Emission is complicated: the beauty of resonant inelastic light scattering *- in the lab with Aron*

Ursula Wurstbauer

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living.knowledge

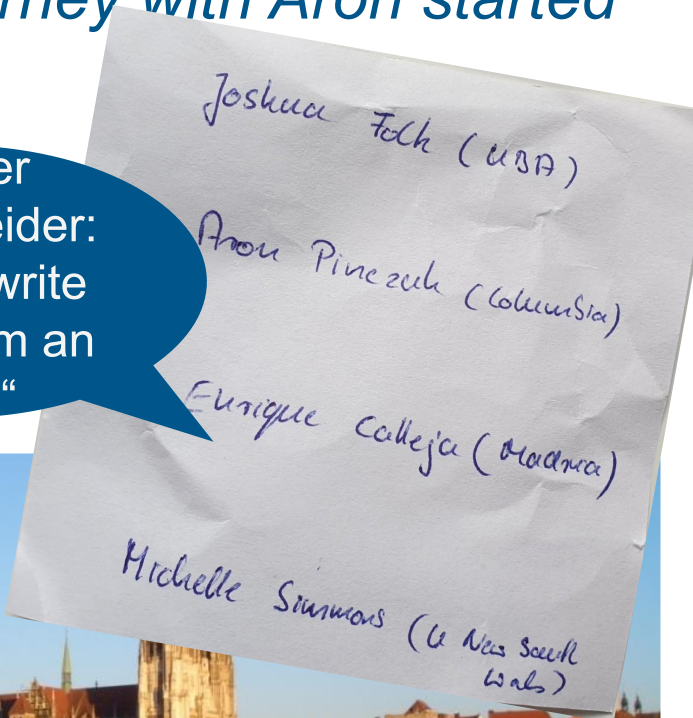
nanoelectronics

“when can you start at Columbia - in 3 months or sooner?”

… the way my journey with Aron started

„Werner – I would like to do a postdoc abroad. Do you where I could go?“

Werner Wegscheider: „I could write all of them an email“

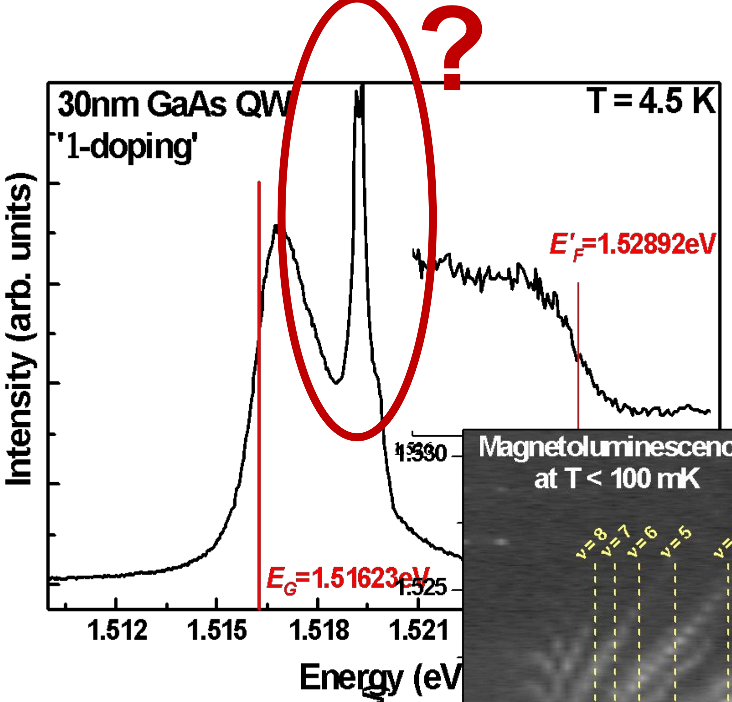


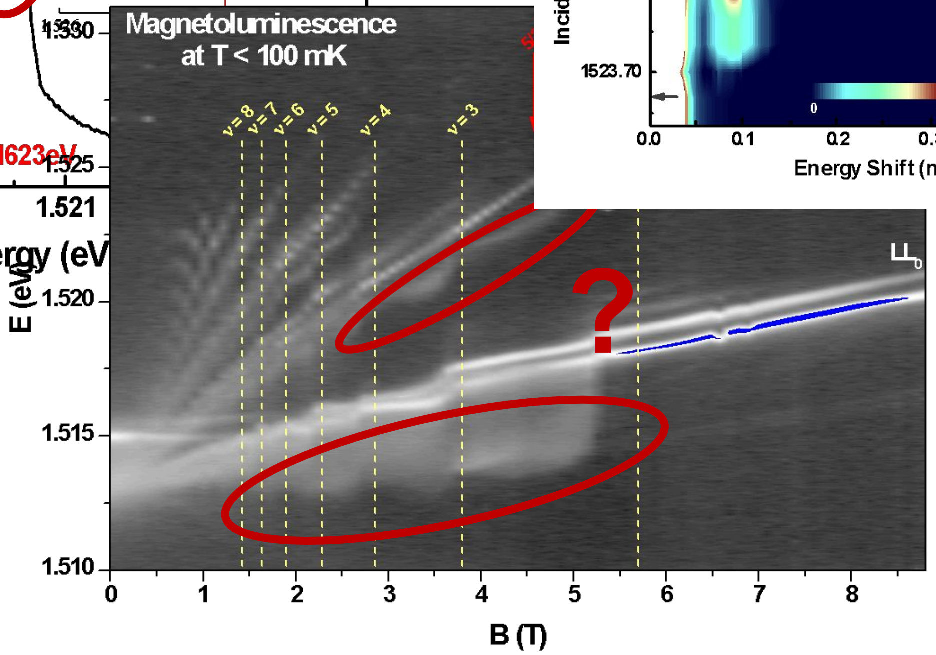
Your husband is a physicist as well? – we need to find another position!”

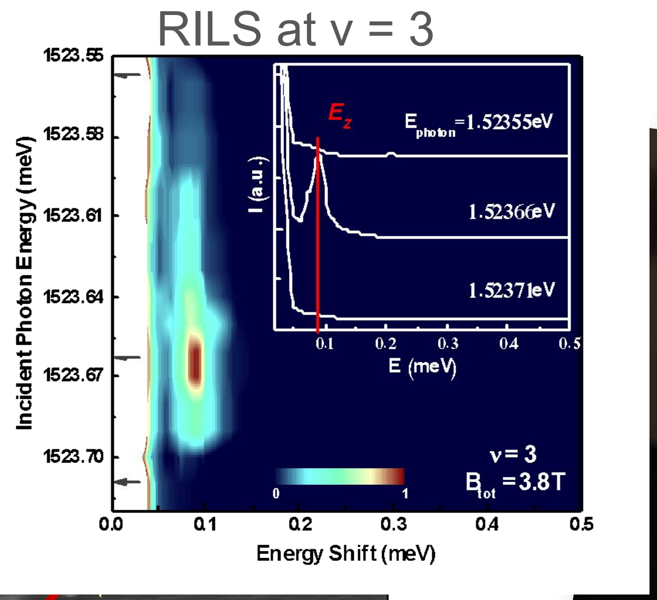
Aron: „Ursula, when can you start? “

“Aron. what are these signatures in emission spectra?”

“… PL is complicated”







“the strength and beauty of RILS on collective excitations”

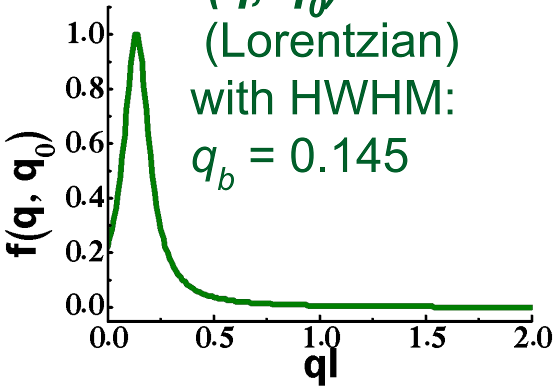
$$I(E,q_0) \propto \int f(q,q_0)\rho(E,q)dq$$

line shape function

mode response function:

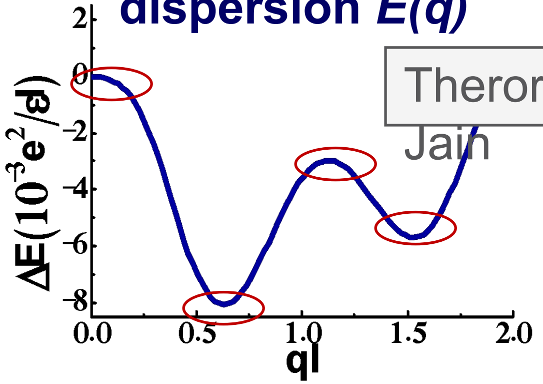
$$\boxed{\rho(q,q_0) = \frac{\Gamma/2}{(E-E(q)^2)+\Gamma^2}}$$

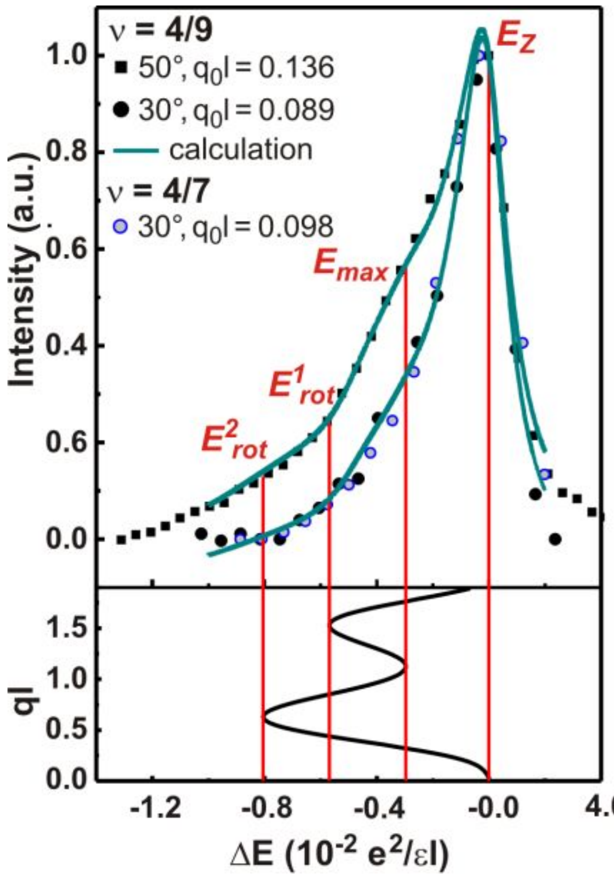
f(q, q$_0$) (Lorentzian) with HWHM: $q_b = 0.145$



calculated **wave vector dispersion *E(q)***

Therory J. Jain





UW et al. PRL 107, 066804 (2011)

“running on sugar”

dark, because it is healthier – but not too dark ☺

WWU MÜNSTER

"running on sugar"

Transforming dark swiss chocolate in PRL and other paper

PRL 107, 066804 (2011) PHYSICAL REVIEW LETTERS week ending 5 AUGUST 2011

Observation of Nonconventional Spin Waves in Composite-Fermion Ferromagnets

U. Wurstbauer,[1,*] D. Majumder,[2] S. S. Mandal,[2] I. Dujovne,[3] T. D. Rhone,[1] B. S. Dennis,[4] A. F. Rigosi,[1] J. K. Jain,[5] A. Pinczuk,[1,6] K. W. West,[7] and L. N. Pfeiffer[7]

nature COMMUNICATIONS

ARTICLE

Received 22 Mar 2015 | Accepted 22 Oct 2015 | Published 26 Nov 2015 DOI: 10.1038/ncomms9981

Fractionally charged skyrmions in fractional quantum Hall effect

Ajit C. Balram[1], U. Wurstbauer[2,3], A. Wójs[4], A. Pinczuk[5] & J.K. Jain[1]

PHYSICAL REVIEW LETTERS 128, 017401 (2022)

Domain Textures in the Fractional Quantum Hall Effect

Ziyu Liu,[1,*] Ursula Wurstbauer,[2] Lingjie Du,[3] Ken W. West,[4] Loren N. Pfeiffer,[4] Michael J. Manfra,[5,6] and Aron Pinczuk[1,7,†]

(Received 4 August 2021; revised 18 October 2021; accepted 12 December 2021; published 6 January 2022)

PRL 110, 026801 (2013) PHYSICAL REVIEW LETTERS week ending 11 JANUARY 2013

Resonant Inelastic Light Scattering Investigation of Low-Lying Gapped Excitations in the Quantum Fluid at $\nu = 5/2$

U. Wurstbauer,[1,*] K. W. West,[2] L. N. Pfeiffer,[2] and A. Pinczuk[1,3]

PHYSICAL REVIEW B 92, 241407(R) (2015) RAPID COMMUNICATIONS

Gapped excitations of unconventional fractional quantum Hall effect states in the second Landau level

U. Wurstbauer,[1,2,*] A. L. Levy,[3] A. Pinczuk,[3,4] K. W. West,[5] L. N. Pfeiffer,[5] M. J. Manfra,[6,7,8] G. C. Gardner,[7] and J. D. Watson[6]

(Received 17 July 2015; published 11 December 2015)

PHYSICAL REVIEW B 95, 085312 (2017)

Collective electronic excitation in a trapped ensemble of photogenerated dipolar excitons and free holes revealed by inelastic light scattering

Sebastian Dietl,[1,2] Sheng Wang,[3] Dieter Schuh,[4] Werner Wegscheider,[5] Jörg P. Kotthaus,[2] Aron Pinczuk,[3,6,7] Alexander W. Holleitner,[1,2,*] and Ursula Wurstbauer[1,2,†]

(Received 13 December 2016; published 27 February 2017)

DOI: 10.1103/PhysRevB.95.085312

PRL 116, 016801 (2016) PHYSICAL REVIEW LETTERS week ending 8 JANUARY 2016

Optical Emission Spectroscopy Study of Competing Phases of Electrons in the Second Landau Level

A. L. Levy,[1,*] U. Wurstbauer,[2,3] Y. Y. Kuznetsova,[1] A. Pinczuk,[1,4] L. N. Pfeiffer,[5] K. W. West,[5] M. J. Manfra,[6,7,8] G. C. Gardner,[7] and J. D. Watson[6]

(Received 27 March 2015; published 8 January 2016)

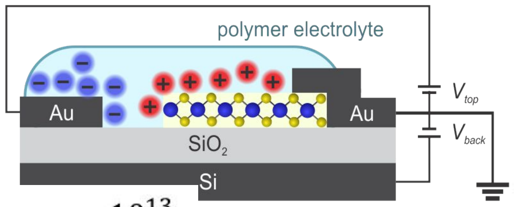
DOI: 10.1103/PhysRevLett.116.016801

only one paper on PL!

"PL is complicated"

"… I am fully convinced and telling it to my students"

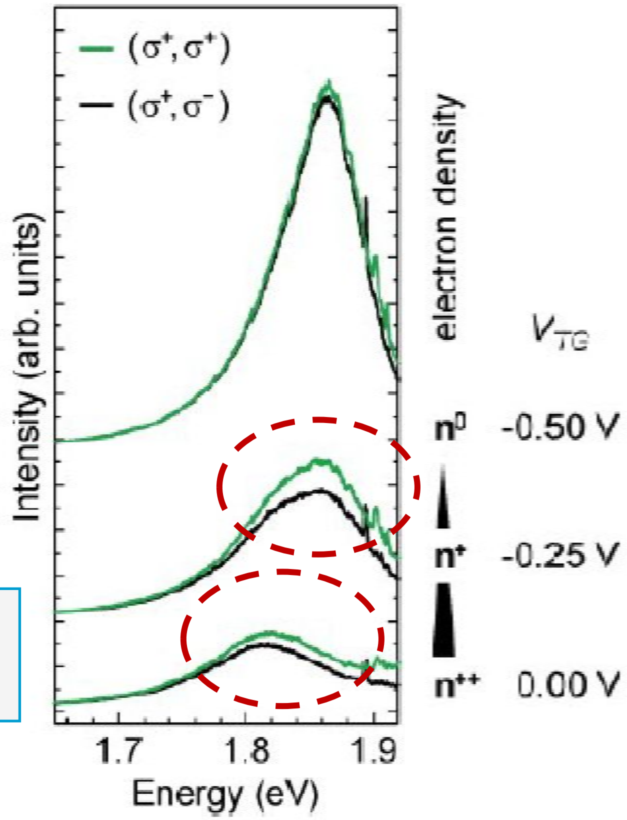
Circularly polarization PL on gated MoS_2 monolayers



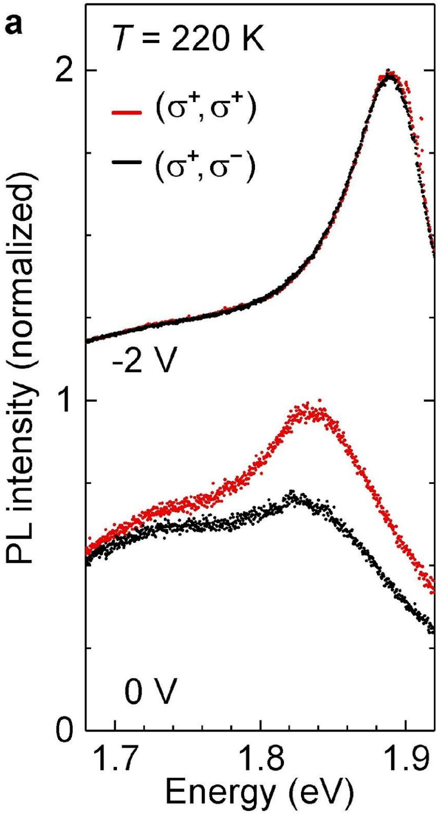
$$\Delta n \approx \frac{10^{13}}{cm^2}$$

Depolarization mechanism at low doping?

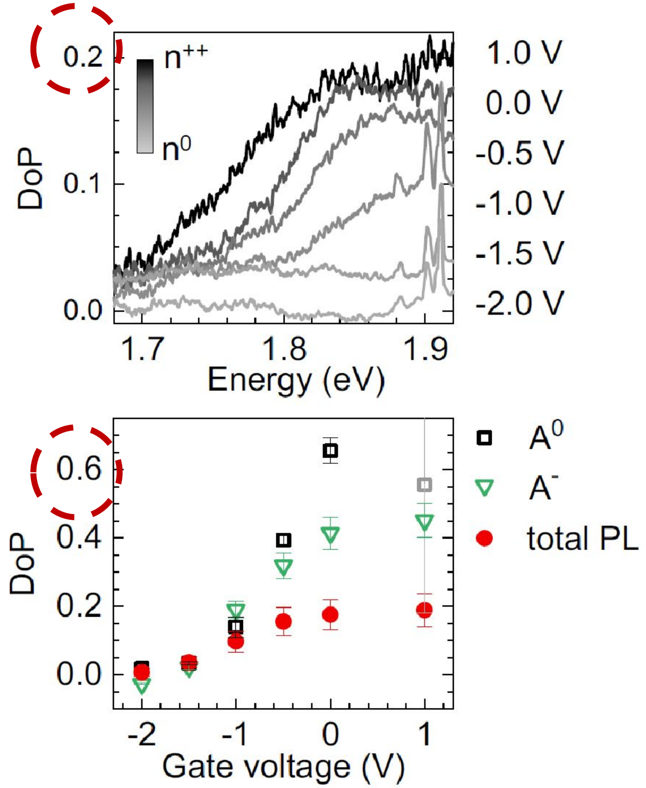
PL at T = 300K



PL at T = 220K



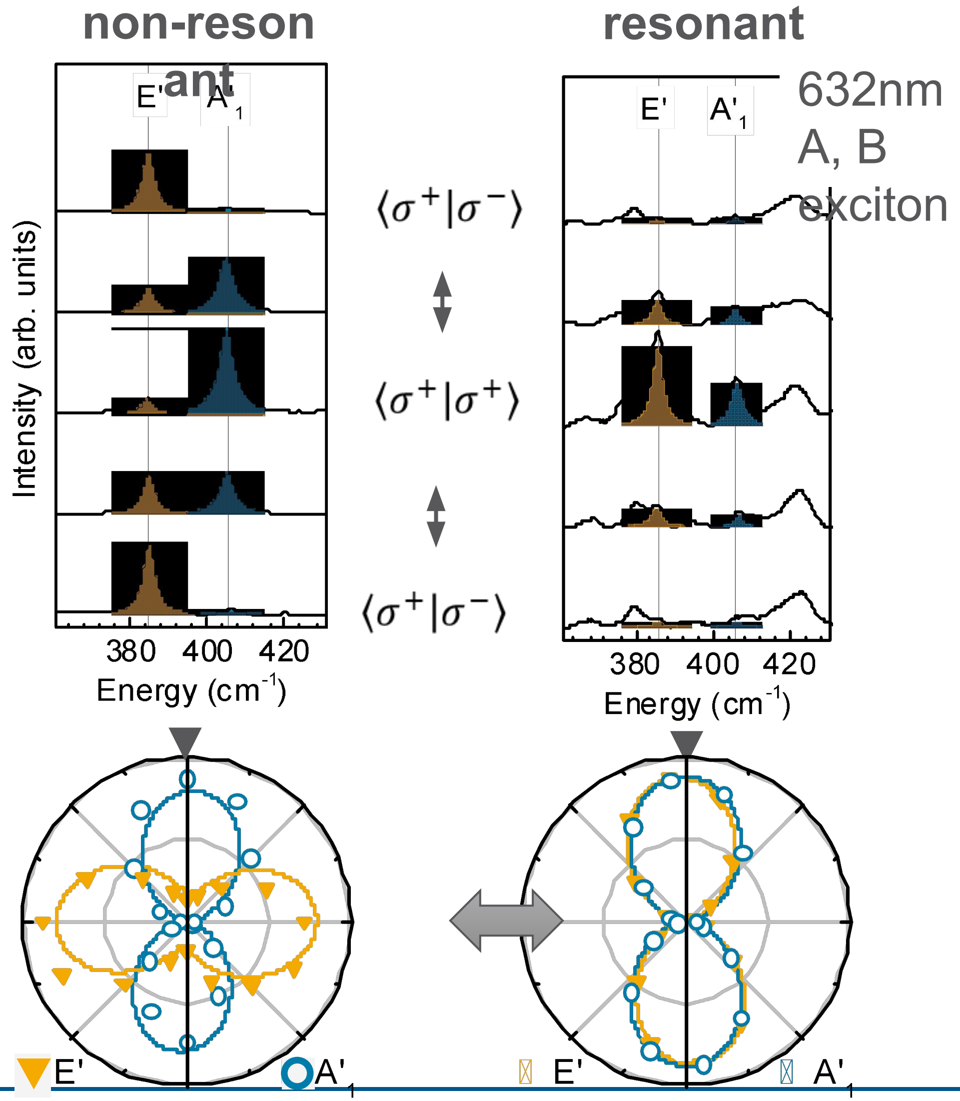
DoP at T = 220K



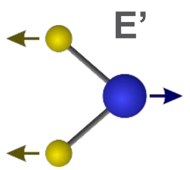
B. Miller, UW *et al.* APL. 106, 122103 (2015)
B. Miller, UW *et al.* Nature Commun. 10, 807 (2019).

"Insights from (R)ILS"

Circularly polarized Raman



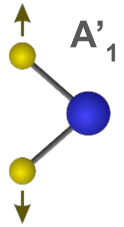
$I \propto |e_s \cdot R \cdot e_i|^2$



$$E'_{DP} = \begin{pmatrix} 0 & d & 0 \\ d & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$E'_{DP} = \begin{pmatrix} d & 0 & 0 \\ 0 & -d & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

→ circular cross-polarized



$$A'_{DP} = \begin{pmatrix} a & 0 & 0 \\ 0 & a & 0 \\ 0 & 0 & b \end{pmatrix}$$

→ circular co-polarized

Fröhlich coupling

$$E_{Fröhlich} = \begin{pmatrix} c & 0 & 0 \\ 0 & c & 0 \\ 0 & 0 & c \end{pmatrix}$$

→ circular co-polarized

B. Miller, UW *et al.* Nature Commun. 10, 807 (2019).

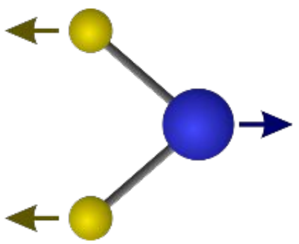
Fröhlich exciton-phonon coupling

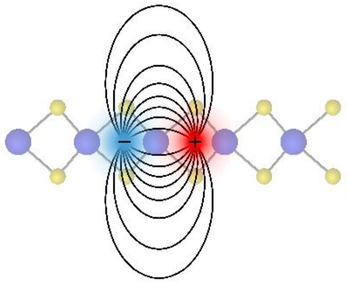
Circularly polarized Raman

LO mode, polar

1s exciton

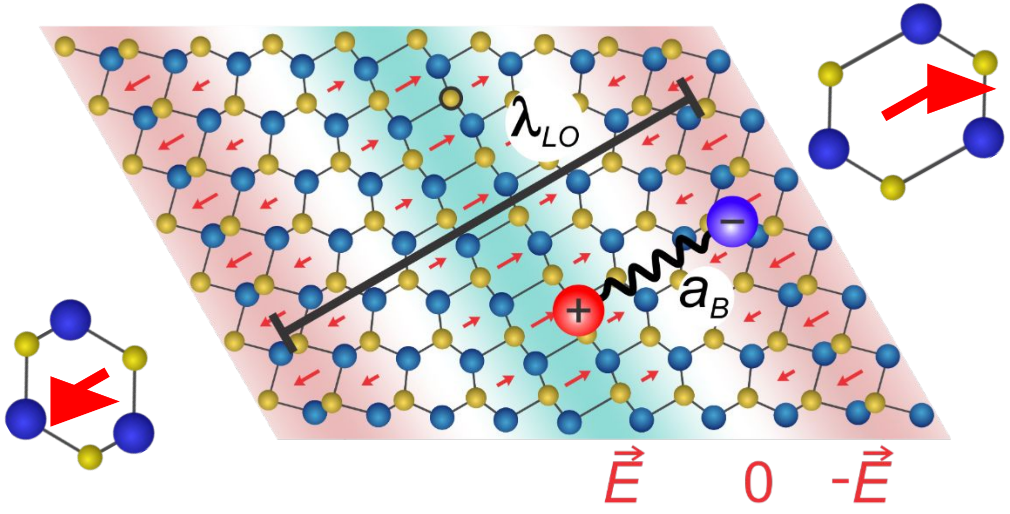
E'





Fröhlich exciton-LO phonon coupling

(long range → macroscopic E-field)



Fröhlich coupling

$$E_{Fröhlich} = \begin{pmatrix} c & 0 & 0 \\ 0 & c & 0 \\ 0 & 0 & c \end{pmatrix}$$

→ circular co-polarized

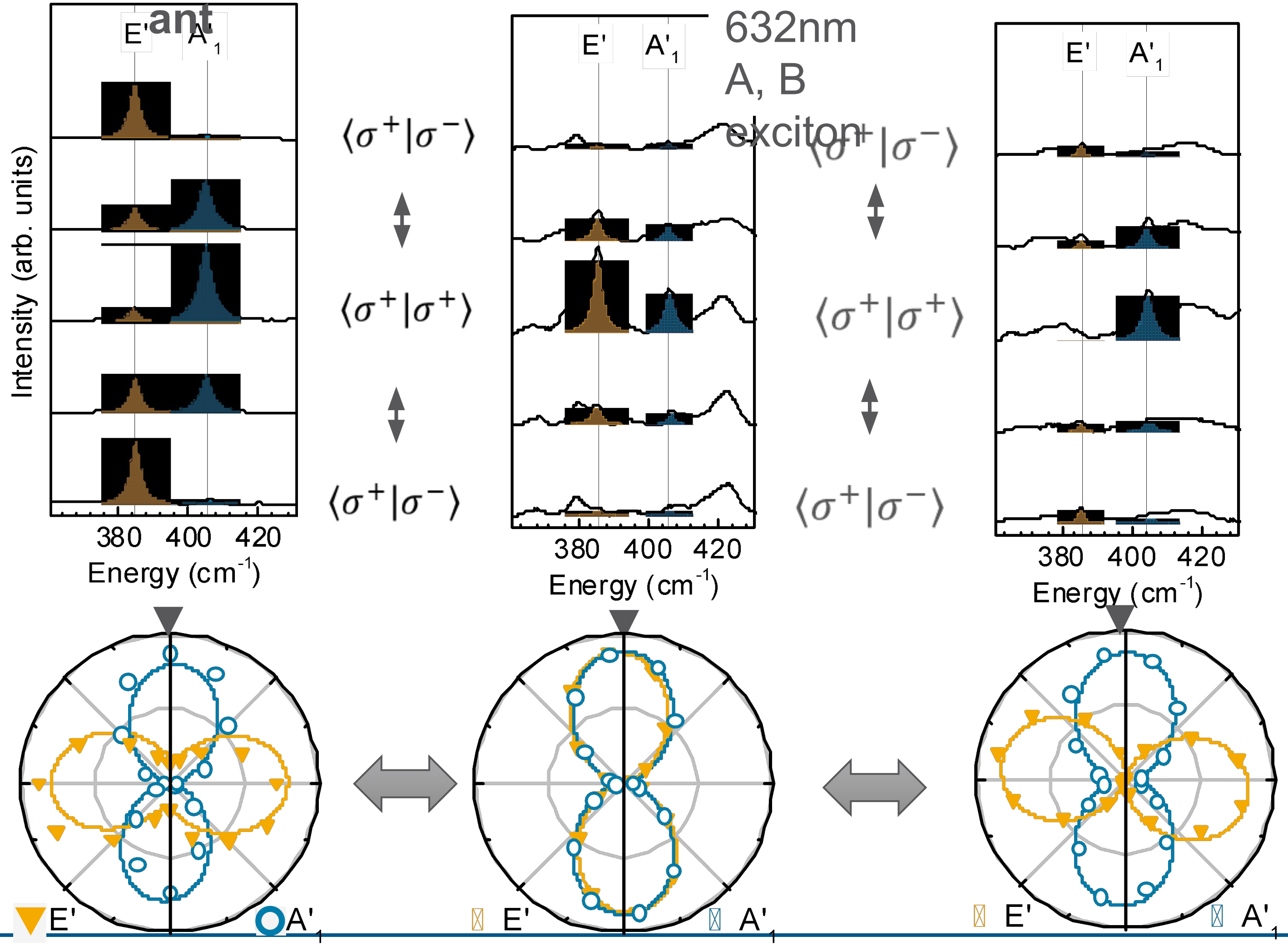
H. Fröhlich, Advances in Physics, 3, 325 (1954).
J. Mendez, E. Cardonna, PRB 31, 3696 (1985).

Ursula Wurstbauer

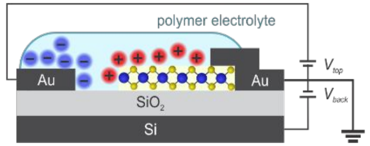
“Insights from (R)ILS”

Circularly polarized Raman

non-resonant | resonant – low doping | resonant – high doping



Field effect devices:



$$\Delta n \approx \frac{10^{13}}{cm^2}$$

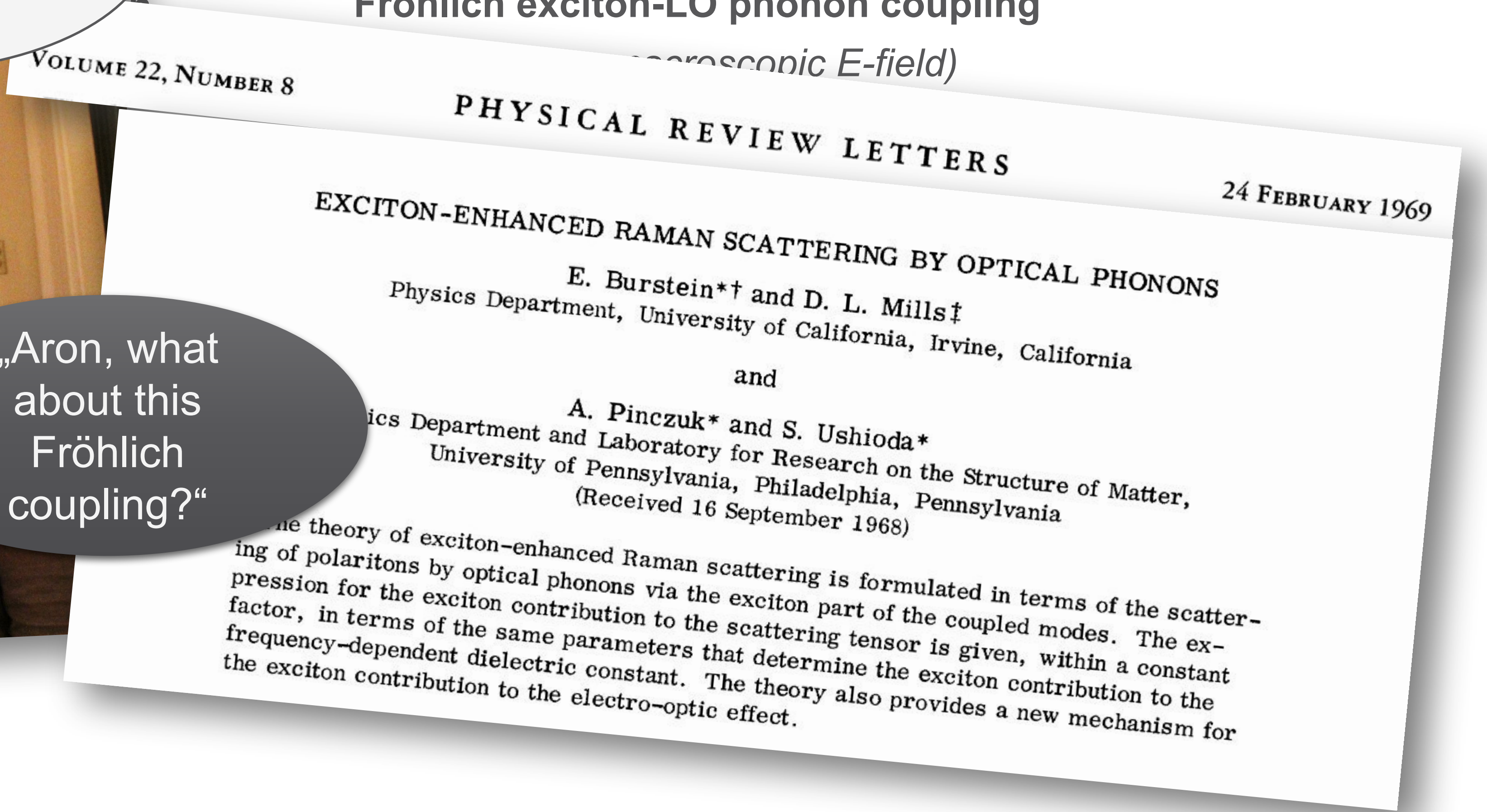
Fröhlich exciton-phonon interaction suppressed by doping and depolarization mechanism.

B. Miller, UW *et al.* Nature Commun. 10, 807 (2019).

Fröhlich exciton-phonon coupling

Fröhlich exciton-LO phonon coupling

croscopic E-field)



VOLUME 22, NUMBER 8 PHYSICAL REVIEW LETTERS 24 FEBRUARY 1969

EXCITON-ENHANCED RAMAN SCATTERING BY OPTICAL PHONONS

E. Burstein*† and D. L. Mills‡
Physics Department, University of California, Irvine, California
and
A. Pinczuk* and S. Ushioda*
ics Department and Laboratory for Research on the Structure of Matter,
University of Pennsylvania, Philadelphia, Pennsylvania

(Received 16 September 1968)

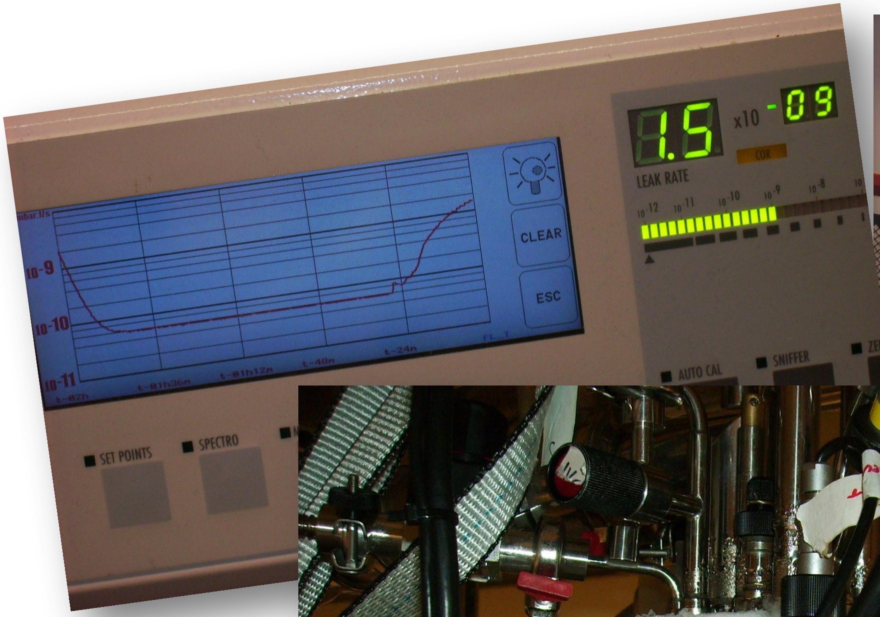
ne theory of exciton-enhanced Raman scattering is formulated in terms of the scattering of polaritons by optical phonons via the exciton part of the coupled modes. The expression for the exciton contribution to the scattering tensor is given, within a constant factor, in terms of the same parameters that determine the exciton contribution to the frequency-dependent dielectric constant. The theory also provides a new mechanism for the exciton contribution to the electro-optic effect.

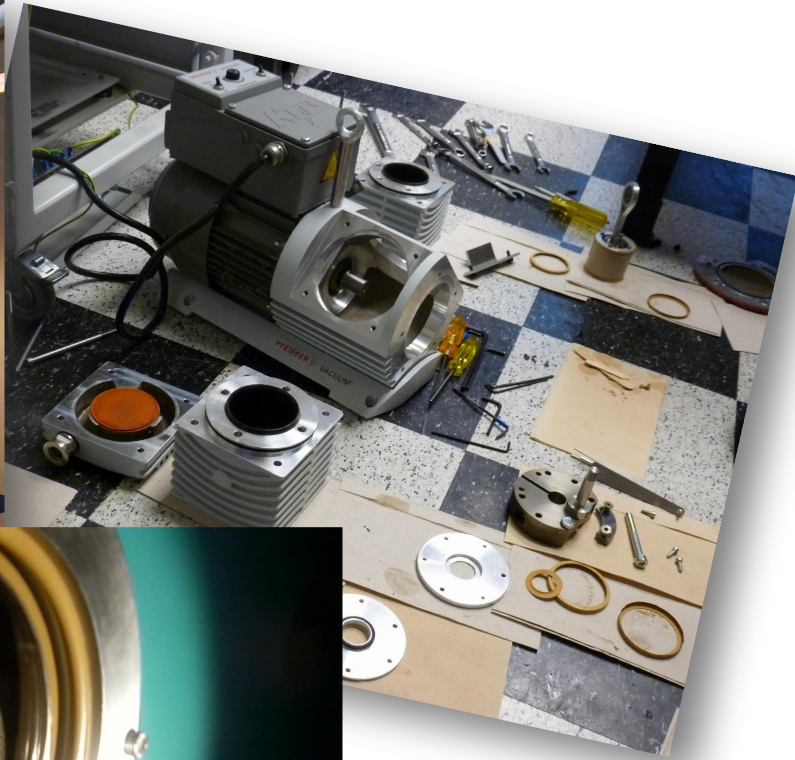
Ursula Wurstbauer

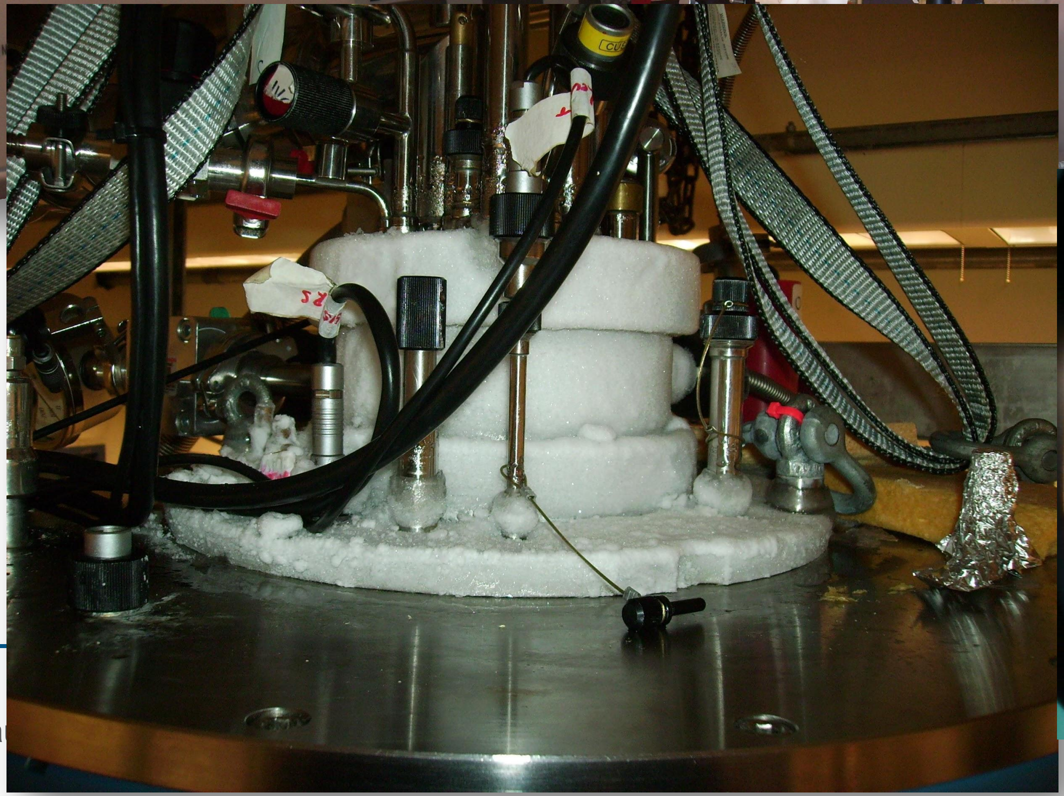
H. Fröhlich, Advances in Physics, 3, 325 (1954).
J. Mendez, E. Cardonna, PRB 31, 3696 (1985).

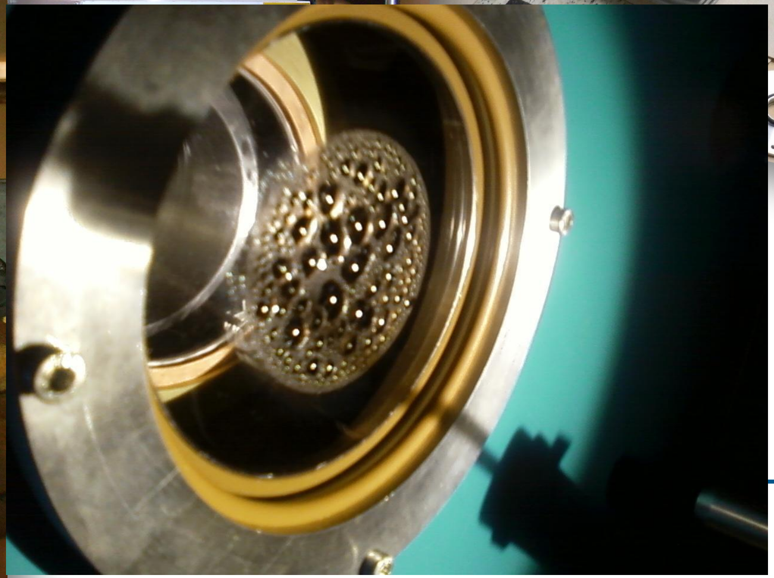
in the lab with Aron

soccer, nuts, fun, tears and the question: “would you like to do a different project”







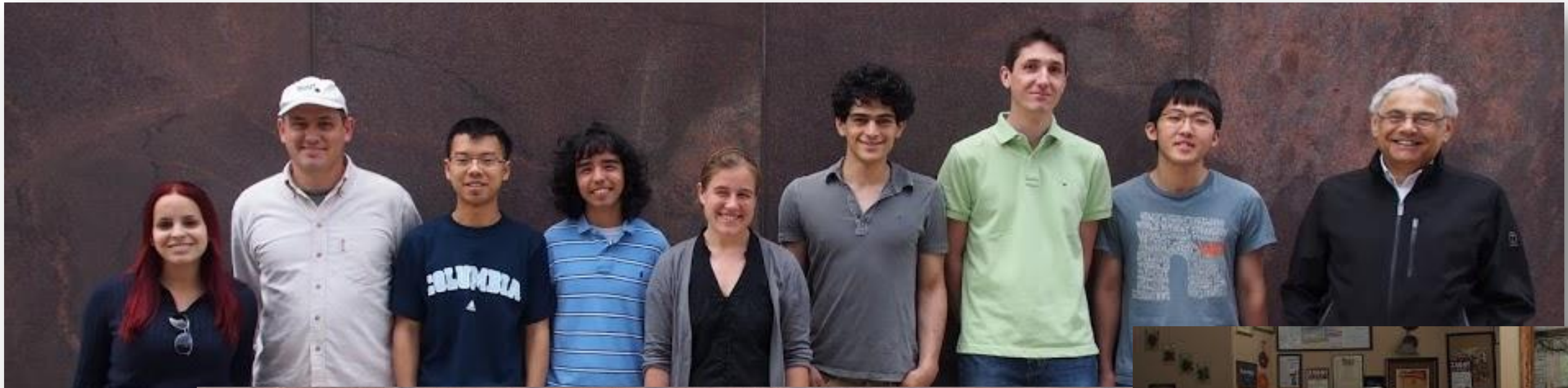


in the lab with Aron

soccer, nuts, fun, tears and lots of data

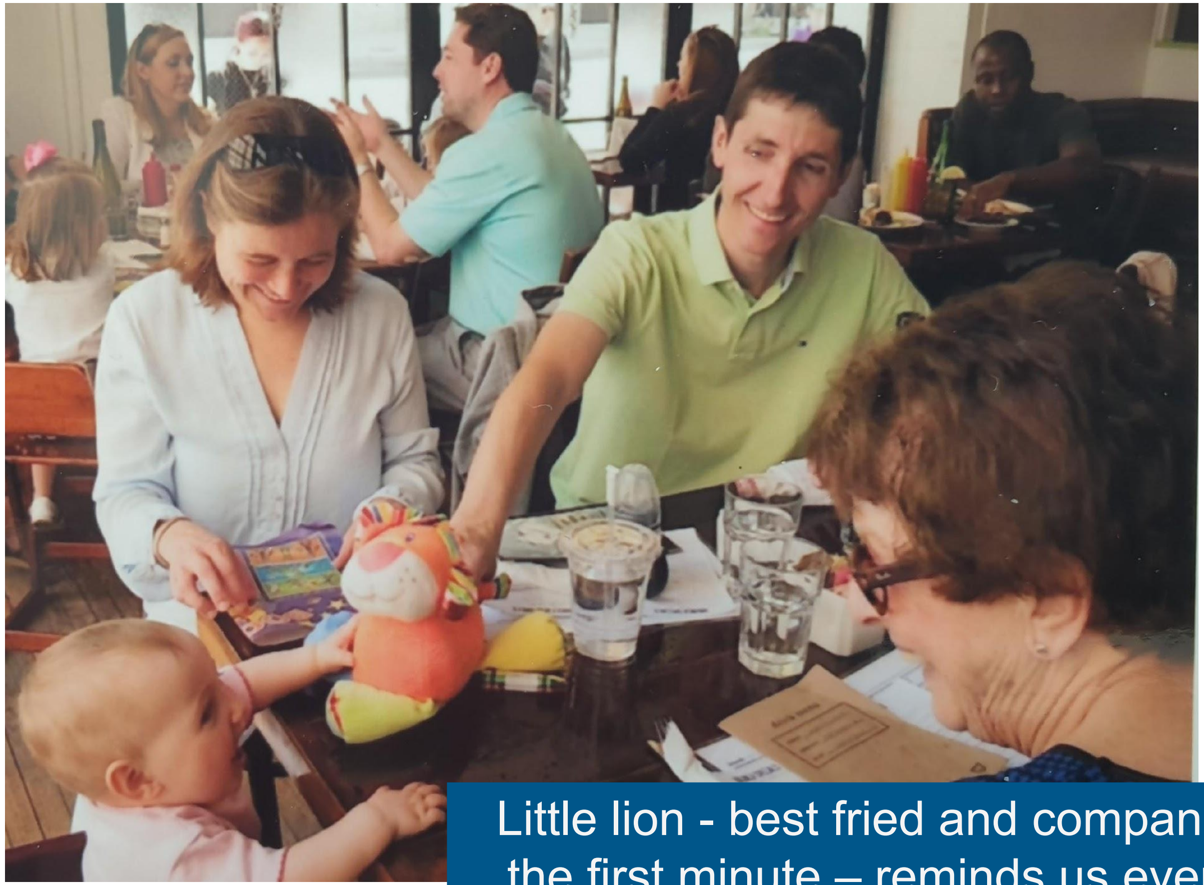
farewell celebrations from Columbia

Going out for group lunch or dinner



Coming back to NYC after 2 years

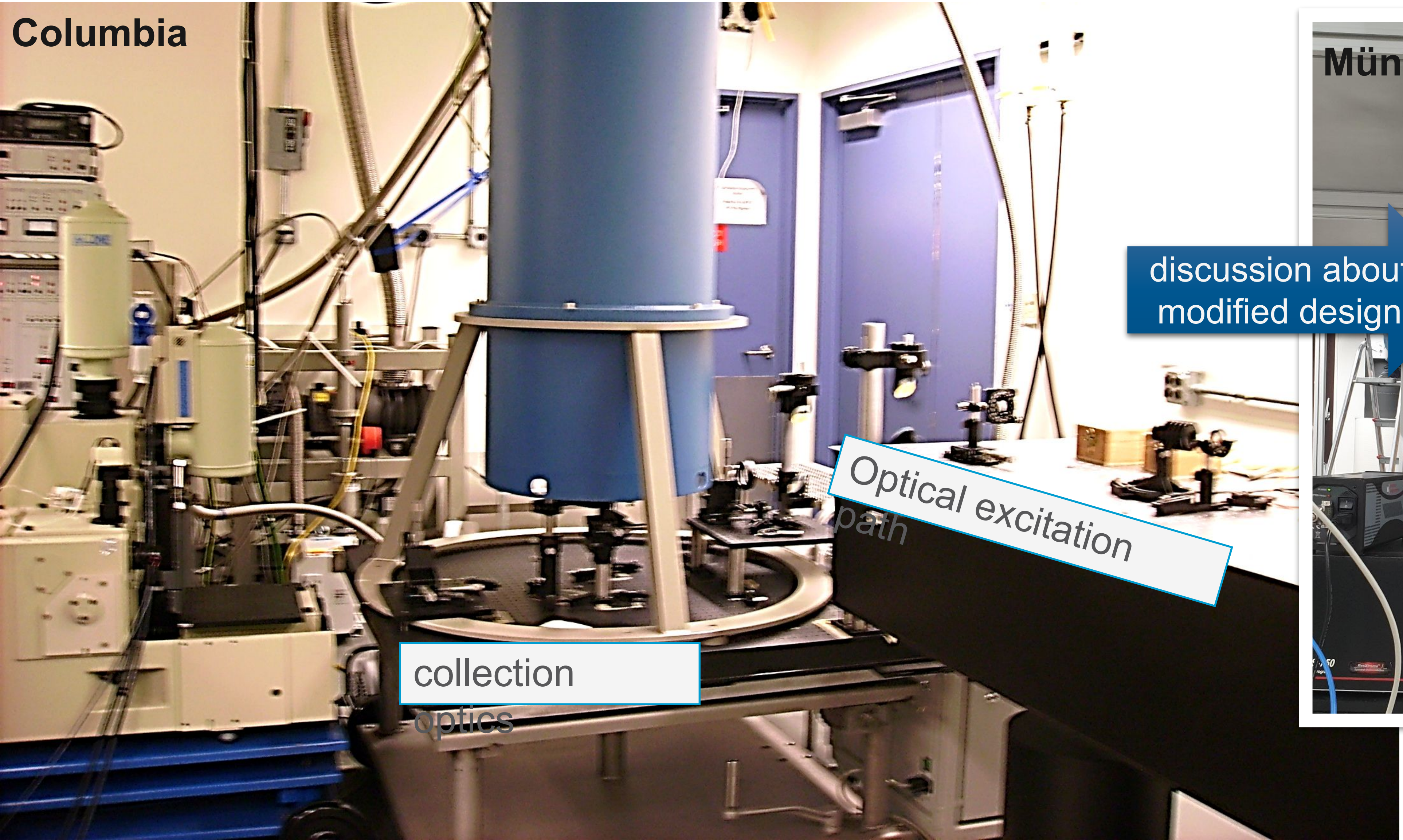
immediately feeling welcome – thank you Aron and Glady's

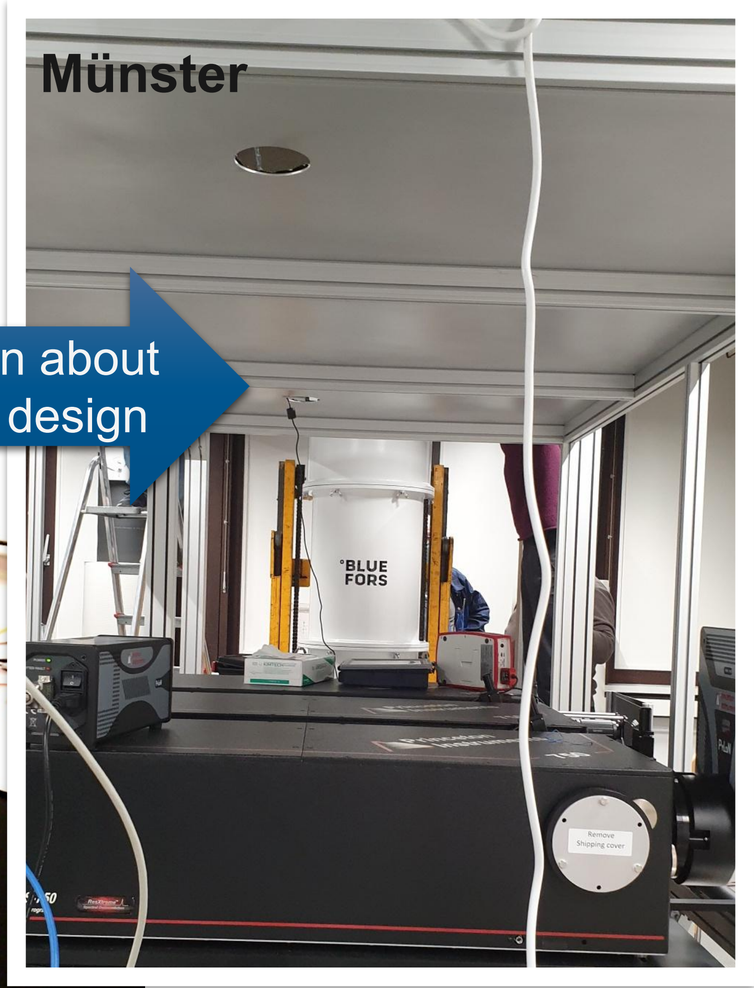


Little lion - best fried and companion of Barbara from the first minute – reminds us every day on Aron and Glady's.

True mentorship and support

during a “lock-down” Zoom session between Pinczuk and Wurstbauer groups

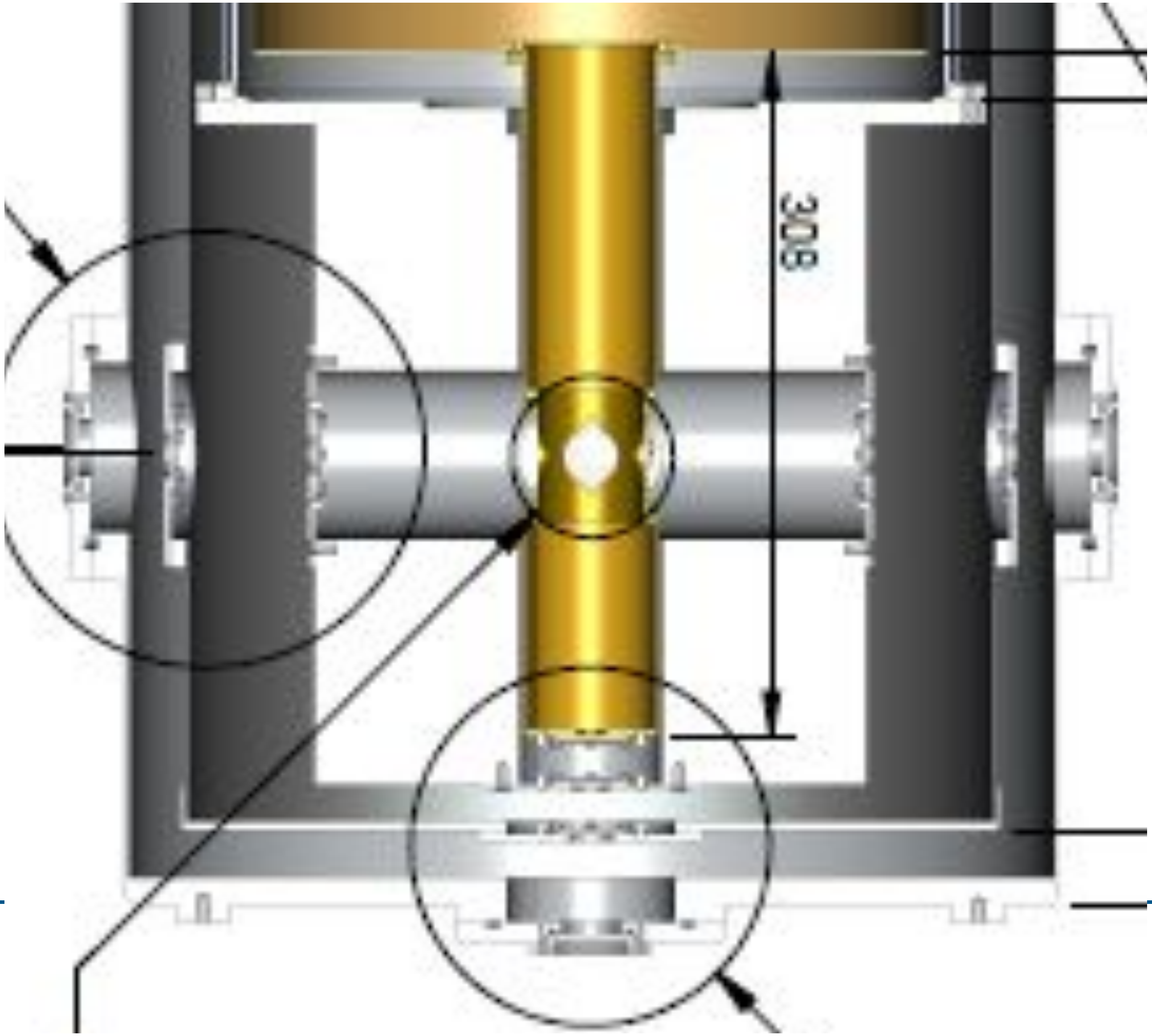




WWU MÜNSTER

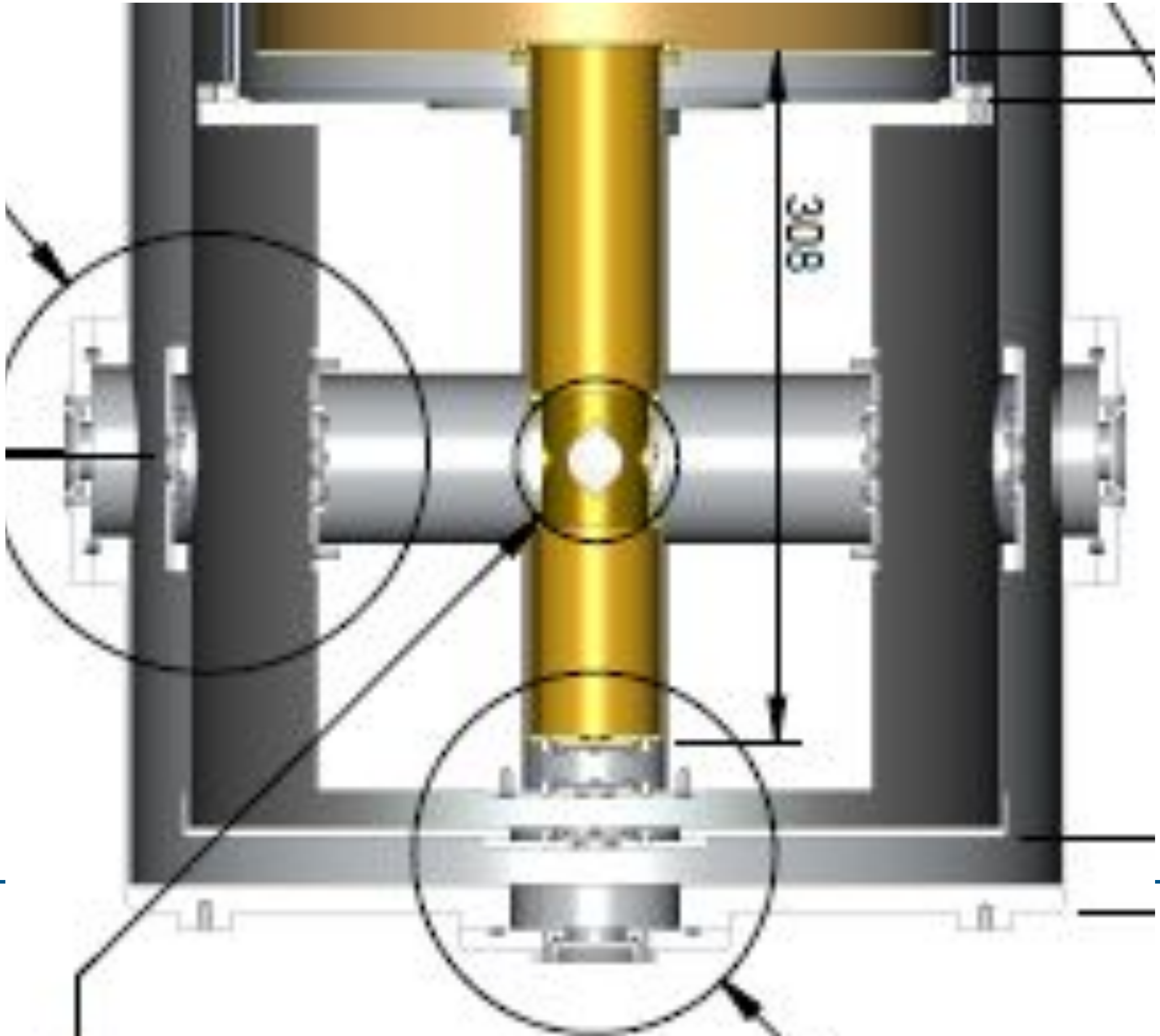
True mentorship and support

during a “lock-down” Zoom session between Pinczuk and Wurstbauer groups

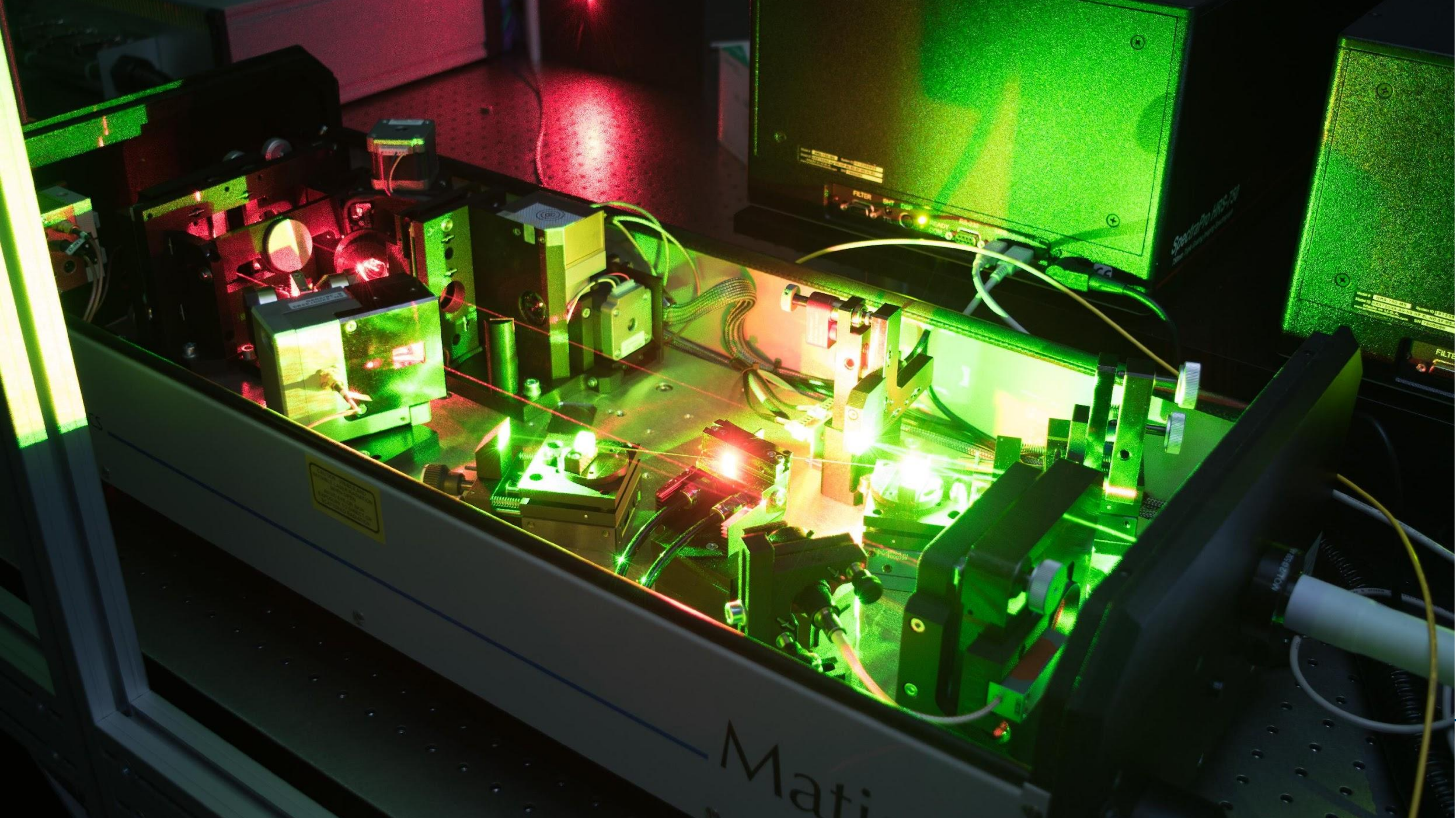


True mentorship and support

during a “lock-down” Zoom session between Pinczuk and Wurstbauer groups



Optical Data	
clear aperture [mm]	4.7
focal length [mm]	2.87
numerical aperture(NA)	0.82
working distance	0.65 mm (1.40 mm)
Spectral Performance	
AR coating (> 80% trasnmission) [nm]	400 .. 1000
apochromatic range (df < +/- delta) [nm]	565 .. 770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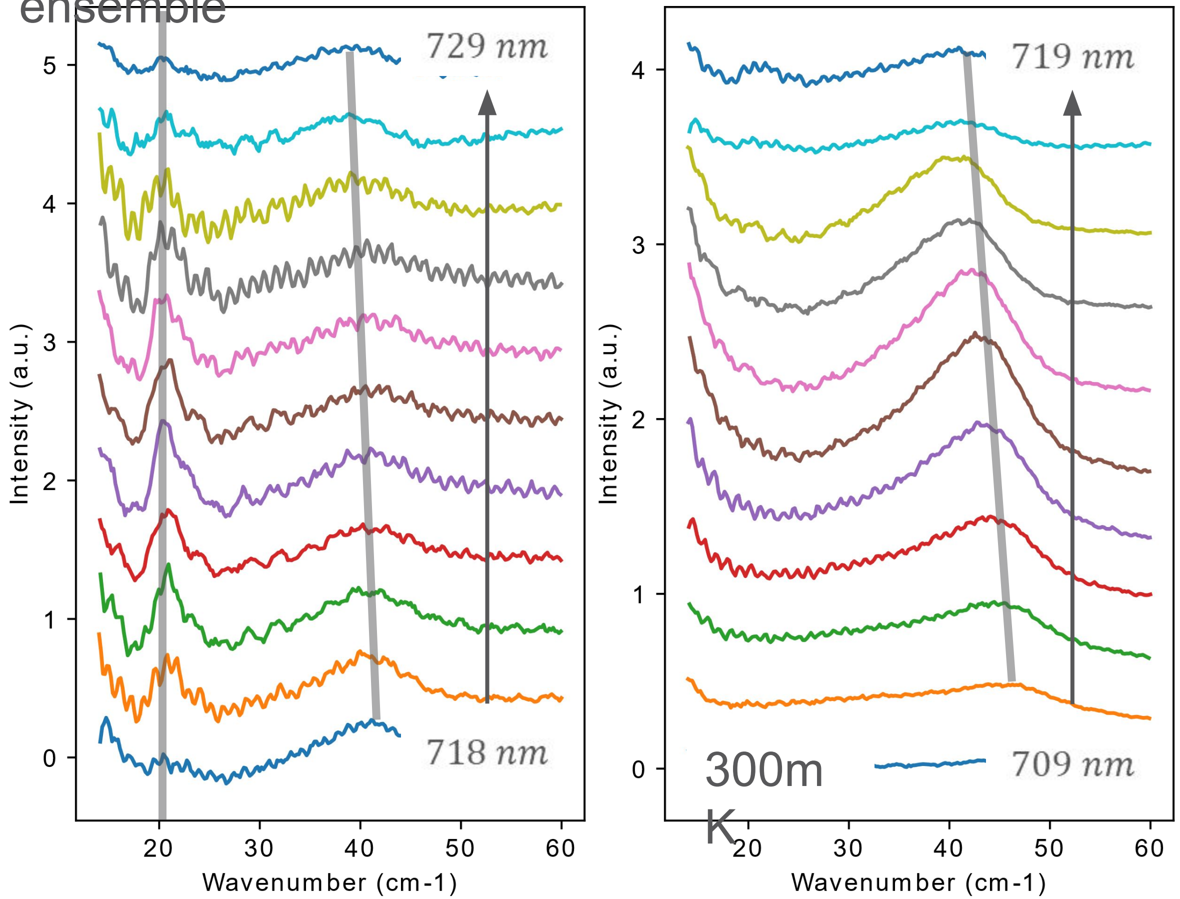
Mati

fingerprints for collective excitation in van der Waals materials from mK-RILS

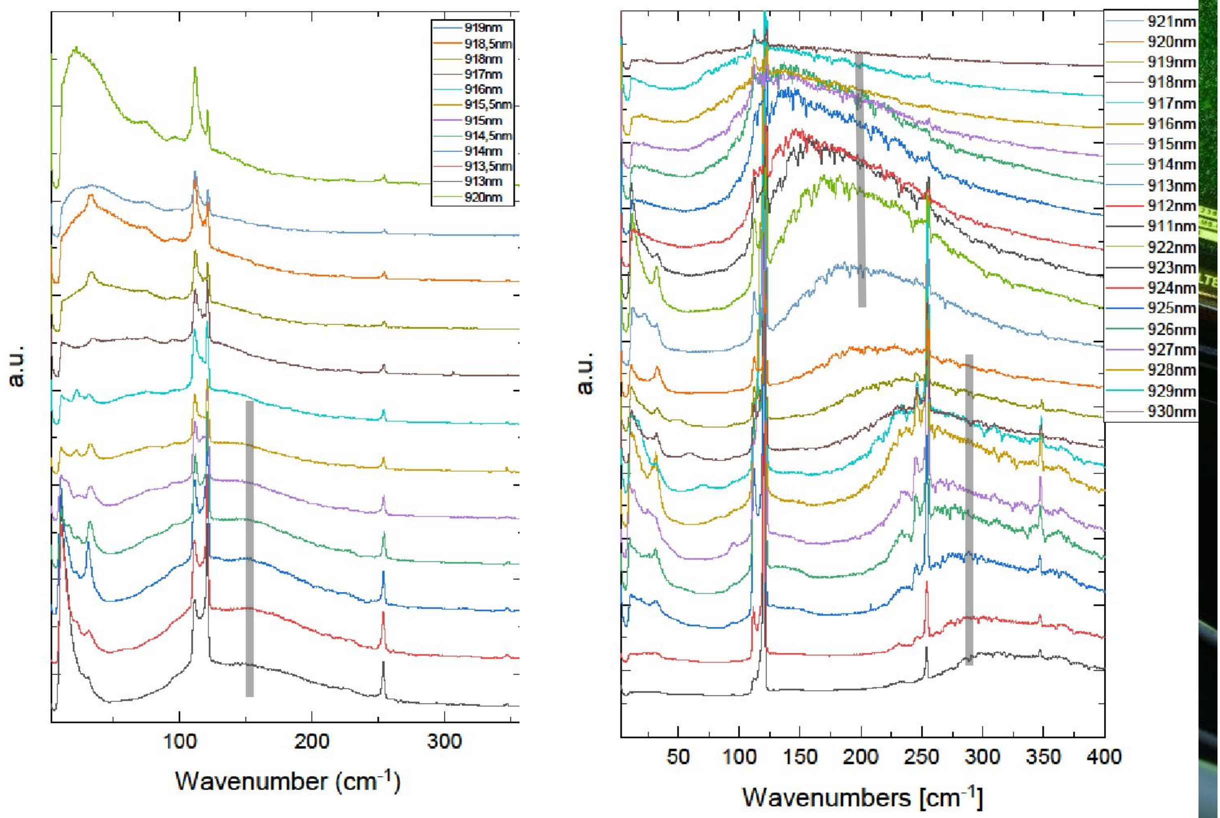
Reconstructed $MoSe_2/WSe_2$ with degenerate IX ensemble



CrSBr – a layered magnetic semiconductor

T = 4K ; B = 0T

T = 4K ; B = 5T



Aron, thank you very much for teaching me and sharing the beauty of RILS – and for the continued support!

A life for science and the science "family" & his students

Mo 27.12.2021 16:11

Aron Pinczuk <ap359@columbia.edu>

Re: Season's Greetings

An ursula@wurstbauer.de

Cc apinczuk PNAS

Sie haben am 29.12.2021 01:14 auf diese Nachricht geantwortet.

Dear Ursula,

Many thanks fo email and season's greeting You have a lovely family. You al look great!

This year my Holiday Season is complicated. This fall our teaching has been in-person.
I am now very busy with calculating final grades and with related activities. In carrying out this work I neglected conventional contacts of the season.

Gladys and I hope you had a wonderful Christmas and Wish you a Very Happy New Year.

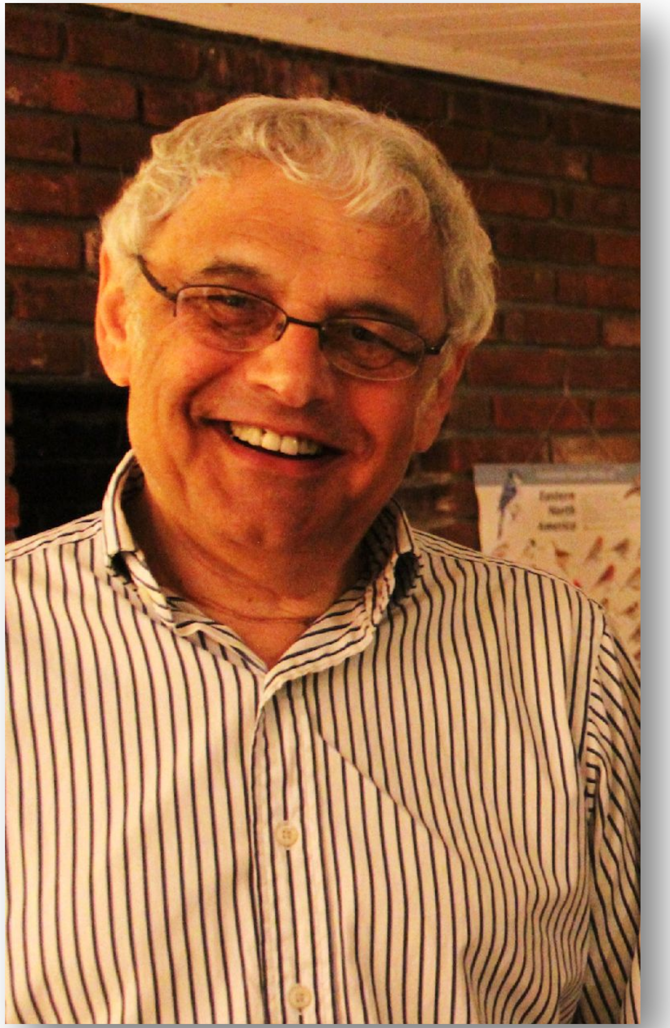
We got the NSF grant and Ziyu started training in the operation of the Kelvinox dil-fridge.

Shall we set up a Zoom session to talk about physics?

With kind regards,

Aron

Aron



Aron, I feel very privileged that I am part of your „science family“ . I truly acknowledge your great mentorship through all the years. Without you I would not be were I am now and I would not be the person I am today.

Thank you!