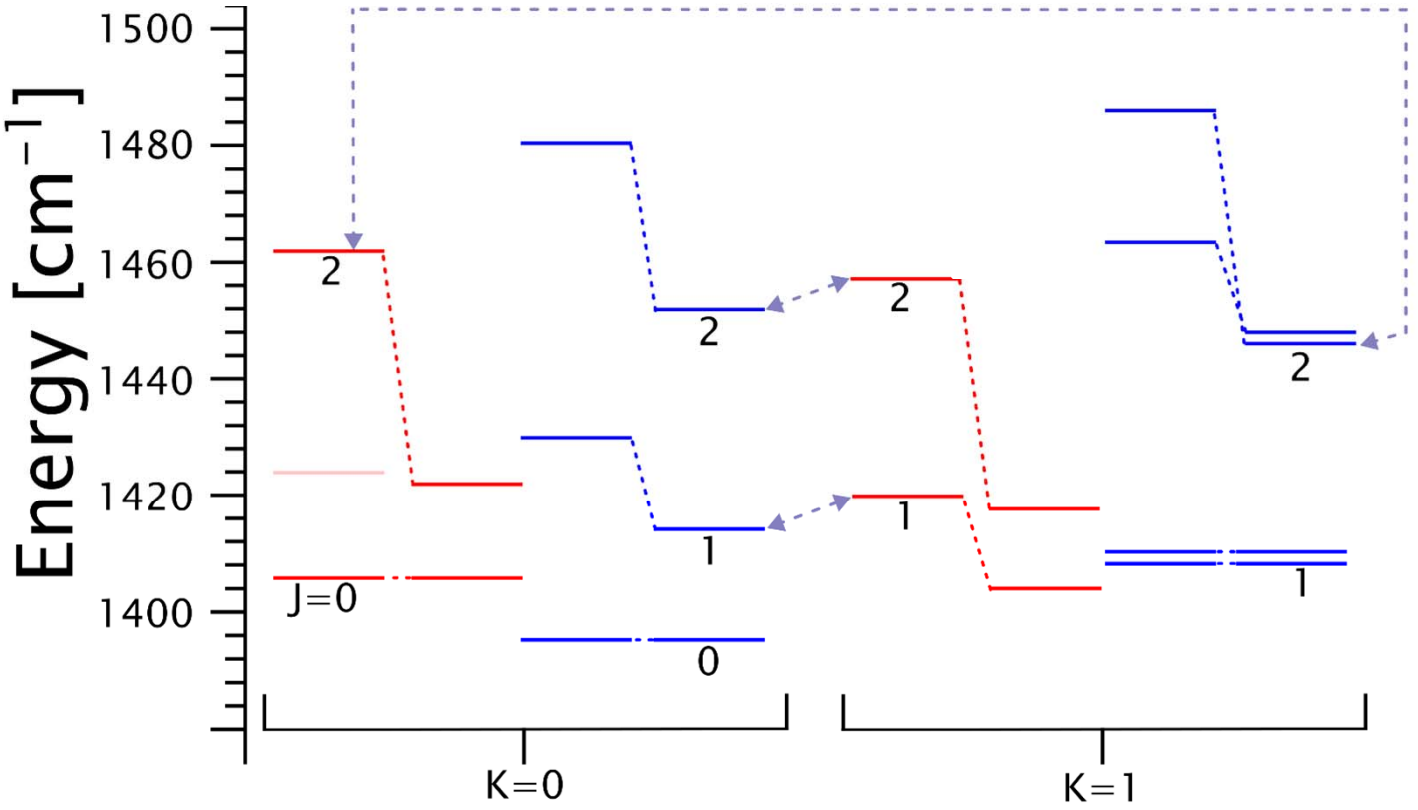

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ν_2 (A_2“)

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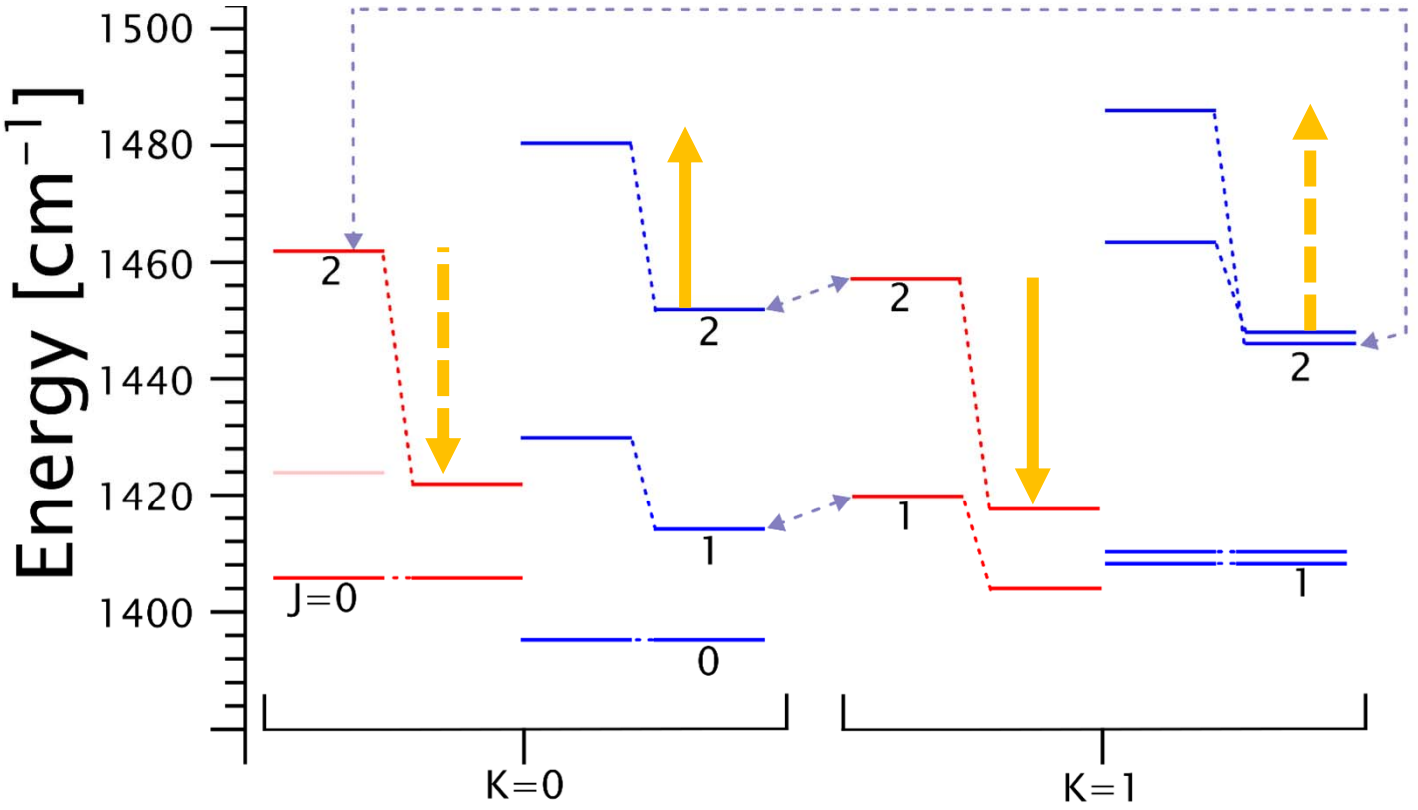
CH_3^+: Coriolis – Interaction



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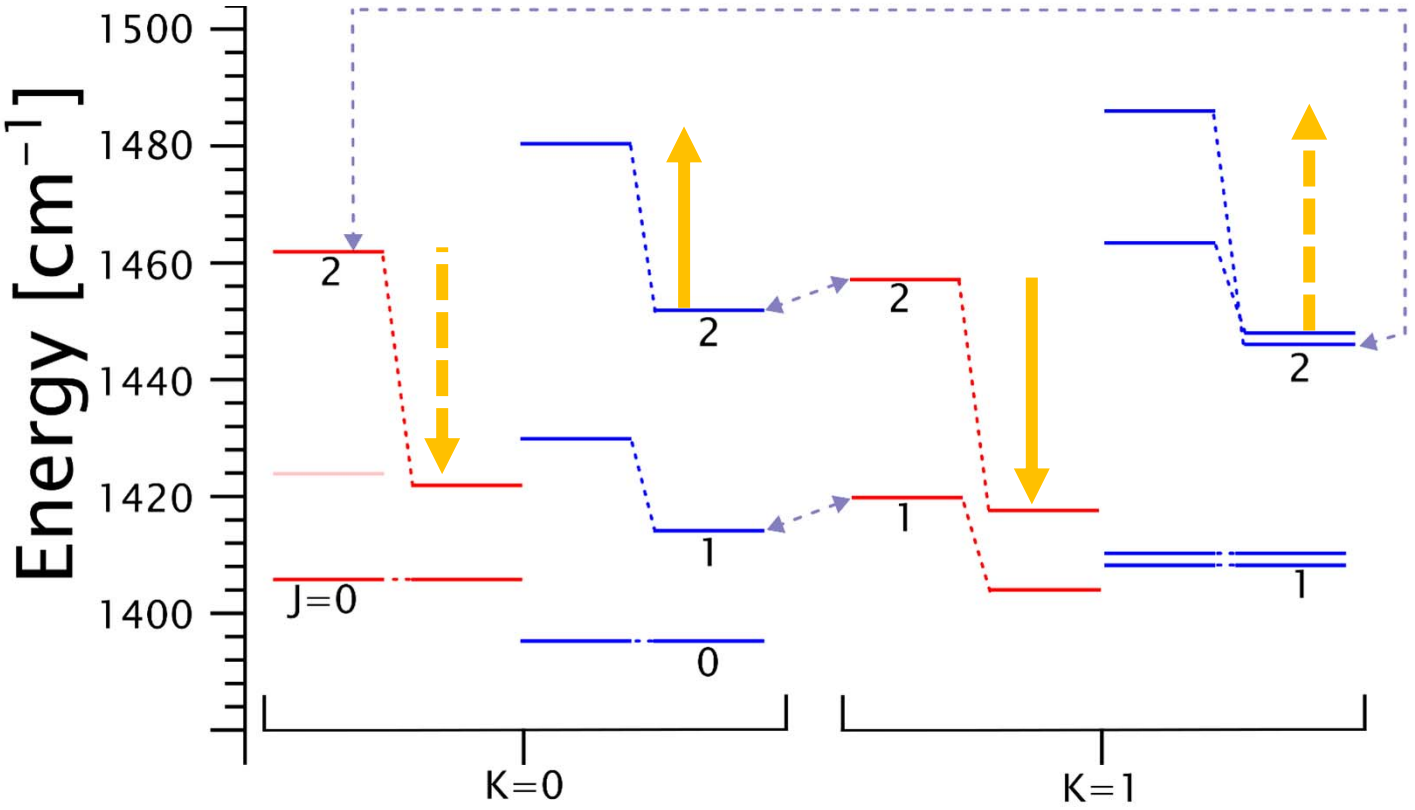
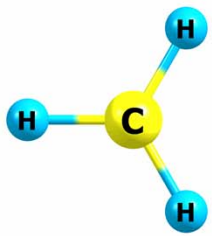
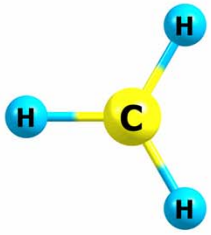
CH_3^+: Coriolis – Interaction



ν_4 (E‘)





ν_2 (A_2“)

A&A accepted

Missing Ions in Laboratory and Space

C^+	**CH^+** **Ro-vib** **Rot** **Deuterium, ^{13}C**	**CH_2^+**	**CH_3^+** **Vib** **Deuterium**	CH_4^+	**CH_5^+** **Vib** **Ro-vib** **Deuterium**
C_2^+	**C_2H^+** **Ro-vib** **Rot**	**$C_2H_2^+$** **Ro-vib** **Deuterium**	**$C_2H_3^+$** **Ro-vib**	$C_2H_4^+$	$C_2H_5^+$
C_3^+	**C_3H^+** **Rot** **Vib** **Ro-vib**	**$c\text{-}C_3H_2^+$** **Ro-vib**	**$c\text{-}C_3H_3^+$** **Vib, Ro-vib** **$c\text{-}C_3H_2D^+$** **Ro-vib**	$C_3H_4^+$	$C_3H_5^+$
		HC_3H^+ **linear** **Ro-vib**	**$H_2C_3H^+$** **asym** **Ro-vib** **Rot**		
		$C_4H_2^+$	**$H_2C_4H^+$** **asym** **Ro-vib**	$C_4H_4^+$	

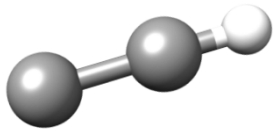
C_2H^+

Open Shell Species: C_2H^+

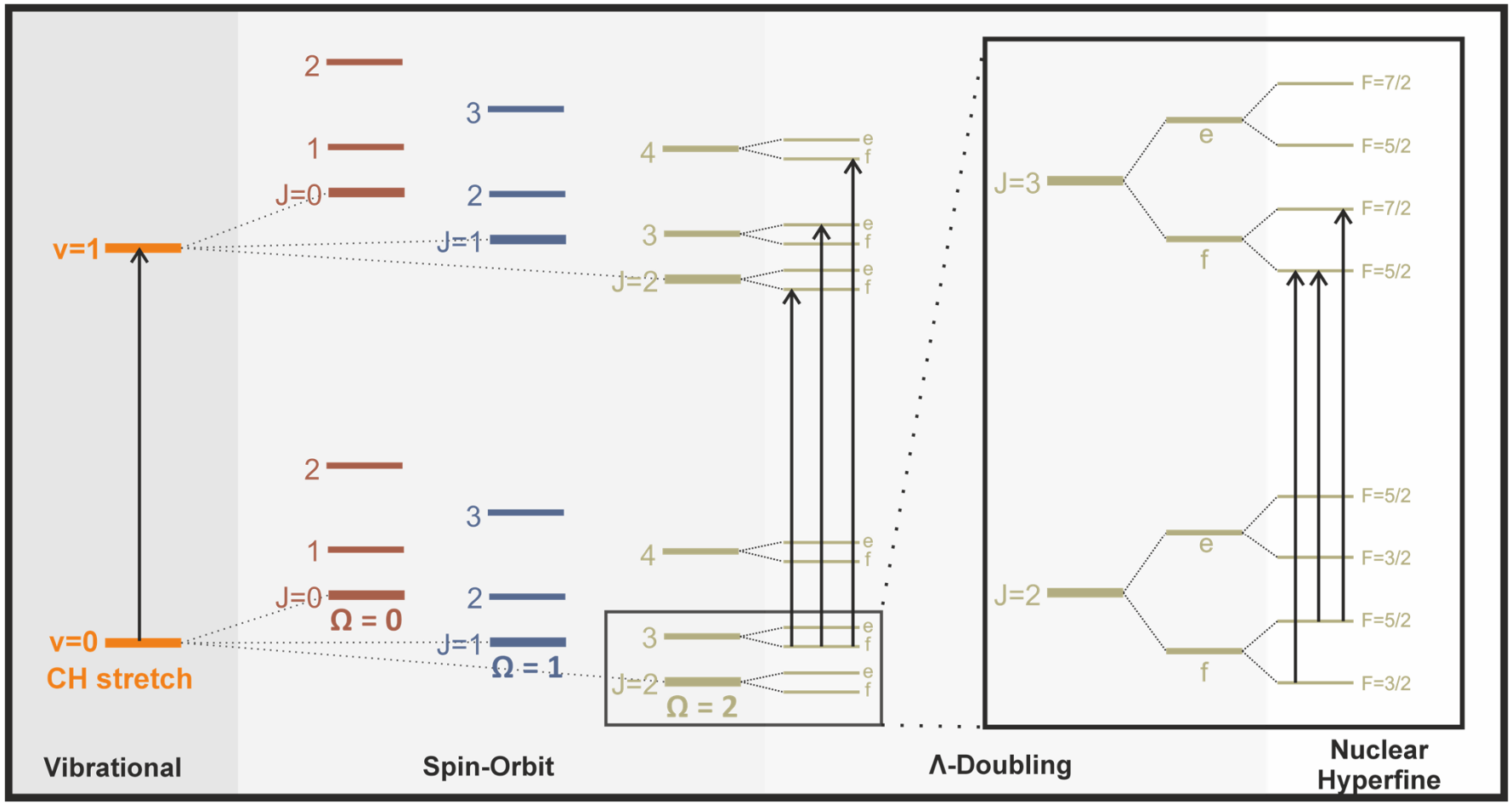
Electron spin S = 1 (Σ= -1, 0, 1)

$^3\Pi$ electronic ground state, $\Lambda = \pm 1$

$\Omega = |\Sigma+\Lambda|$ = 0, 1, 2 (spin-orbit states), A= -36 cm^{-1}



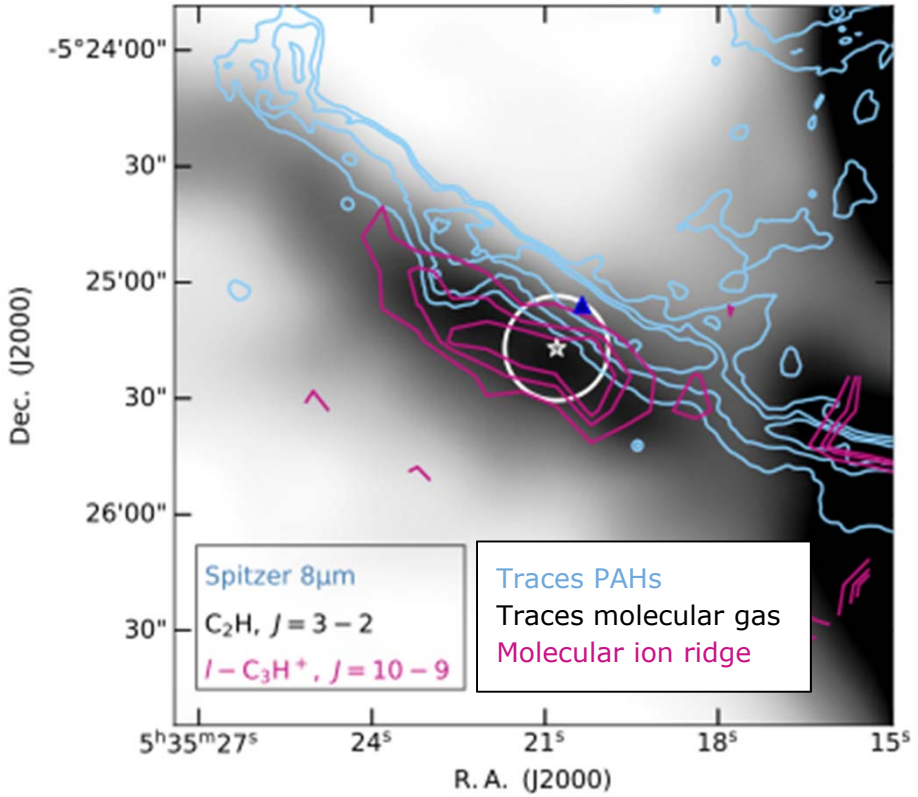
H (I= 1/2)



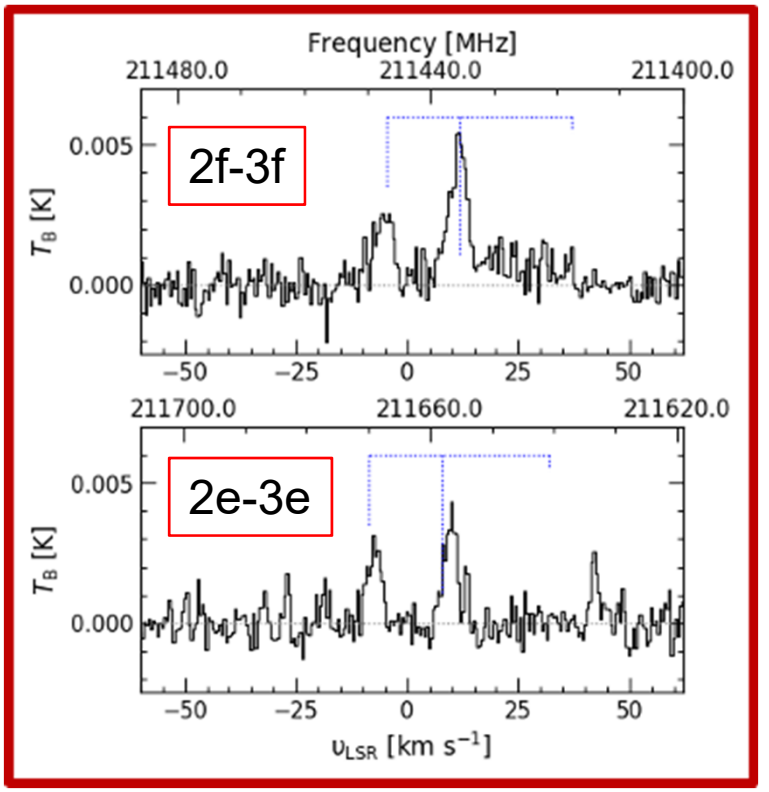
K. Steenbakkers, et al., J. Phys. Chem. A, **130**, 3163–3174 (2026)

Finding C_2H^+ in Orion Bar

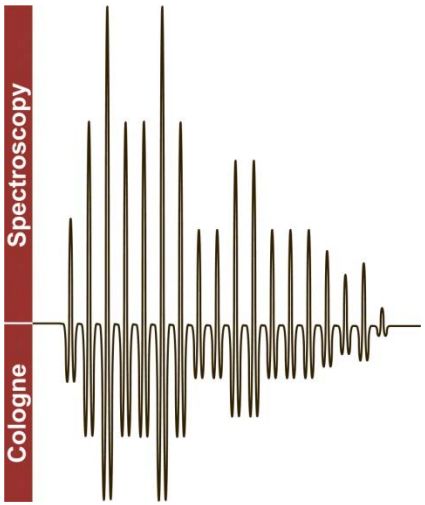
- Characteristic fine structure pattern of J = 2 – 3 rotational transition



▲ CH_3^+, Berné et al. 2023

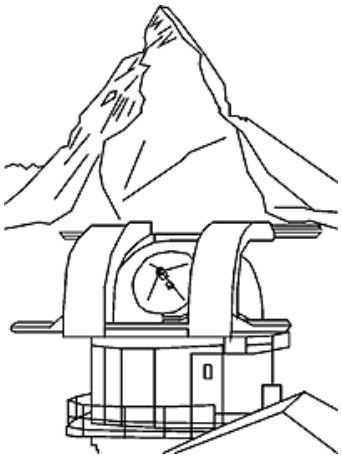


λ-doubling ~ 200 MHz & HFS



Missing Ions in Laboratory and Space

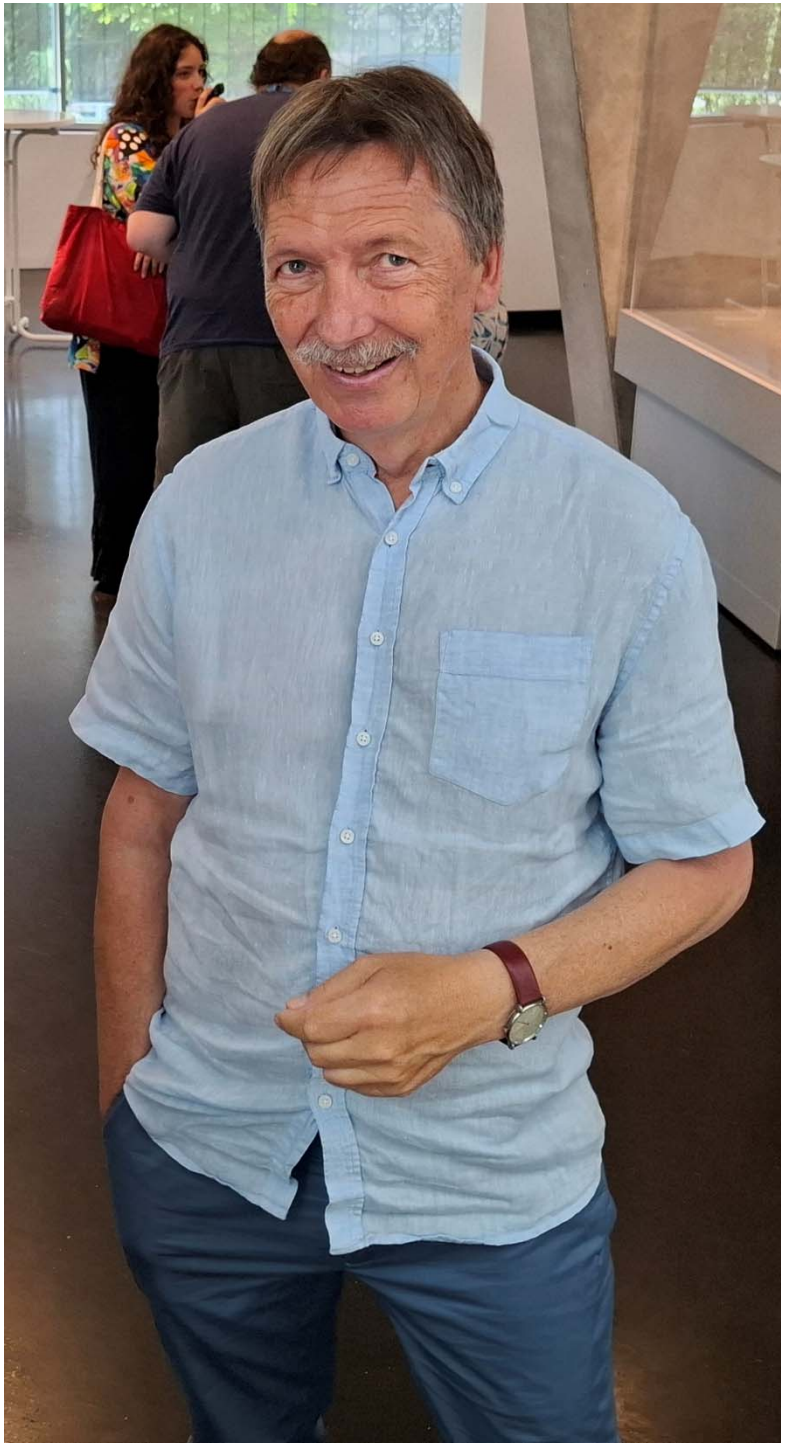
Stephan Schlemmer
I. Physikalisches Institut,
Universität zu Köln



- Laborastrophysics in Germany & Thomas Henning
- Ion Chemistry in Space & Dieter Gerlich
- Ion Spectroscopy & Cologne

Thank you
Thomas

30 years
support
for
Laboratory
Astrophysics



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