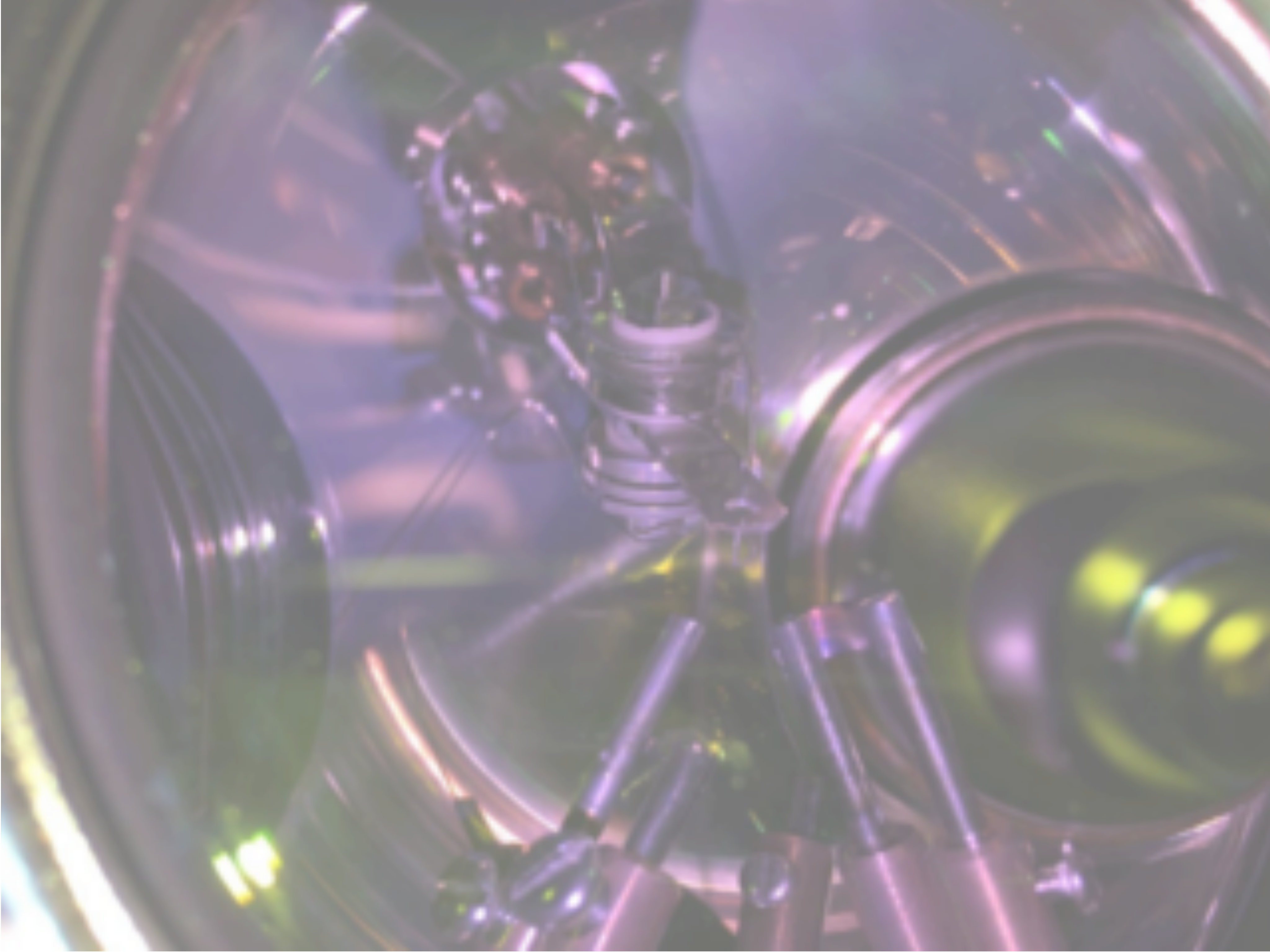


Spectroscopy with twisted ligh
or: how ions learnt how to stop worrying and love the twist

Gallieno Denardo Award, Trieste 2019

Christian Tomás Schmiegelow

universidad de buenos aires - exactas
departamento de física
Juan José Giambiagi

CONICET

Roadmap to this talk

Part 1

Context and history: Spectroscopy and twisted Light

Part 2

Results: Atomic Spectrocopy with Twisted Light

Part 3

Closing: Thanks, future plans, other things.

Polarization Rotation

1811

Argo: rotation of polarization by Quartz crystals

1815

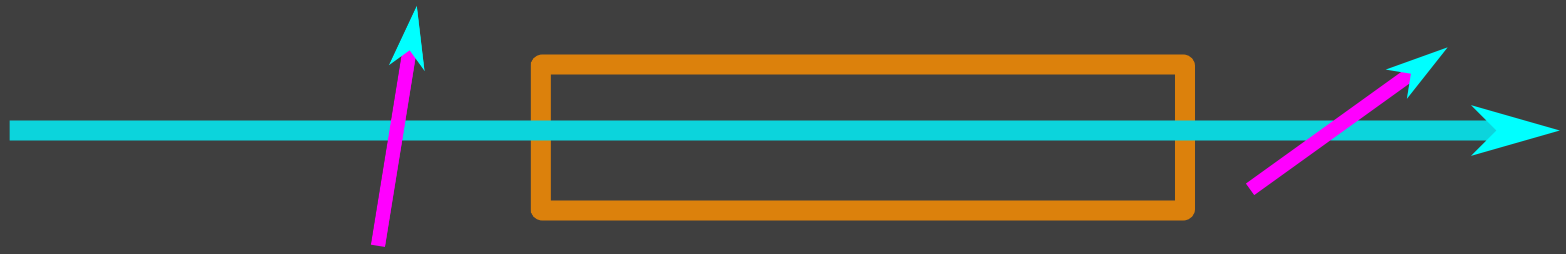
Biot: rotarion of polarization by Organic Chemicals

1820

Herschel: quartz and "anti-quartz"

1849 and 1974

Pasterur, van't Hoff and Lebel:
dextro and levo molecules explanation



Light-Matter Interaction Summary

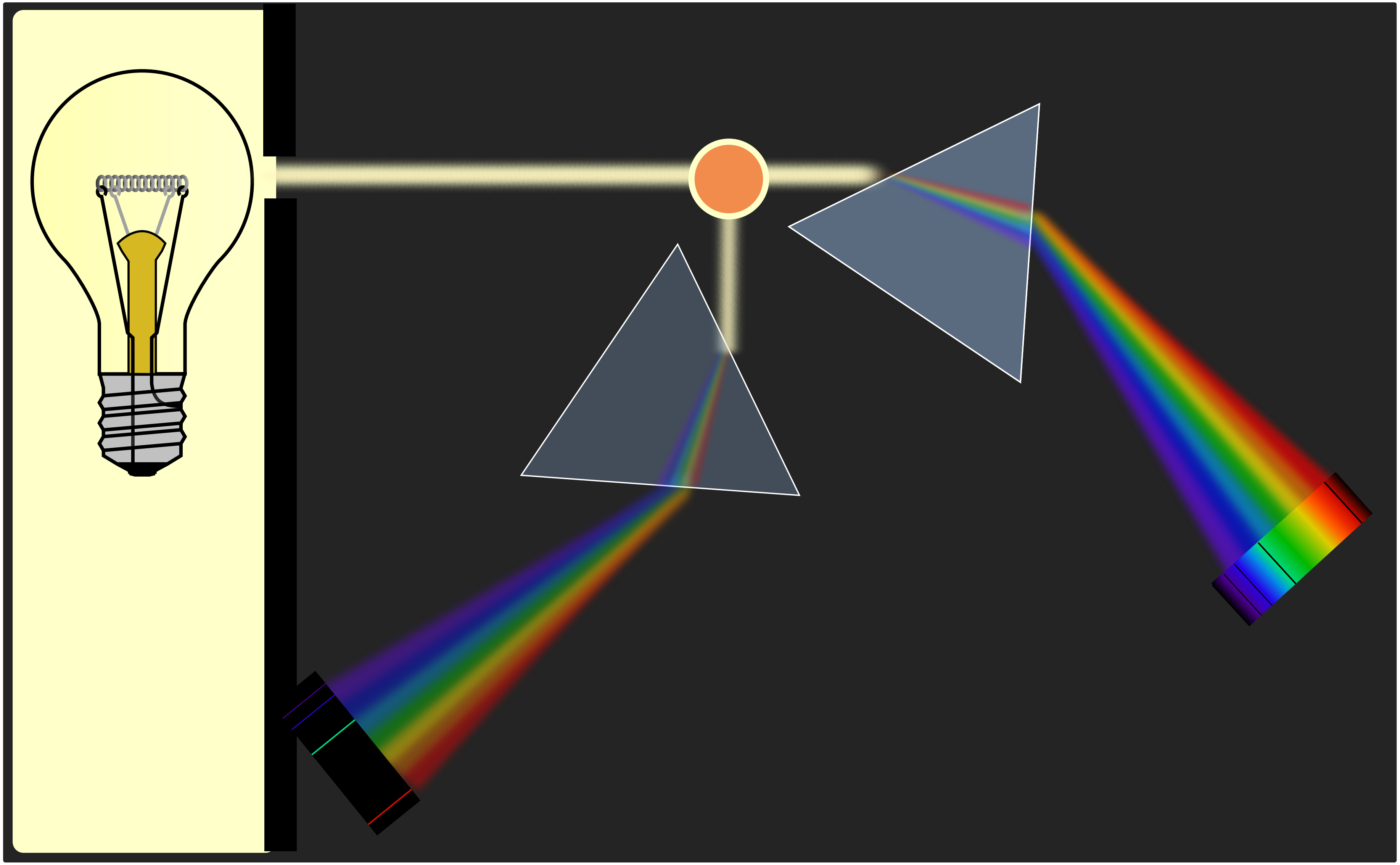
	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
Energy - Linear Momentum			
Spin Angular Momentum			✓ Optical Activity
Orbital Angular Momentum			

Light-Matter Interaction Summary

	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
Energy - Linear Momentum			✓ Refraction
Spin Angular Momentum			✓ Optical Activity
Orbital Angular Momentum			

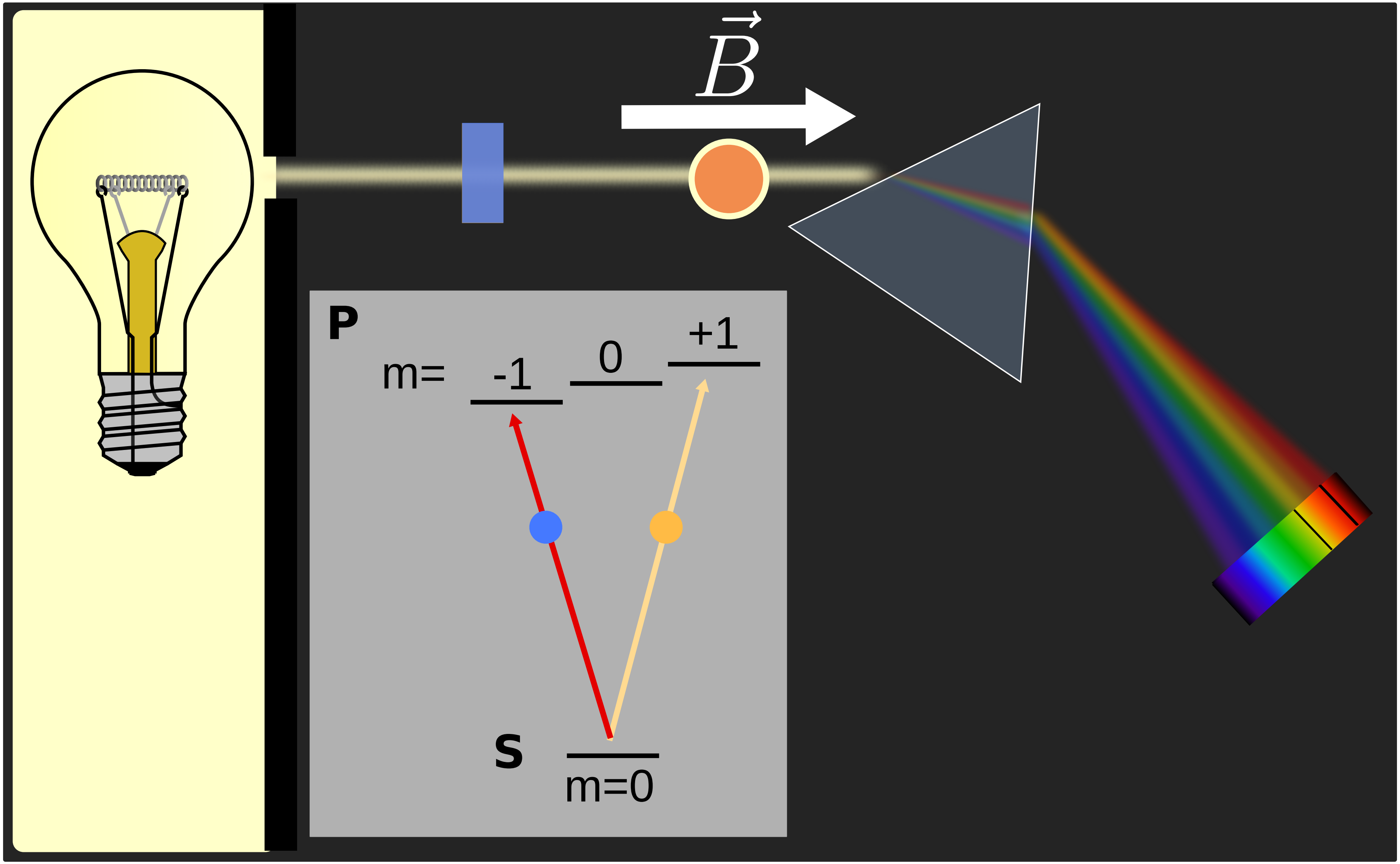
Atomic Spectroscopy

Wollaston and Fraunhofer (1802 and 1814)



Atomic Spectroscopy

Zeeman Splitting



Light Matter interaction
Photon Angular Momentum

Über eine Anomalie bei der Polarisation der Ramanstrahlung
- W. Hanle, Naturwissenschaften May 1931, Volume 19, Issue 18, pp 375-375
- R. Bär, Naturwissenschaften May 1931, Volume 19, Issue 22, pp 463-463

Evidence for the Spin of the Photon from Light-Scattering.
- C. V. Raman & S. Bhagavantam, Nature 128, 114-115 (18 July 1931)

Also...
- A. Kastler, Compt. Rend., 193 (1931) 1075.
- J. Cabannes, J. Phys., 2 (1931) 381.

Non existence d'un spin des photons

A. Kastler - J. Phys. Radium 2, 159-164 (1931)

....

....

....

The Nobel Prize in Physics 1966 was awarded to Alfred Kastler "for the discovery and development of optical methods for studying Hertzian resonances in atoms".

Light-Matter Interaction Summary

	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
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Spin Angular Momentum	✓ Hanle & Bär		✓ Optical Activity
Orbital Angular Momentum			

Light field description

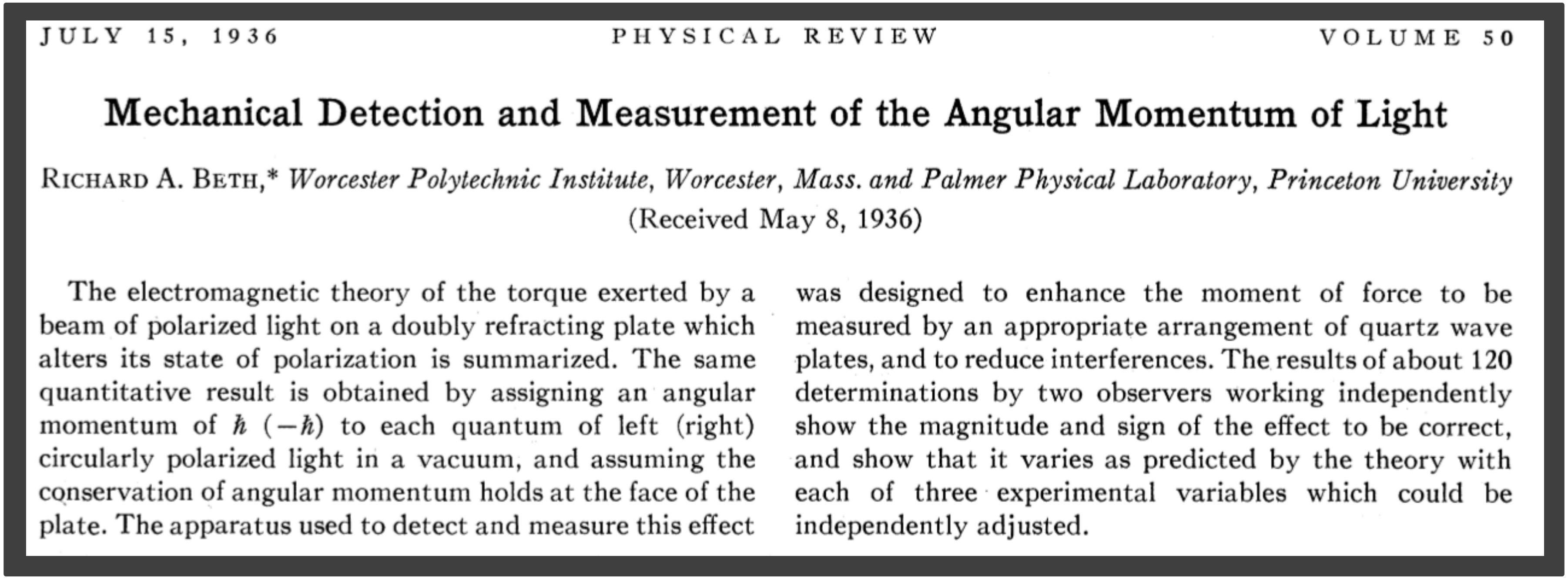
Oscilating Field

$$A = A_{lp}(\rho, \phi, z)\ \vec{\epsilon}\ e^{-i\omega t}$$

Mechanical Efects

Mechanical Effects

1936,Beth - Angular Momentum


JULY 15, 1936 PHYSICAL REVIEW VOLUME 50

Mechanical Detection and Measurement of the Angular Momentum of Light

RICHARD A. BETH,* *Worcester Polytechnic Institute, Worcester, Mass. and Palmer Physical Laboratory, Princeton University*

(Received May 8, 1936)

The electromagnetic theory of the torque exerted by a beam of polarized light on a doubly refracting plate which alters its state of polarization is summarized. The same quantitative result is obtained by assigning an angular momentum of $\hbar$ ($-\hbar$) to each quantum of left (right) circularly polarized light in a vacuum, and assuming the conservation of angular momentum holds at the face of the plate. The apparatus used to detect and measure this effect was designed to enhance the moment of force to be measured by an appropriate arrangement of quartz wave plates, and to reduce interferences. The results of about 120 determinations by two observers working independently show the magnitude and sign of the effect to be correct, and show that it varies as predicted by the theory with each of three experimental variables which could be independently adjusted.

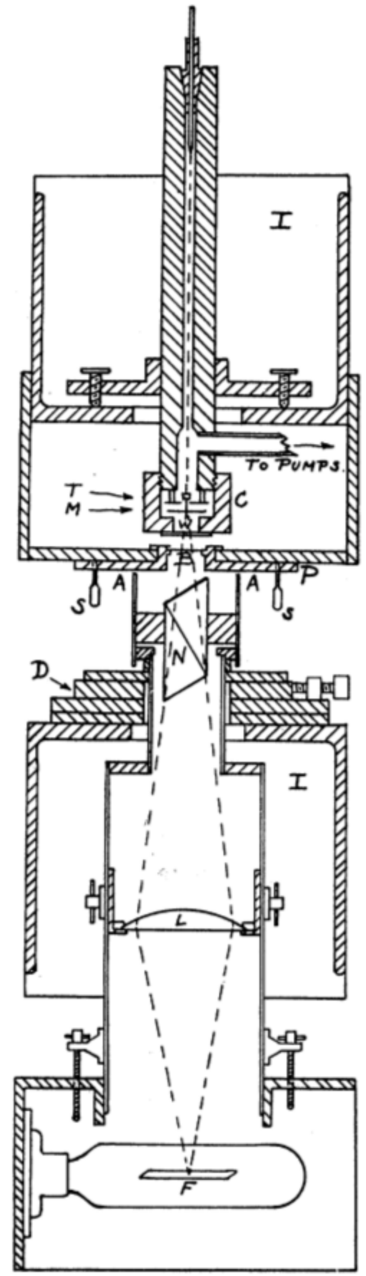


Fig. 1. Diagram of apparatus.

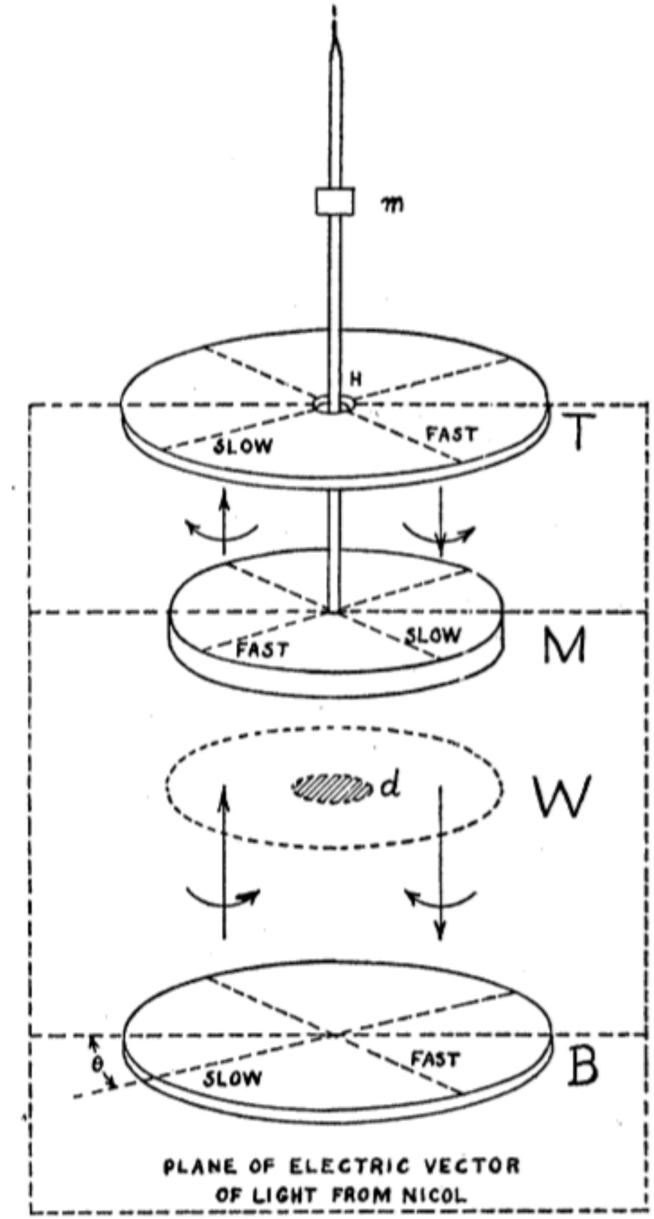


Fig. 3. Wave plate arrangement.

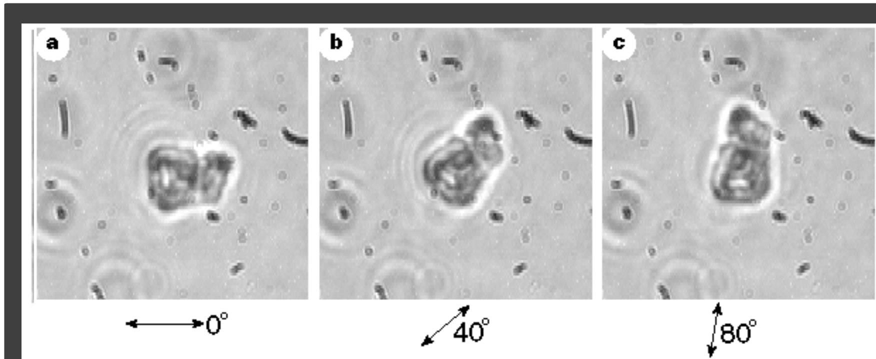
Light Matter interaction
Beth revisited - Angular Momentum

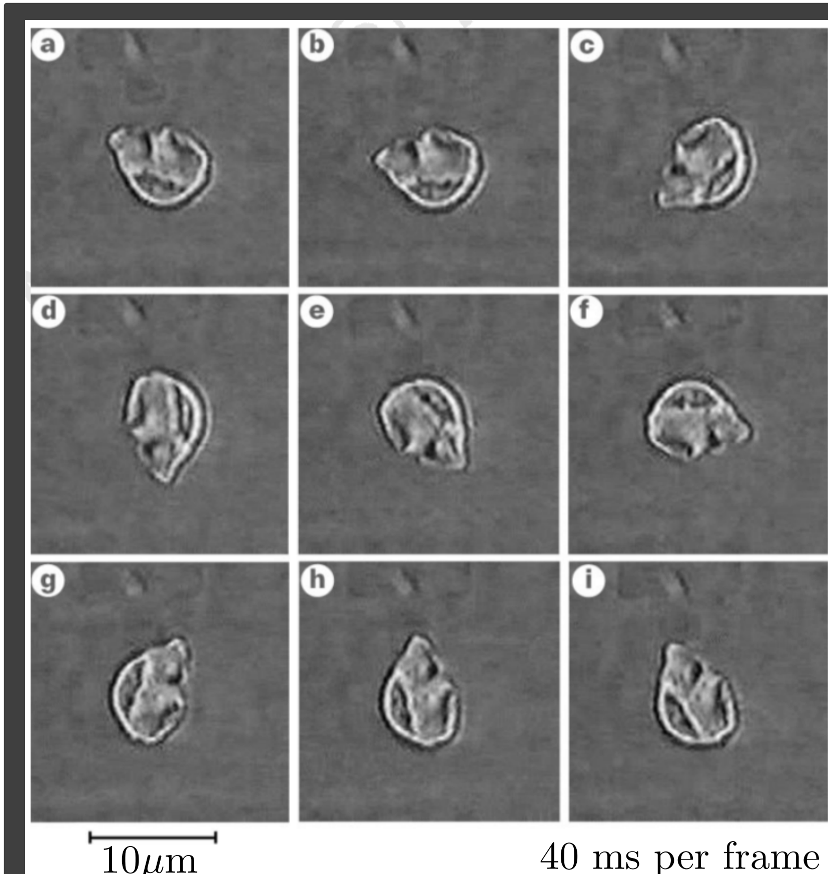
NATURE | VOL 394 | 23 JULY 1998

Optical alignment and spinning of laser-trapped microscopic particles

M. E. J. Friese, T. A. Nieminen, N. R. Heckenberg & H. Rubinsztein-Dunlop

Centre for Laser Science, Department of Physics, The University of Queensland, Brisbane, Queensland 4072, Australia





Mechanical Effects

Linear Momentum

1619

Kepler: Comet Tails

1901

Nicols radiometer

19xx

Photon recoil

19xx

Satellites and spacecrafts

NOT - Crooks Radiometer.

Light-Matter Interaction Summary

	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
Energy - Linear Momentum	✓ Fraunhofer	✓ Radiation Pressure	✓ Refraction
Spin Angular Momentum	✓ Hanle & Bät	✓ Beth	✓ Optical Activity
Orbital Angular Momentum			

Light field description

Plane Wave

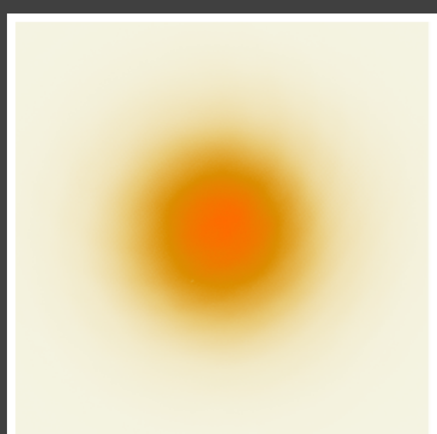
$$A = A_{lp}(\rho, \phi, z)\vec{\epsilon} e^{ikz} e^{-i\omega t}$$

Twisted Light

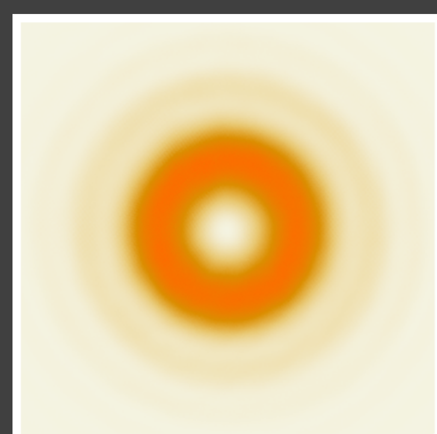
$$A = A_{lp}(\rho, \phi, z)\vec{\epsilon}e^{ikz}e^{-i\omega t}$$

$$\mathbf{A}_{lp} = \mathbf{A_0}\ \frac{w_0}{w(z)} \exp\left(\frac{-\rho^2}{w(z)} + \frac{ik\rho^2}{2R(z)} + i\Phi_g(z)\right)$$

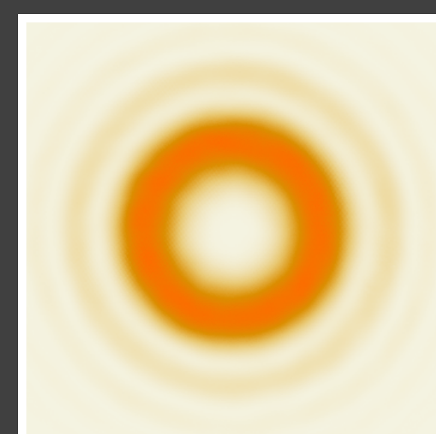
$$\sqrt{\frac{2p!}{\pi(|l|+p)!}} \left(\frac{\sqrt{2}\rho}{w(z)}\right)^{|l|} \mathcal{L}_p^{|l|}\left(\frac{2\rho^2}{w^2(z)}\right) \exp(il\phi)$$



$l = 0$



$l = 1$



$l = 2$

Orbital Angular Momentum of Light

who got the party started?

PHYSICAL REVIEW A VOLUME 45, NUMBER 11 pg. 8185 1 JUNE 1992

Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes

L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman
Huygens Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

a Laguerre-Gauss beam...

... has spin and **orbital** angular momentum.

$$\mathbf{M} = \epsilon_0 \mathbf{r} \times \langle \mathbf{E} \times \mathbf{B} \rangle$$

$$M_z = \frac{l}{\omega} |u|^2 + \frac{\sigma_z r}{2\omega} \frac{\partial |u|^2}{\partial r}$$

$$J/cP = (l + \sigma_z)/\omega$$

Orbital Angular Momentum of Light

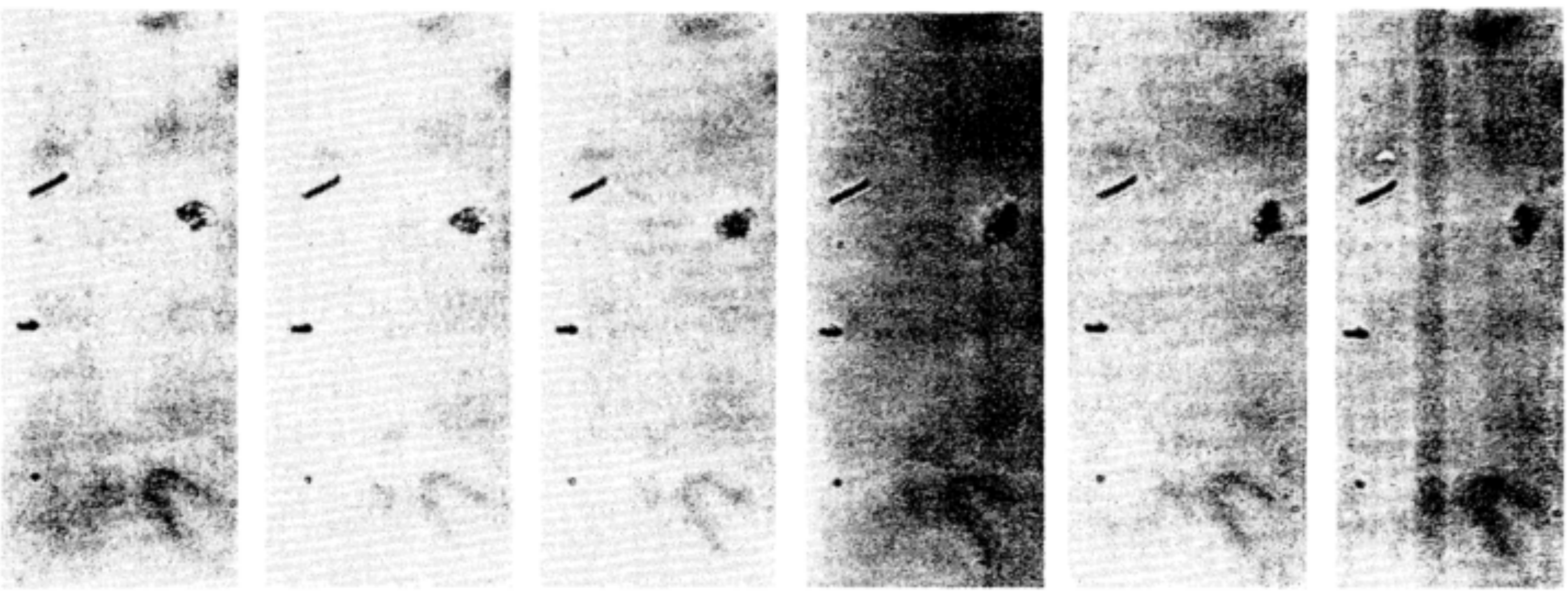
twisting micropic particles

VOLUME 75, NUMBER 5 PHYSICAL REVIEW LETTERS 31 JULY 1995

pg. 826

Direct Observation of Transfer of Angular Momentum to Absorptive Particles from a Laser Beam with a Phase Singularity

H. He, M. E. J. Friese, N. R. Heckenberg, and H. Rubinsztein-Dunlop
Department of Physics, The University of Queensland, Brisbane, Queensland, Australia Q4072



Orbital Angular Momentum of Light

twisting micropic particles

Video intermission coutersy of the
University of Southampton – Optoelectronics Research Centre

Light-Matter Interaction Summary

	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
Energy - Linear Momentum	✓ Fraunhofer	✓ Radiation Pressure	✓ Refraction
Spin Angular Momentum	✓ Hanle & Bät	✓ Beth	✓ Optical Activity
Orbital Angular Momentum		✓ Rubenstein Dunlop	

twisted light optical activity

failed attempts

Araoka, F., Verbiest, T., Clays, K. & Persoons, A.
Interactions of twisted light with chiral molecules: an experimental investigation.
Phys. Rev. A 71,055401 (2005).

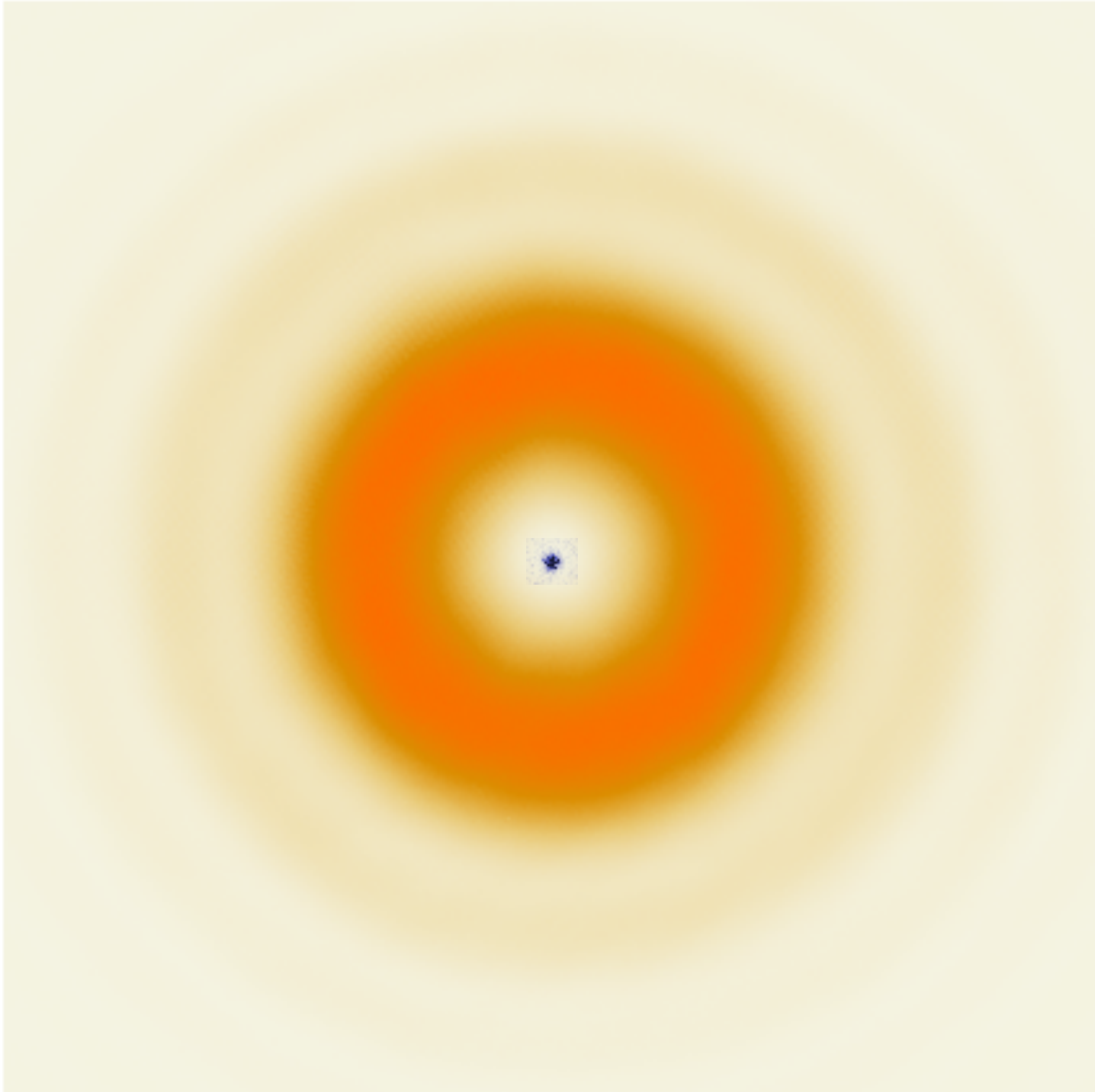
Löffler, W., Broer, D. J. & Woerdman, J. P.
Circular dichroism of cholesteric polymers and the orbital angular momentum of light.
Phys. Rev. A 83, 065801 (2011).

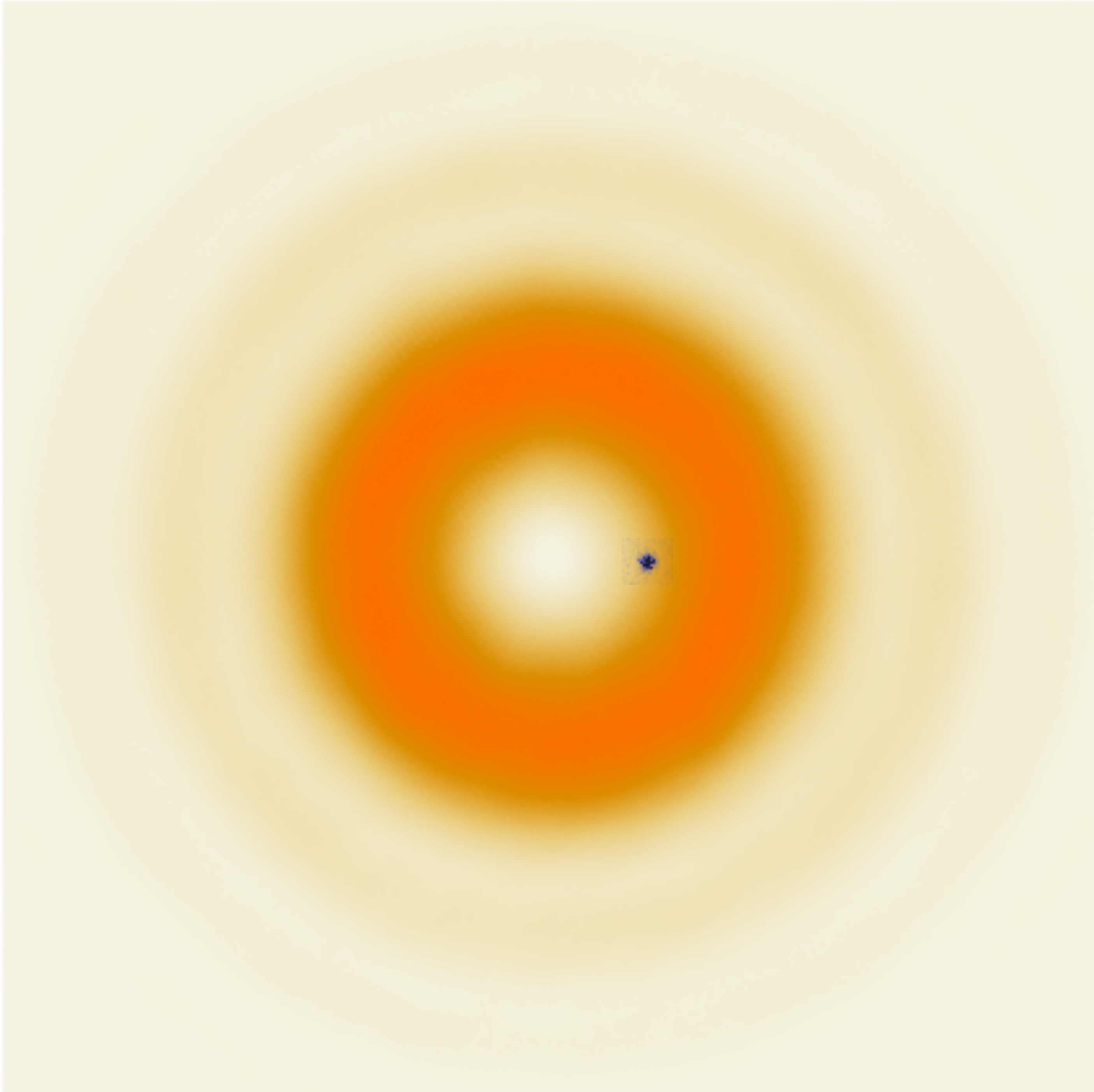
Mathevet, R., de Lesegno, B. V., Pruvost, L. & Rikken, G. L. J. A.
Negative experimental evidence for magneto-orbital dichroism.
Opt. Express 21, 3941–3945 (2013).

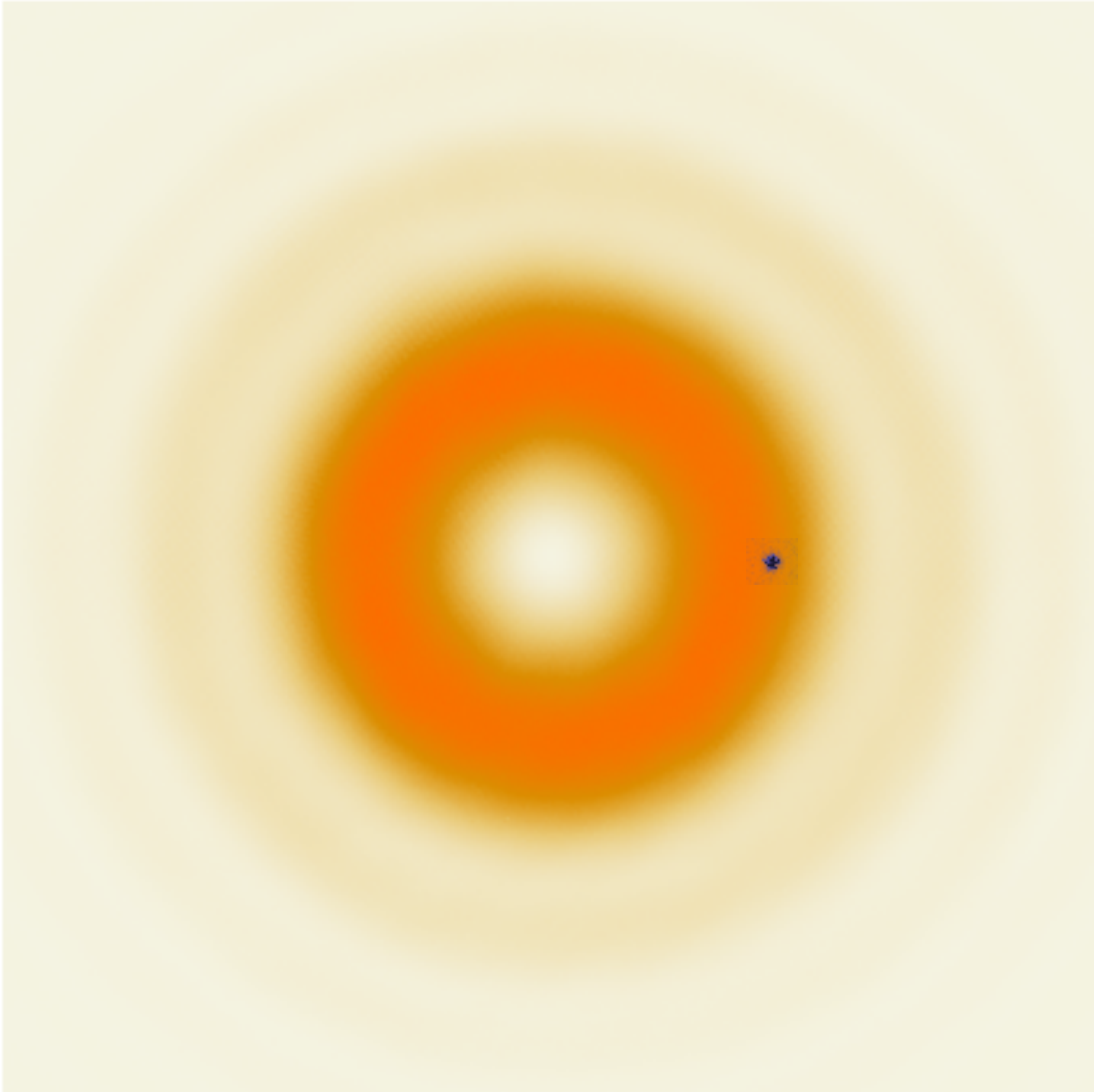
Light-Matter Interaction Summary

	Atomic Spectroscopy	Mechanical Effects on Matter	Mechanical Effects on Light
Energy - Linear Momentum	✓ Fraunhofer	✓ Radiation Pressure	✓ Refraction
Spin Angular Momentum	✓ Hanle & Bät	✓ Beth	✓ Optical Activity
Orbital Angular Momentum	?	✓ Rubenstein Dunlop	✗

part 2.
Atomic Spectroscopy with twisted Light







Light Matter interaction

Symmetries - Dipole and Quadrupole Transitions

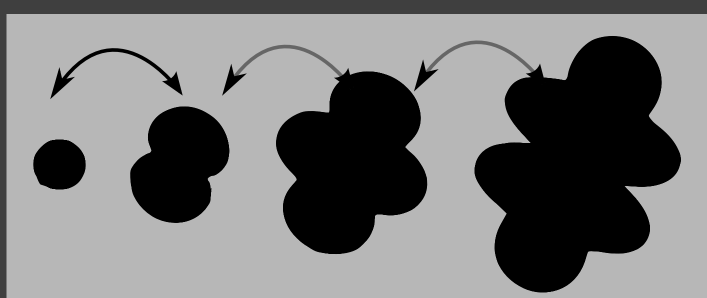
Fermi's Golden Rule $\Gamma_{i\to f} = \frac{2\pi}{\hbar} \left|\langle f | H_{int} | i \rangle\right|^2 \rho$

Light-Matter Interaction $H_{int} \propto A \cdot p + p \cdot A$

Electric Dipole
oscilating electric field

$$\mathbf{A} \approx \mathbf{A}_0\, e^{-i\omega t}$$

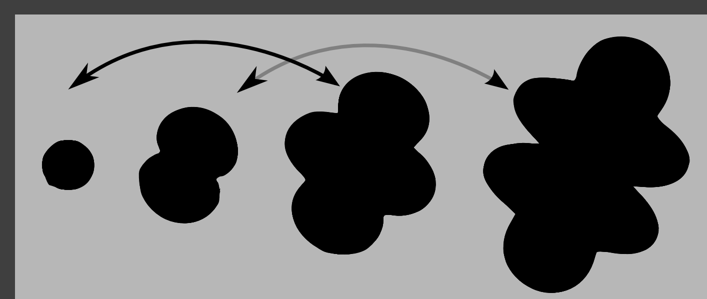
$|i\rangle, |f\rangle \qquad \Delta l = 1$



Electric Quadrupole
oscilating gradient - it's a wave!

$$\mathbf{A} \approx \mathbf{A}_0\, ikz\, e^{-i\omega t}$$

$|i\rangle, |f\rangle \qquad \Delta l = 2$

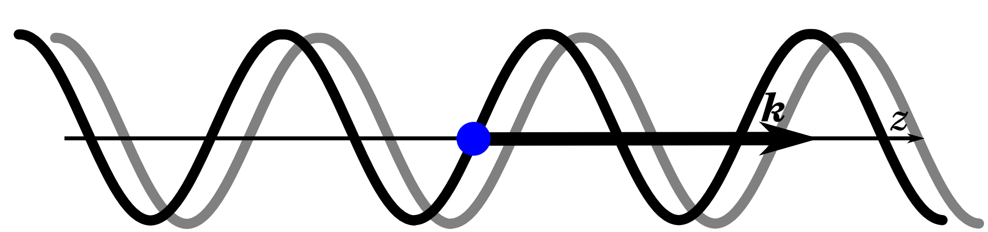


Travelling Wave

$$\mathbf{A} = \mathbf{A}_0 e^{i(kz-\omega t)}$$

Field Amplitude and
Longitudinal Gradient

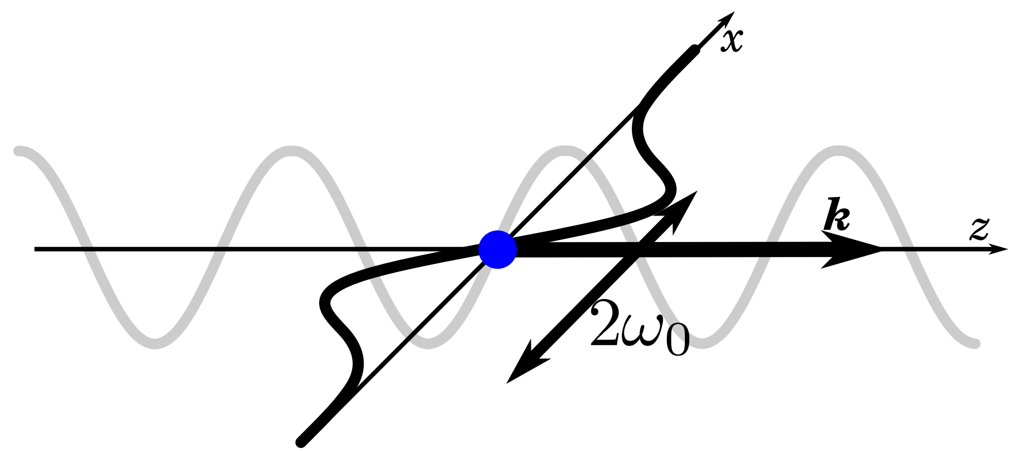
$$\mathbf{A} \approx \mathbf{A}_0(1+ikz)e^{-i\omega t}$$



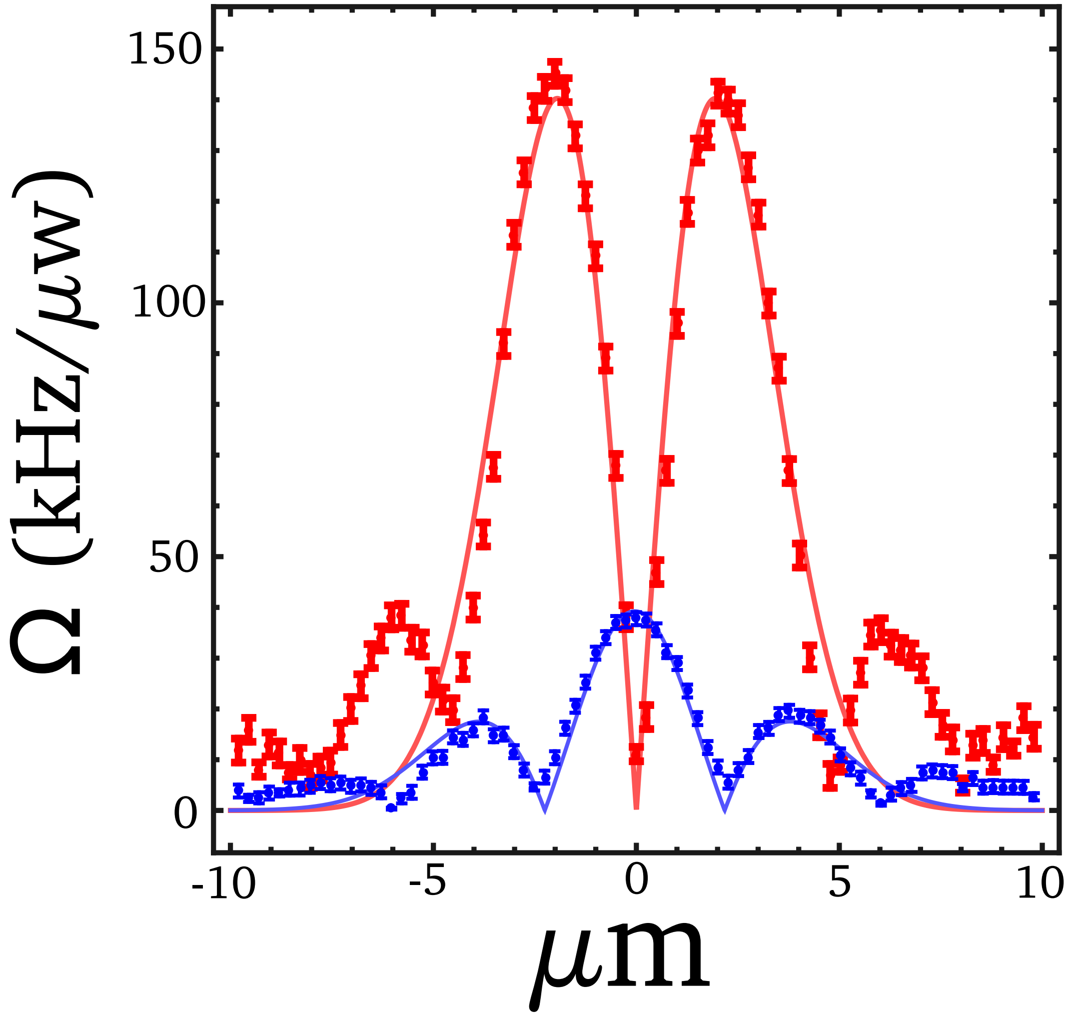
Vortex Beam

Transerse Field Gradient
with no Amplitude

$$\mathbf{A}_{10} \approx \mathbf{A_0}\frac{\sqrt{2}\rho}{w_0}e^{i\phi}\,e^{-i\omega t}$$



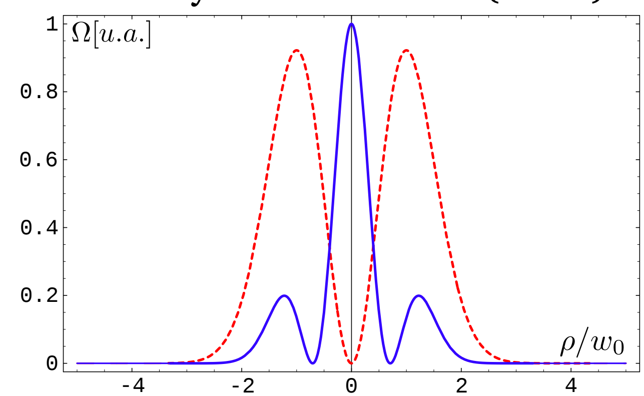
Experimental results
excitation along the beam profile



Longitudinal Gradient
- proportional to sqrt(intensity) -

Transverse Gradient

prediction Schmiegelow & Schmidt-Kaler
Eur. Phys. J. D **66**: 157 (2012)

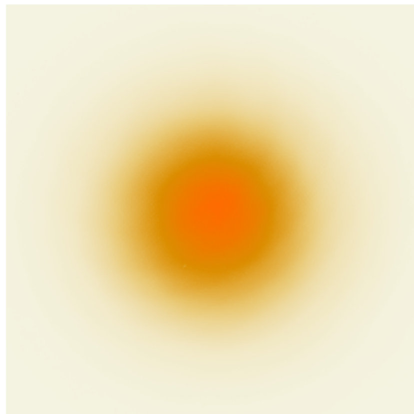
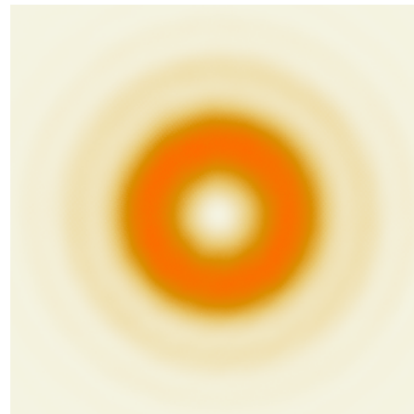
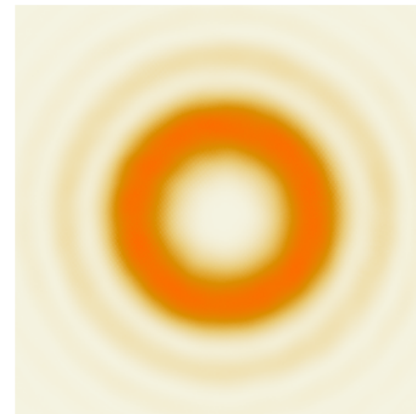


Nature Comm. 7, 12998 (2016)

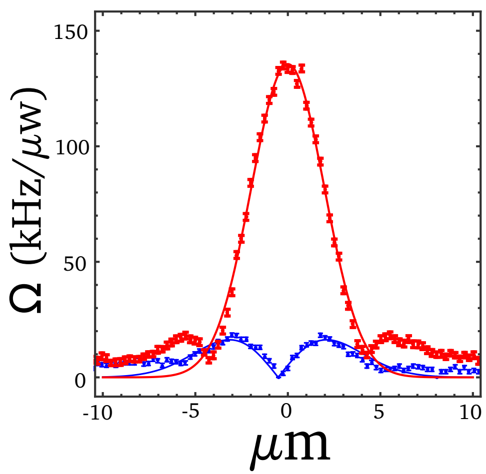
Experimental results
excitation along the beam profile

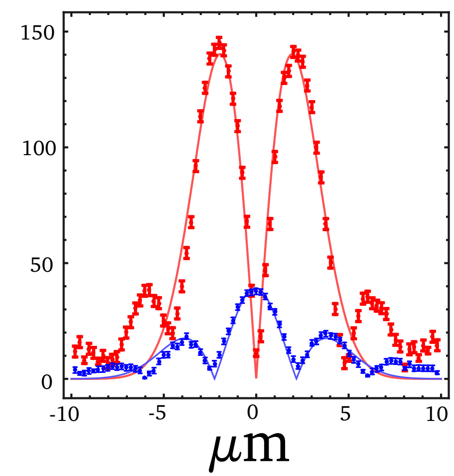
Gaussisan Beam *l=0* | **Doughnut Beam** *l=1* | **Ring Beam** *l=2*

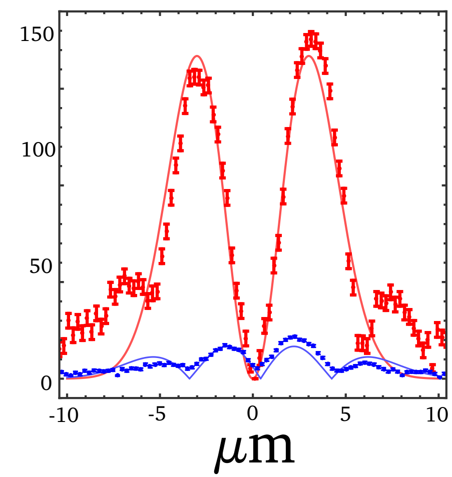
Beam Intensity Profiles
(measured with CCD
before focusing on the ion)

Quadrupole Excitation
as a function of the
position of the ion
in the beam





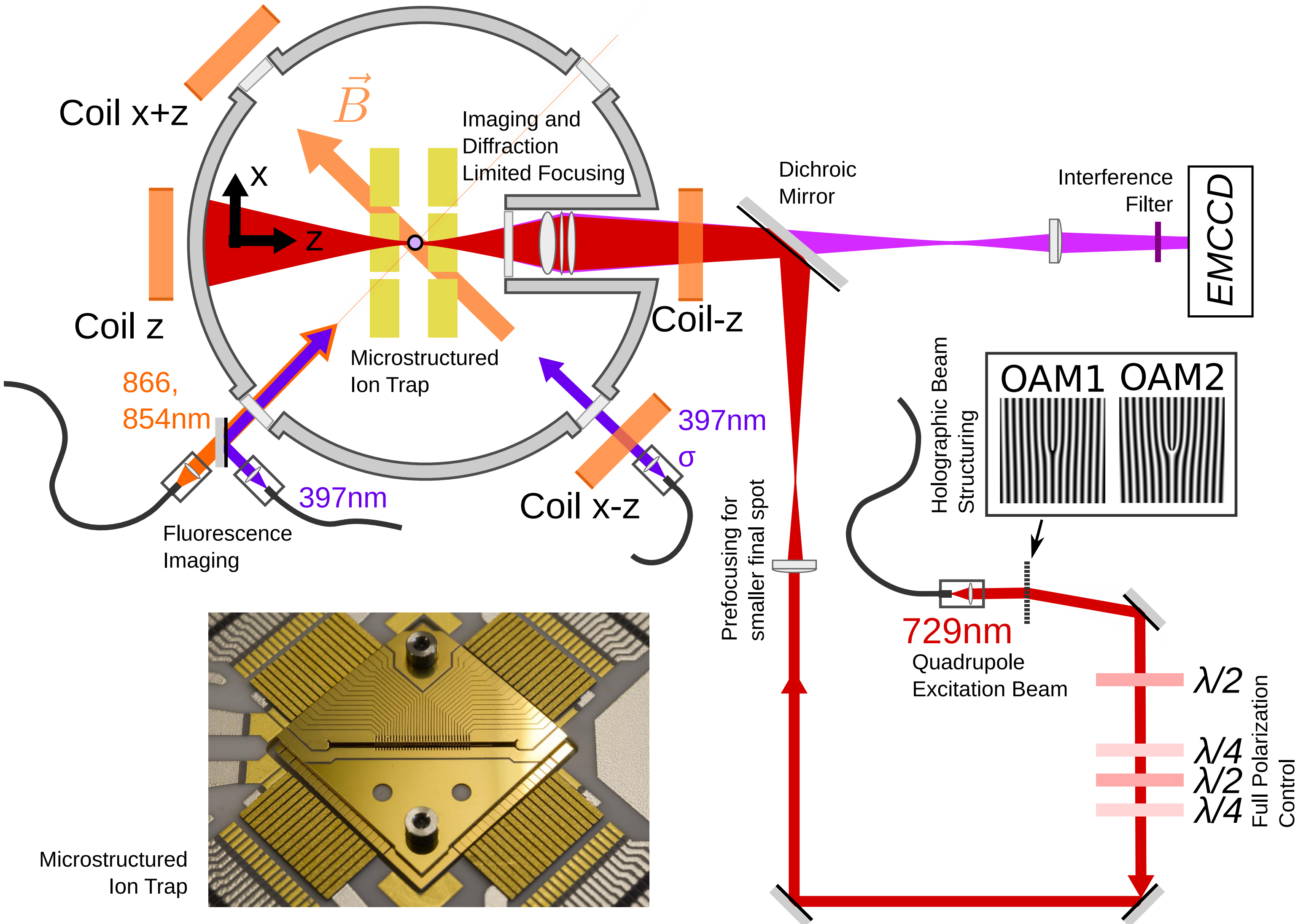


Longitudinal Gradient
proportional to sqrt(intensity)

Transverse Gradient

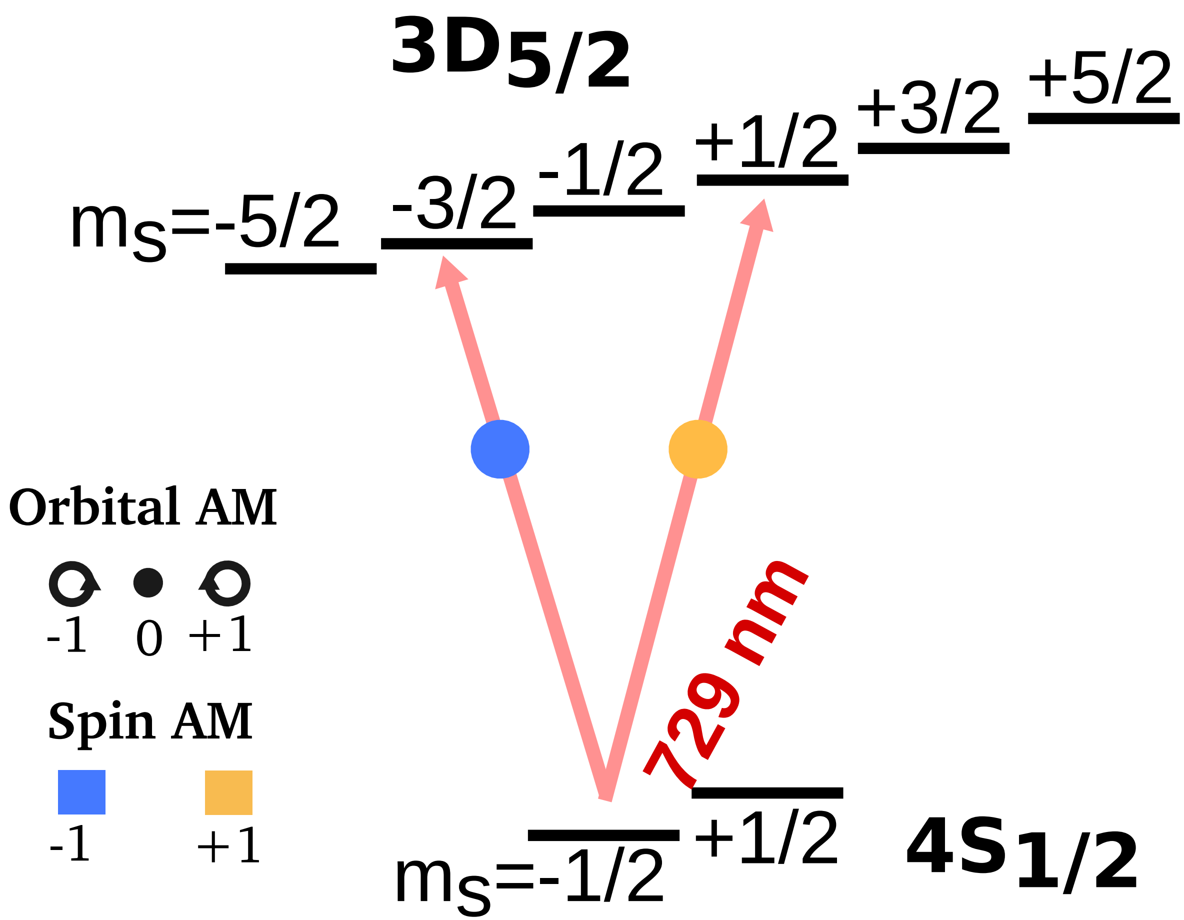
Schmiegelow et. al., Nat. Comm. 7, 12998 (2016)

Experimental setup



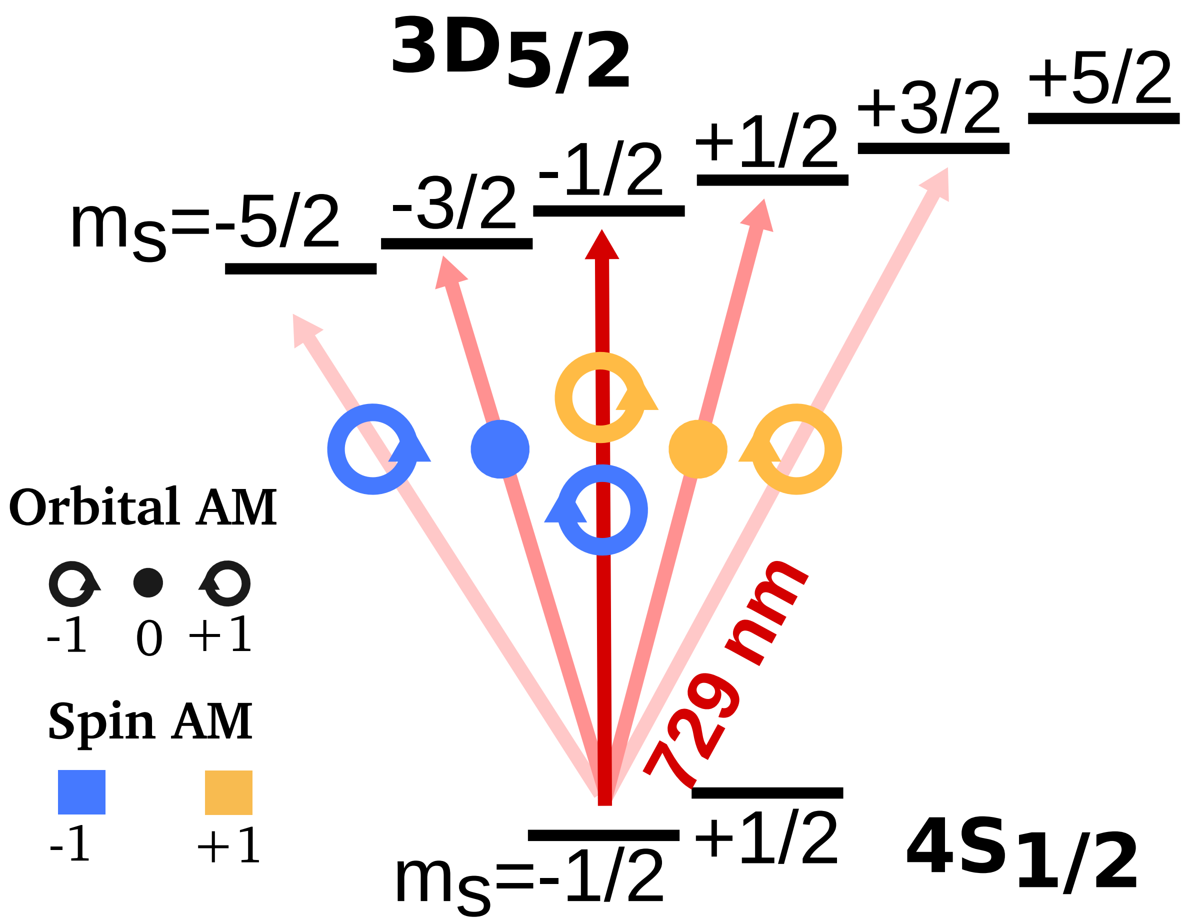
Quadrupole Energy Levels Ca+

Allowed transitions indicated.



Quadrupole Energy Levels Ca+

Allowed transitions indicated.



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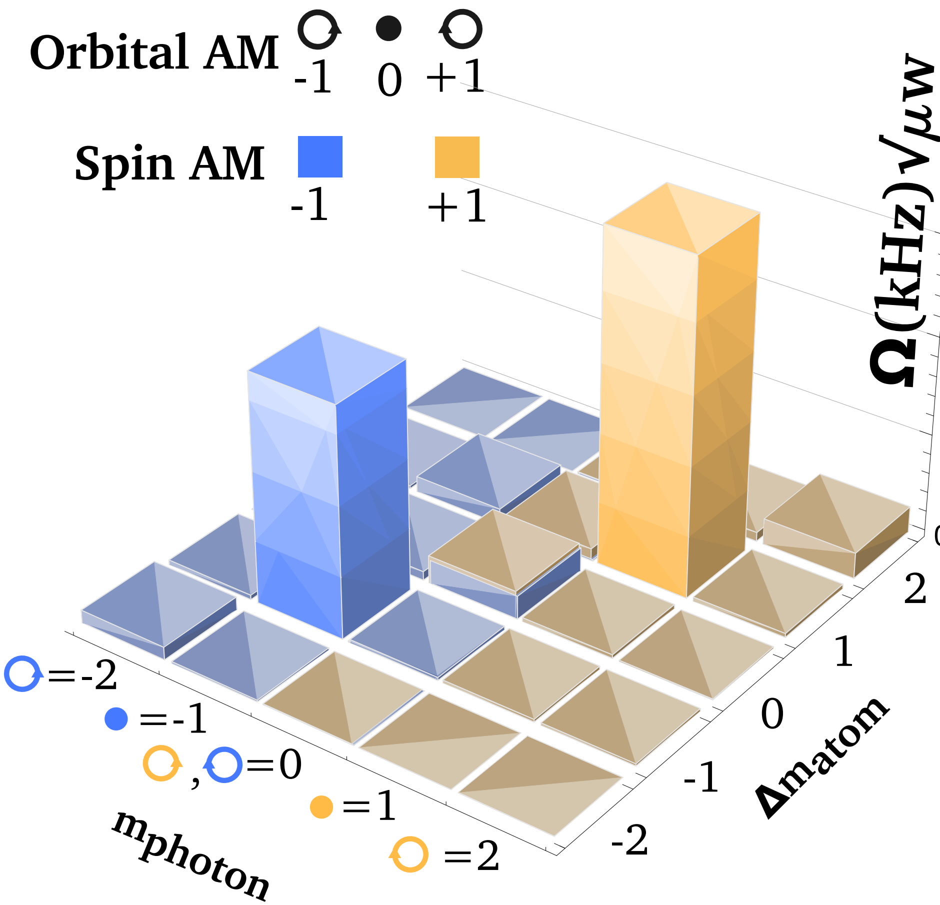
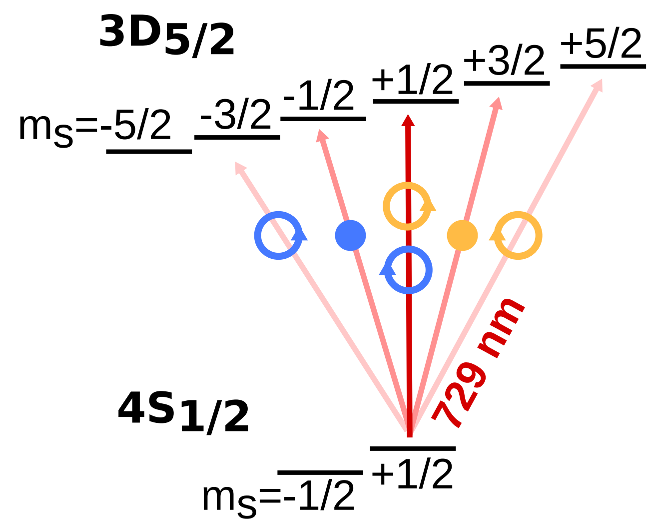


from $m_S=+1/2$



Schmiegelow et. al., Nat. Comm. 7, 12998 (2016)

OAM in photons can interact with atomic internal degrees of freedom.

- Atoms love the extra twist -

Local brightnes is not all that matters.

- Atoms can also get excited in the dark -

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Orbital Angular Momentum	✓ We!!	✓ Rubenstein Dunlop	✗

Light-Matter Interaction Summary

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Orbital Angular Momentum	✓ We!!	✓ Rubenstein Dunlop	✗ ?

?

?

Applications

part 3.
thanks, present and future

LIAF

Laboratorio de Iones y Átomos Fríos

Departamento de Física, Universidad de Buenos Aires
Instituto de Física de Buenos Aires, CONICET

LIAF

Laboratorio de Iones y Átomos Fríos

Departamento de Física, Universidad de Buenos Aires
Instituto de Física de Buenos Aires, CONICET

Founders

Juan Pablo Paz

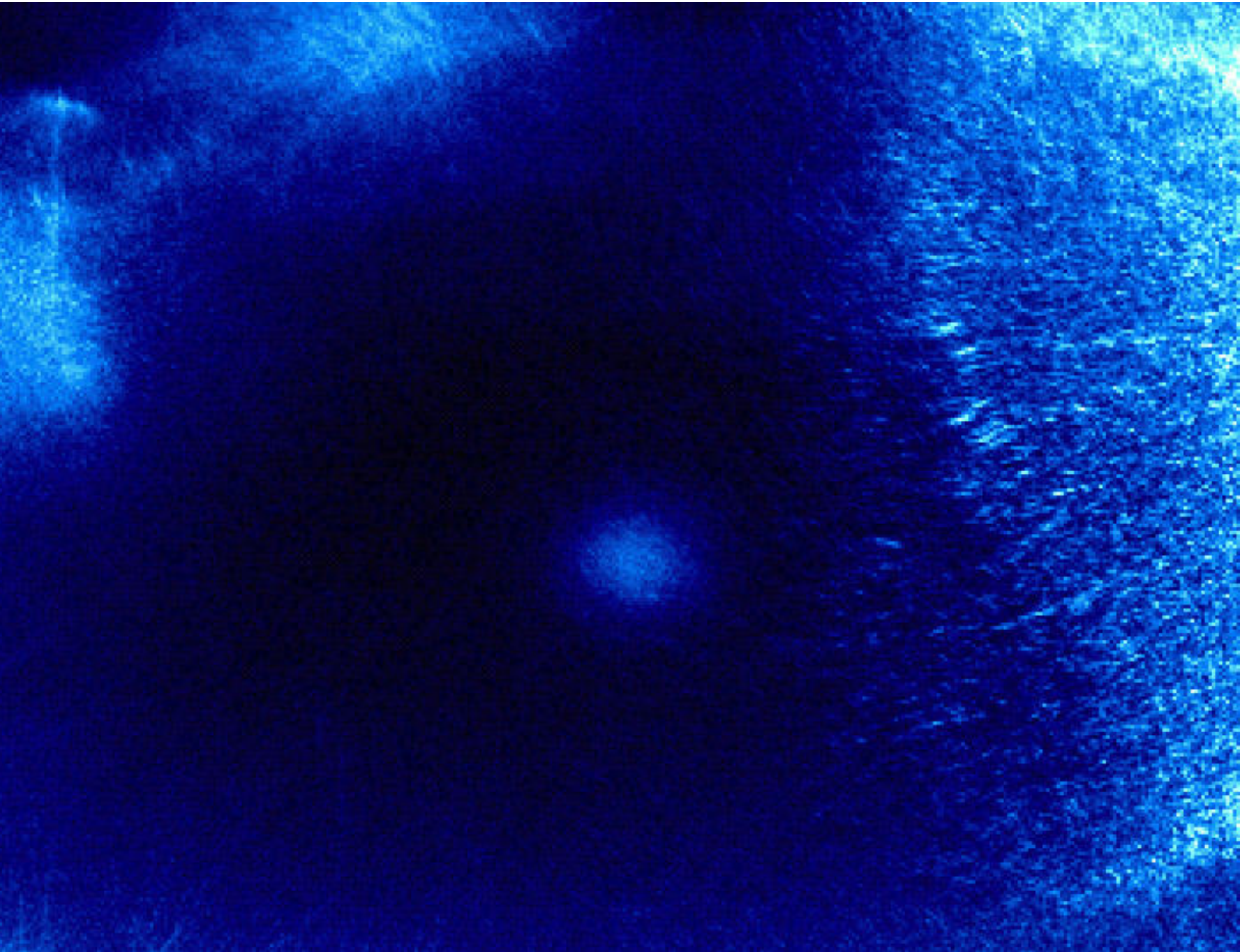
Miguel Larotonda

Augusto Roncaglia

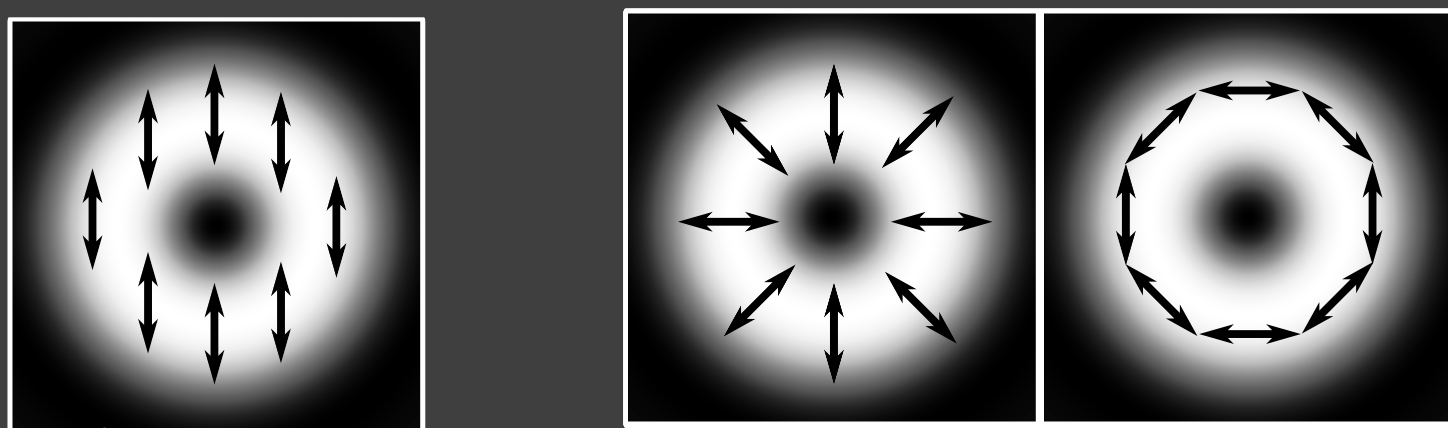
Christian Schmiegelow

Objective: build a lab for research on fundamental aspects of quantum theroy and applications


Billabong



Stuctured Light - Vector Beams

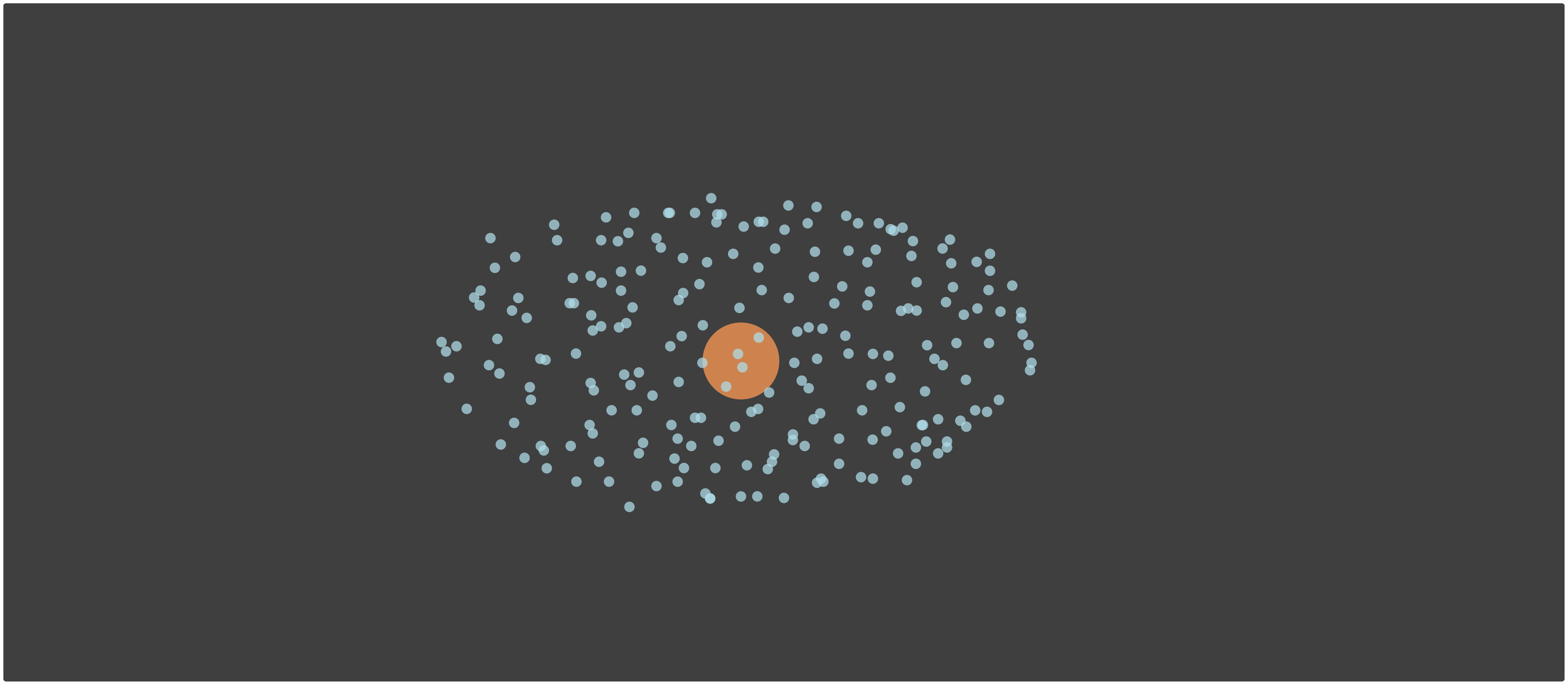


uniform polarization

radially polarized

azimutally polarized

Nano Cryostats



Themodynamics of small systems

part 3.
thanks, present and future

Trajectory

Undergraduate - Universidad Nacional de La Plata, Argentina

PhD - Centro de Investigaciones para la Defensa and
Universidad de Buenos Aires, Argentina

Posdoc - University of Mainz, Germany

Currently - Universidad de Buenos Aires, Argentina

My three keys to work

- work enviroment and friendship
- collaborators local and intenrational
- work-hard, play-hard

thank you for your attention