Physics and ART

Robert Streubel

Physics and Astronomy

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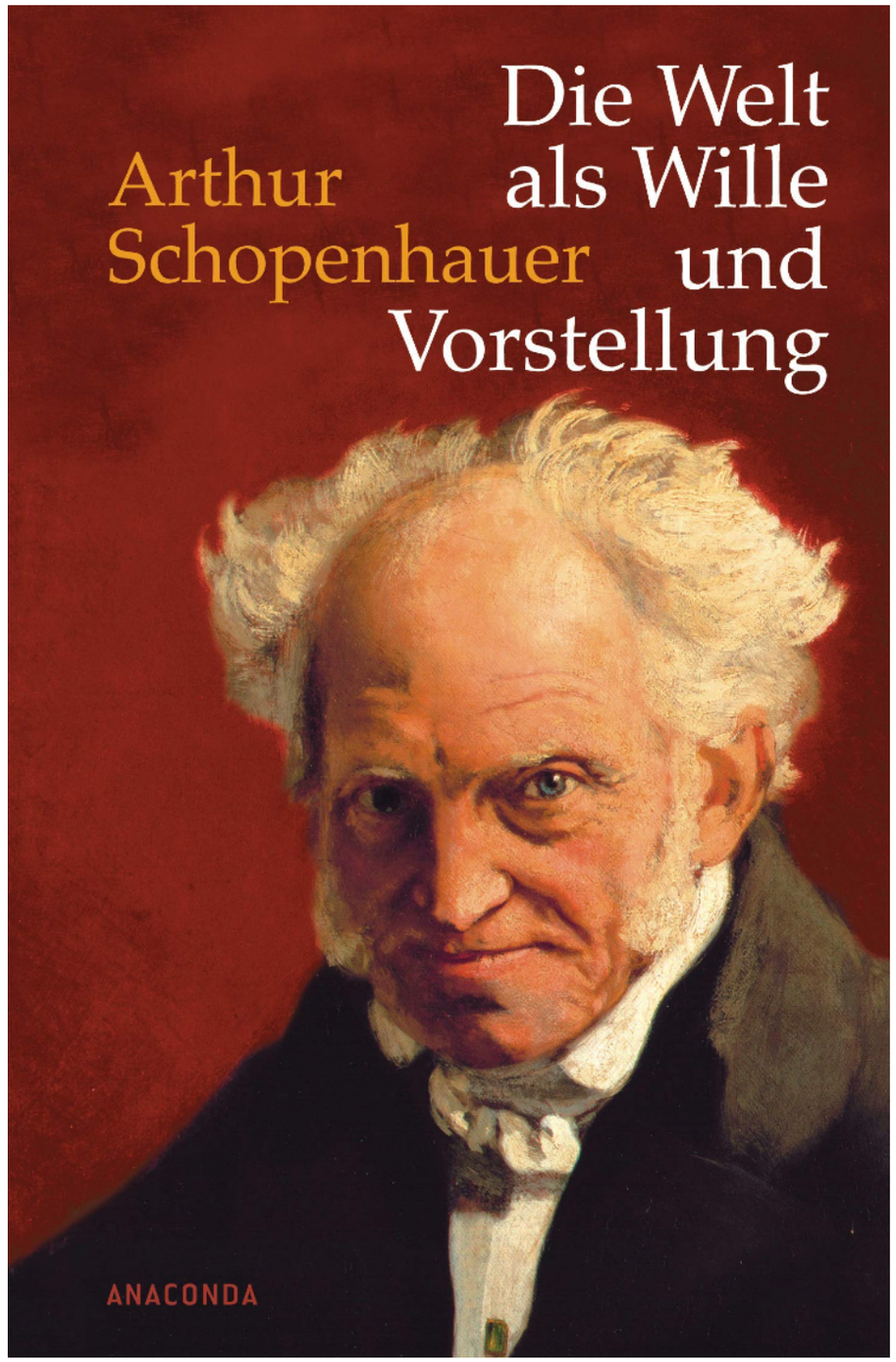
2021 Nebraska Physics & Astronomy Fall Summit

Everyone Perceives the World Differently

Perception

The World as Will and ~~Representation~~
(written in my home town—1818)



- We perceive the world as we "want" through our *biased, mediated senses*
- How do others perceive us, our surroundings?
- What is the actual objective state (truth)?

- Does it even exist?
- How do we know whether we are awake or asleep?
- Ancient "The Matrix"

This is not only a philosophical questions!

Physics and Art

Integrating arts with sciences enhances
inclusion, dissemination, understanding, education.

Physics — **Creativity and creation** — *Art*

Rational, logical
Precise, approximative
Abstract
Mathematical equations

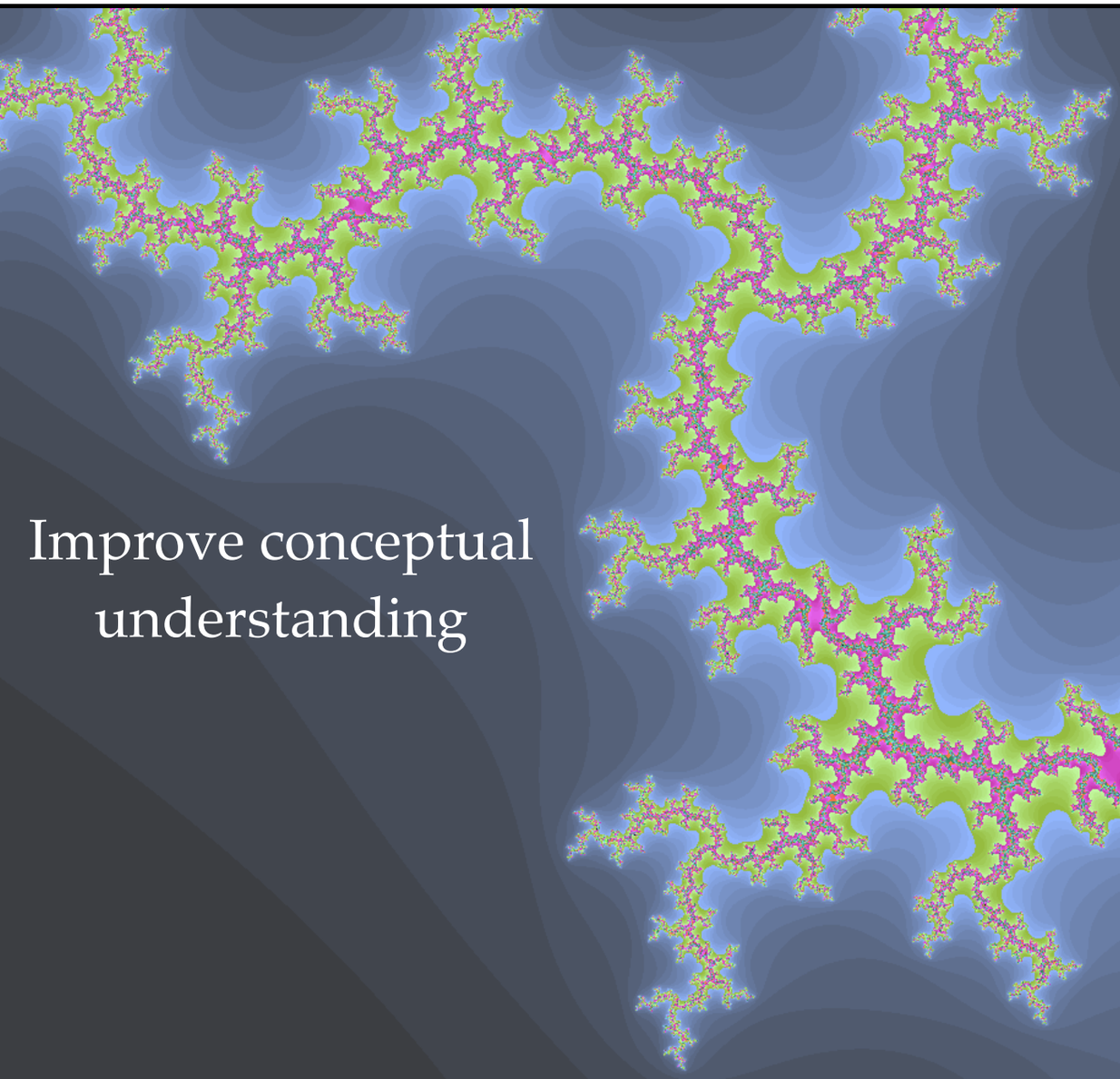
Seeks to relate phenomena of
nature to mathematical constructs
and predict causality

Emotional
Abstract
Technical
Perspective, colorspace

Man-made visualization or
demonstration
Cave drawing, sculptures, light,
materials sciences, virtual reality

A picture speaks more than thousand words
You'd better spend thousand words when thinking about creation.

Goals



Make STEM education more interesting and less abstract

Engage students and general public

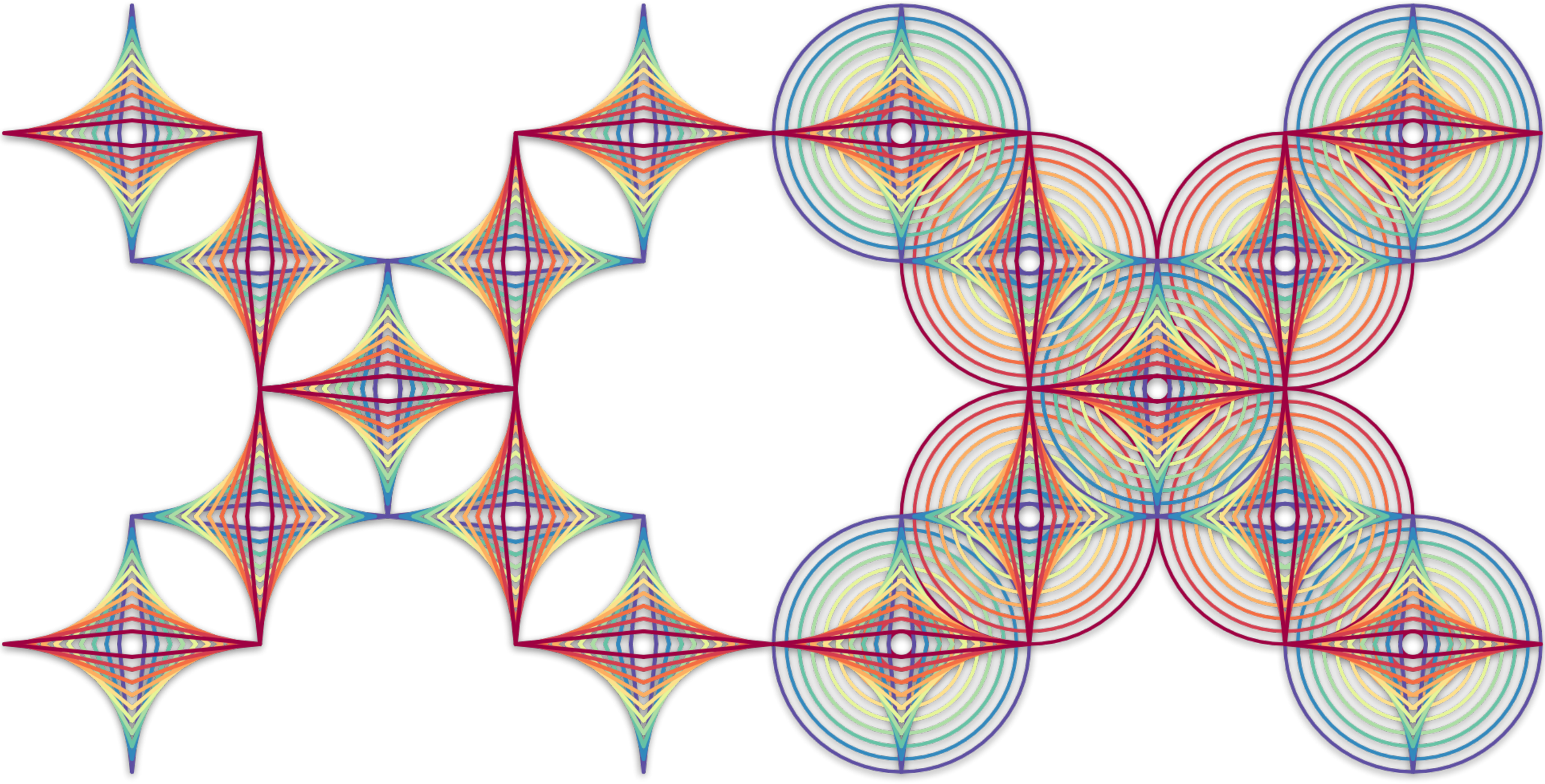
Improve conceptual understanding

Create art from physical principles

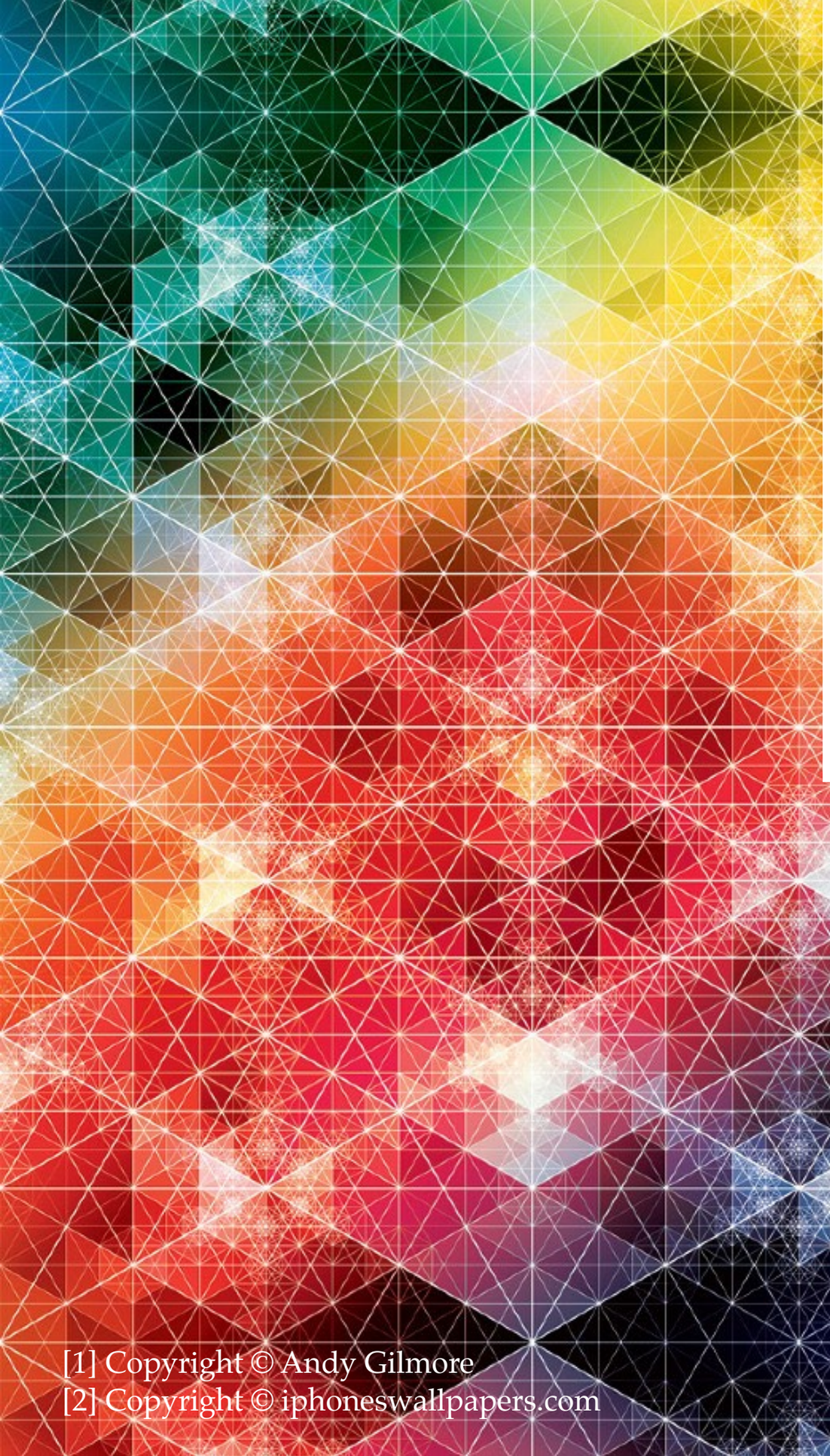
Visualize physical mechanisms to foster understanding

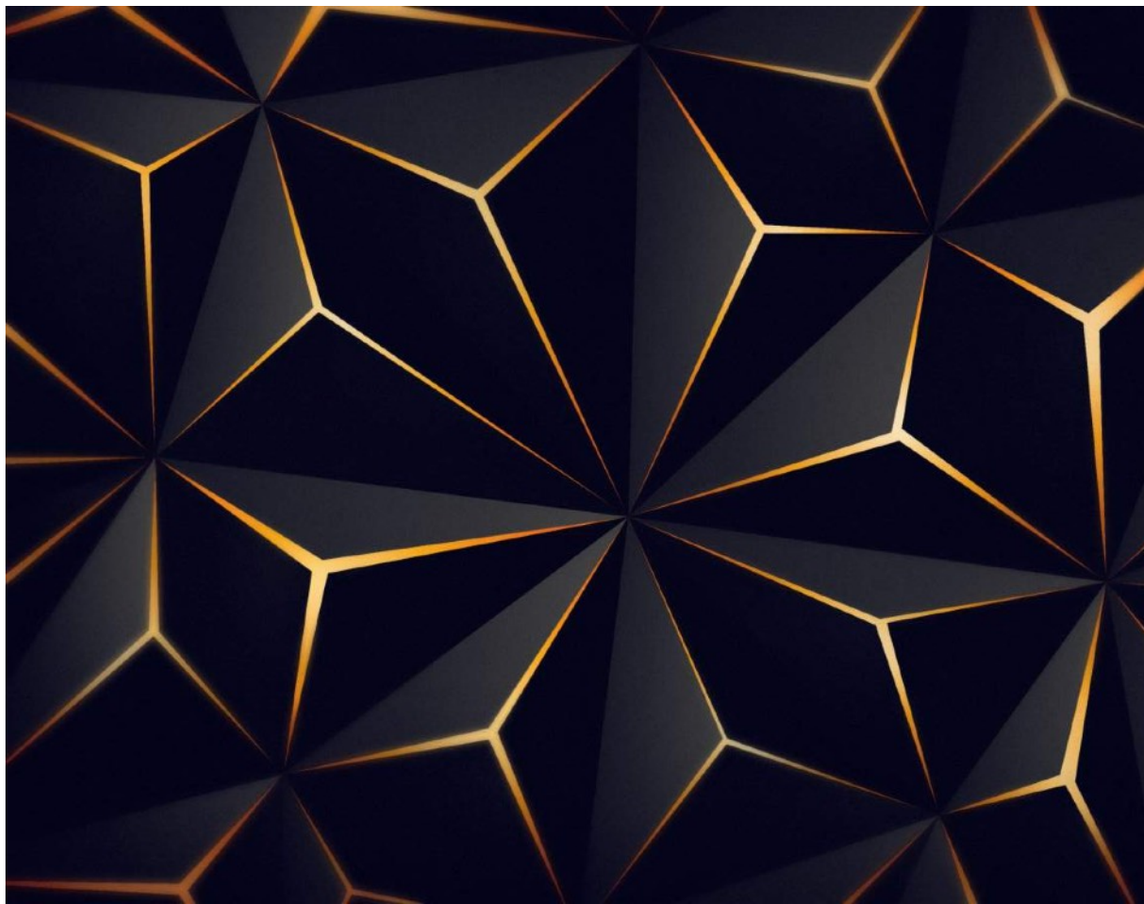
Soften boundaries between natural and liberal sciences

Straights and Circles



Attention to details and precision. Perseverance. Hand drawing and/or computing skills.

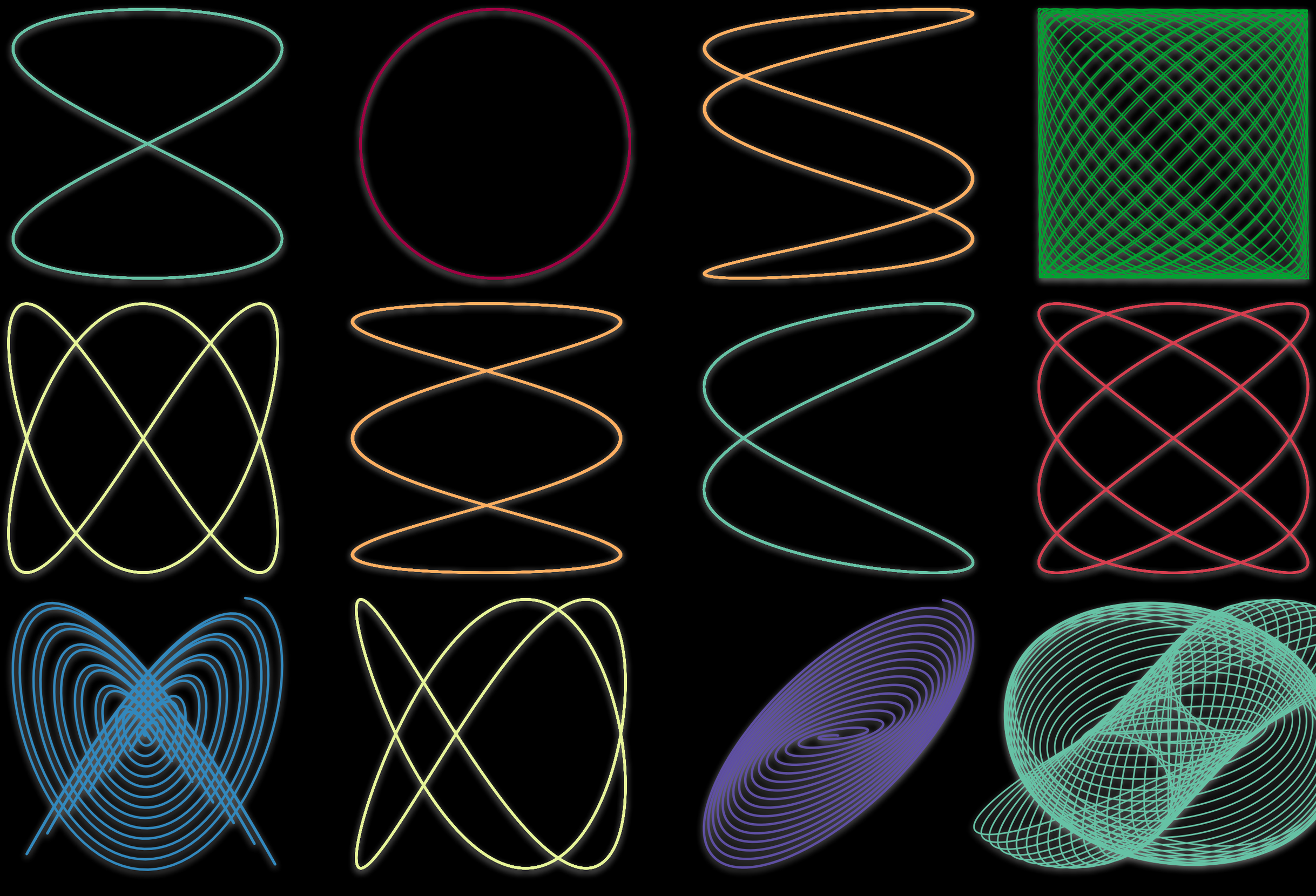




[1] Copyright © Andy Gilmore
[2] Copyright © iphoneswallpapers.com

$$\left(\sin\frac{x}{N}+\phi,\cos\frac{y}{M}\right)$$

Lissajous Curves

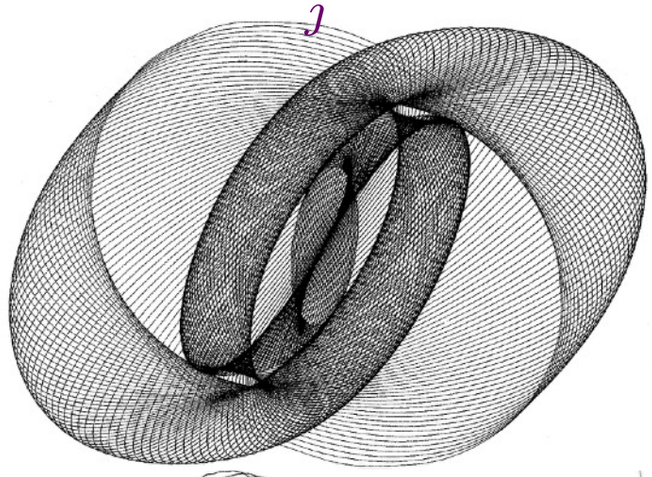


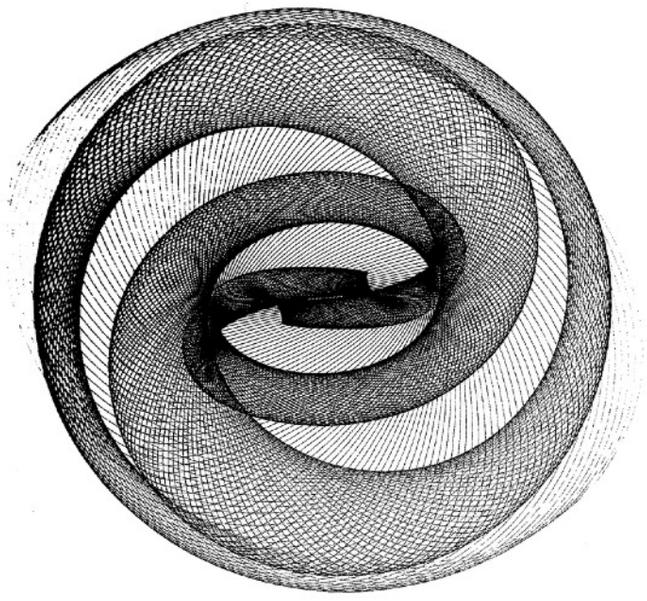
Harmonograph with Coupled Pendula

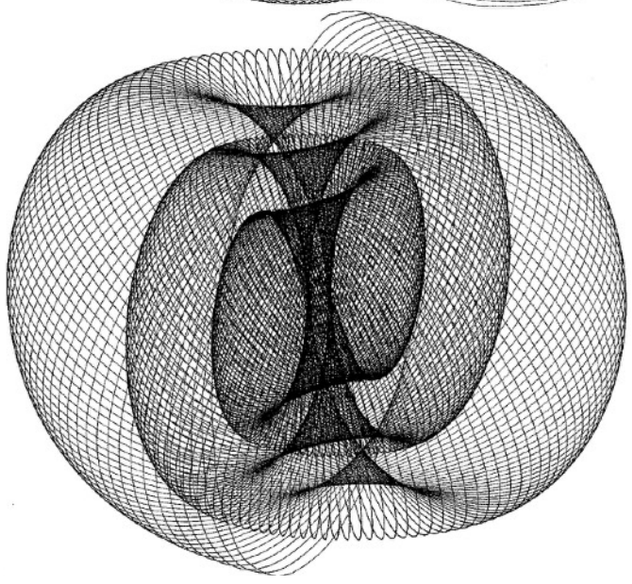
$$x(t) = \sum_j A_j \sin(f_j t + \phi_j) e^{-d_j t},$$

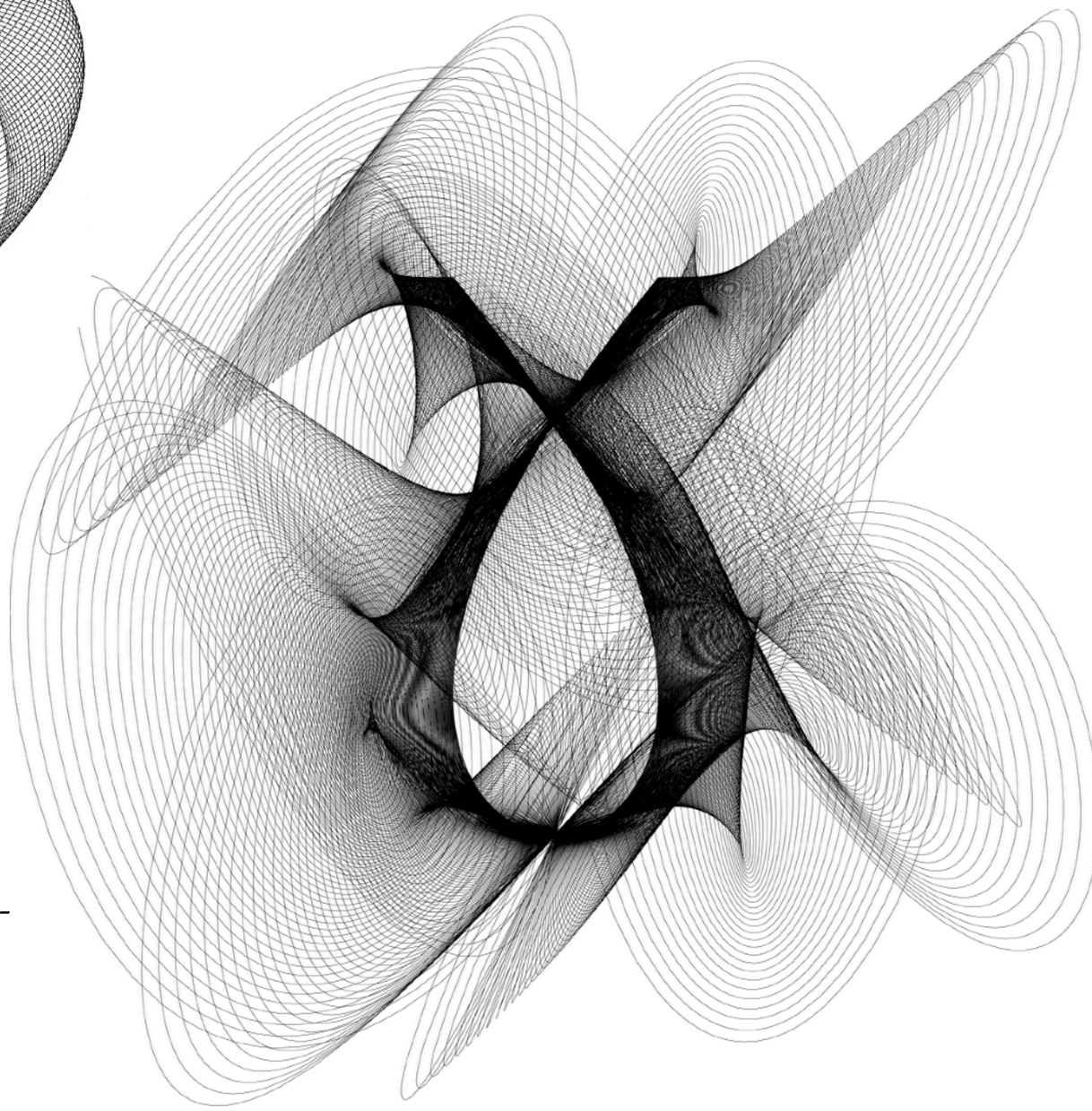
$$y(t) = \sum_j A_j \sin(f_j t + \phi_j) e^{-d_j t}.$$

Eigenfrequency should be slightly different.





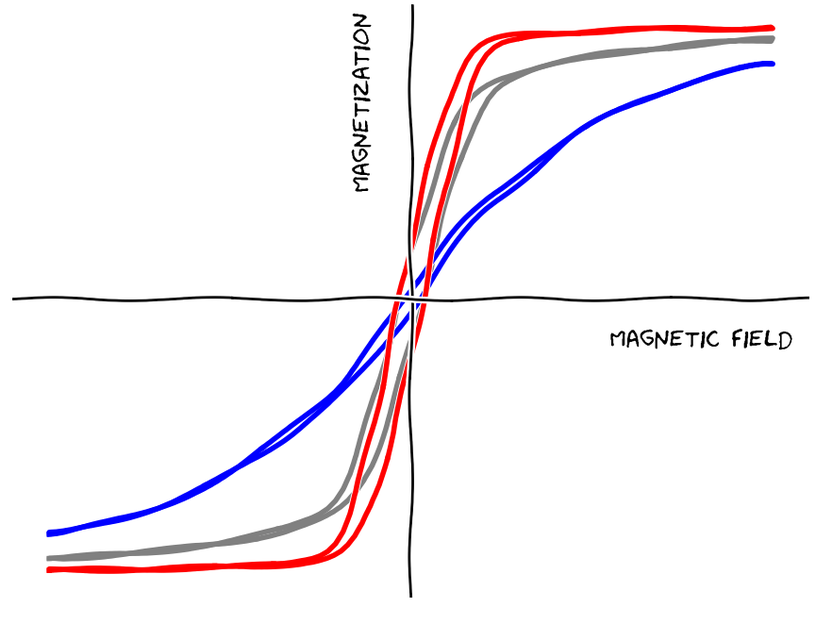




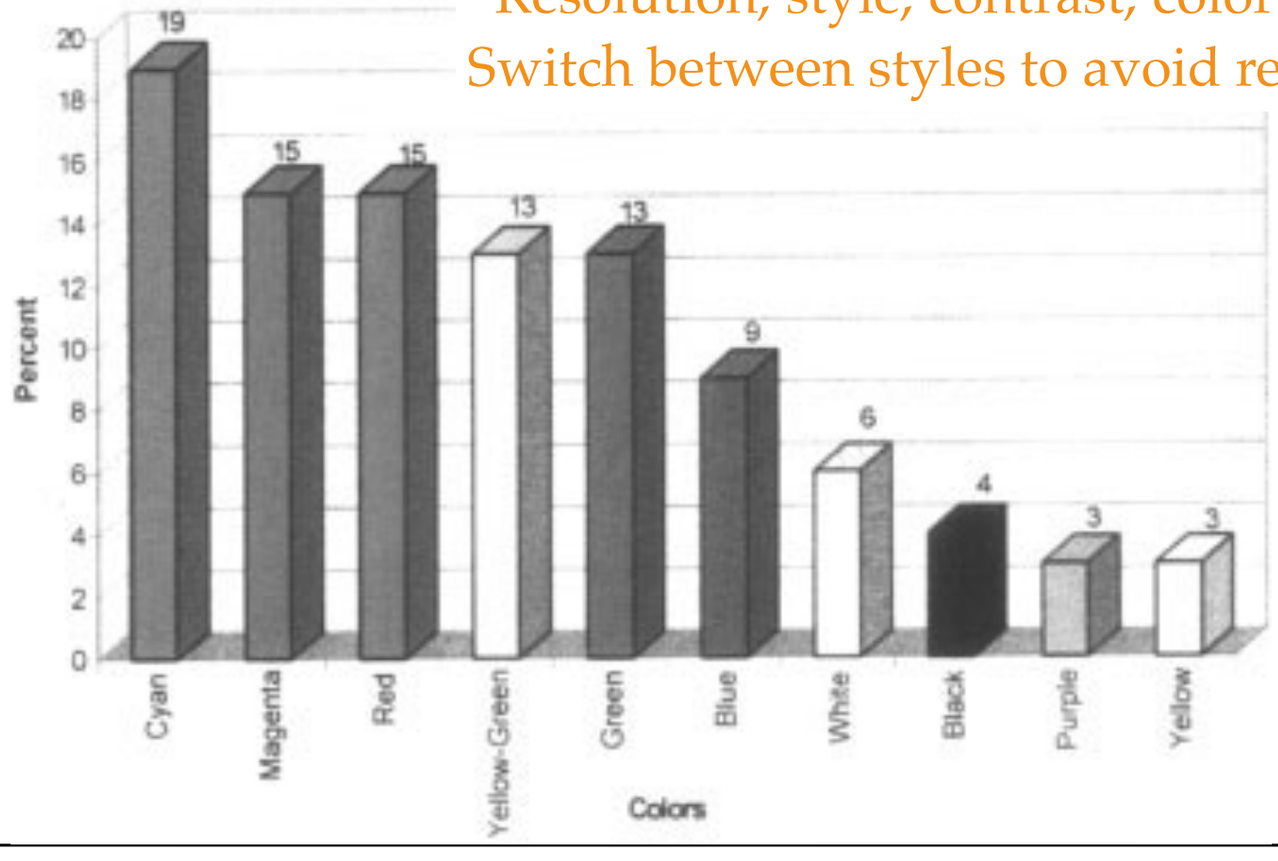
[1] https://sites.dartmouth.edu/biomed/2015/04/21/the-harmonograph-a-new-exhibit-at-the-matthews-fuller-health-sciences-library
[2] http://harmonographs.freewebspace.com/photo.html

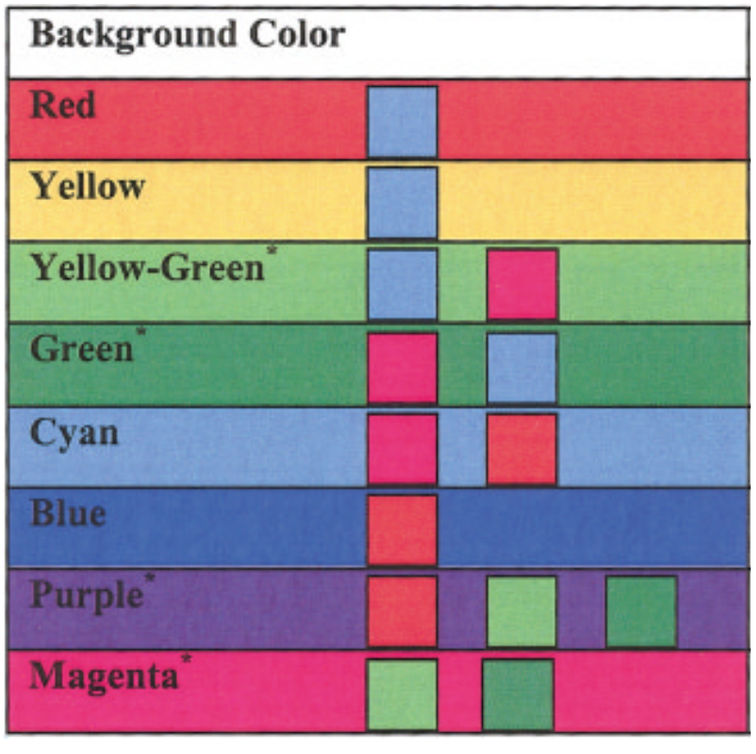
[3] Copyright © Conor Lawless

Catching Attention



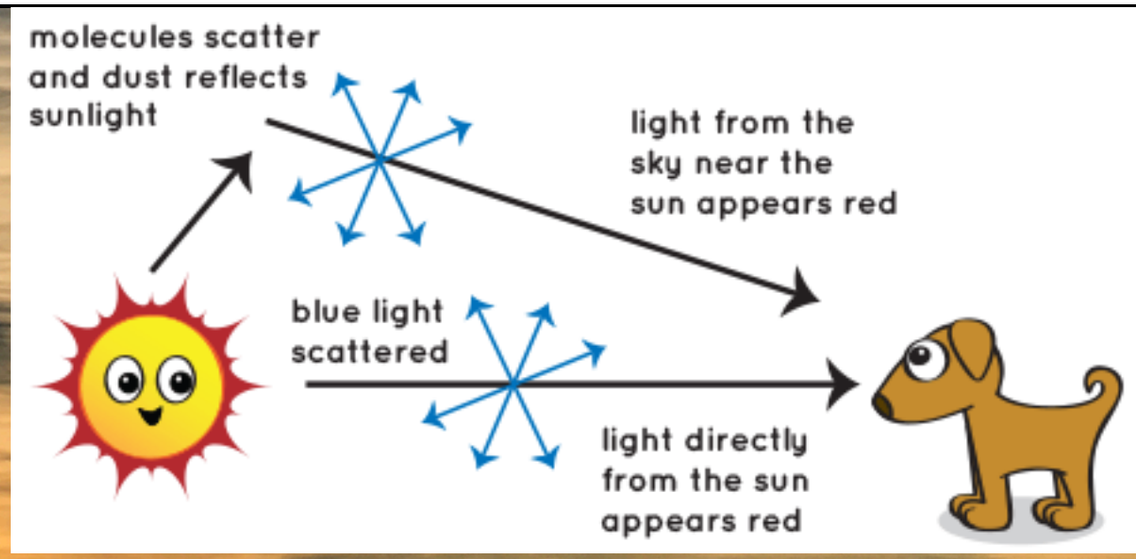
Resolution, style, contrast, color matter.
Switch between styles to avoid repetition.





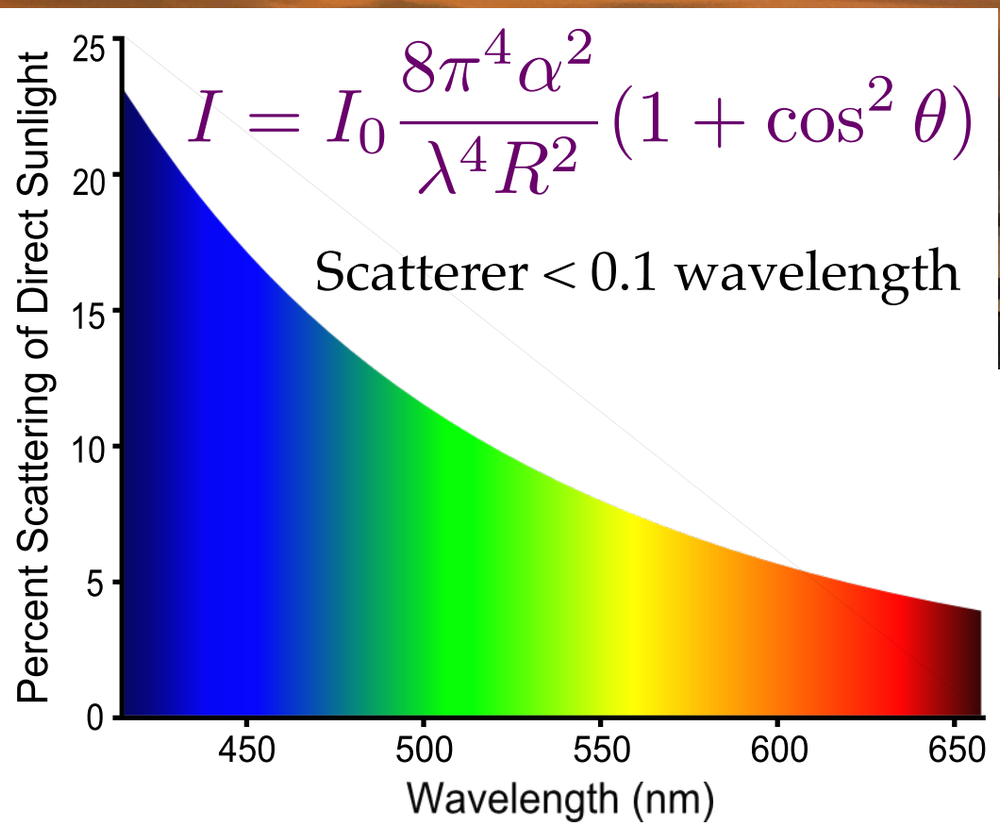
[1] Nat. Commun. 11:5444 (2020); Col. Res. Appl., 29, 20 (2004).

Rayleigh Scattering

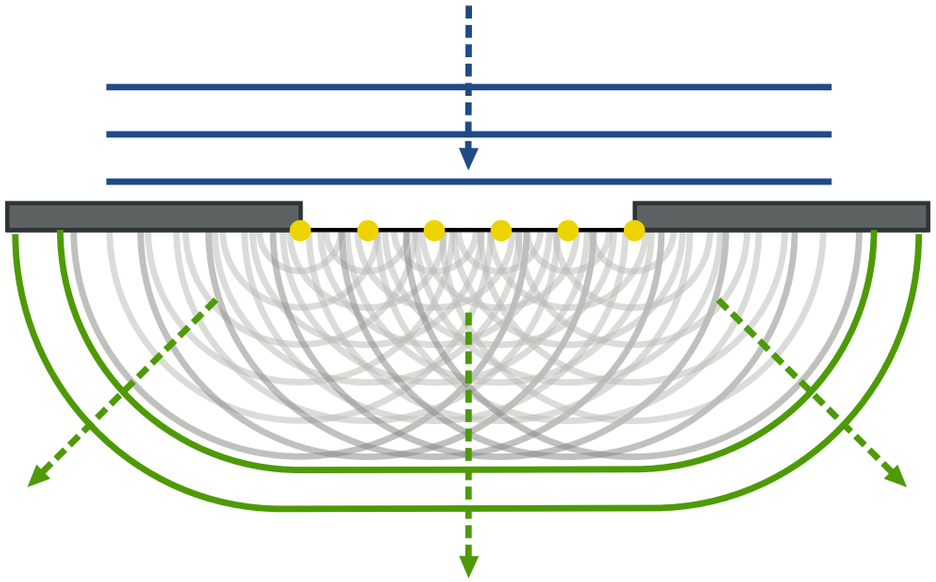


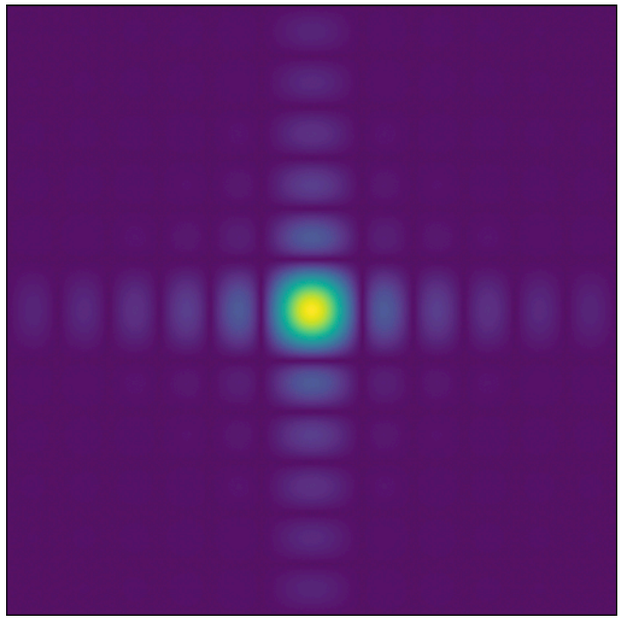
$$I = I_0 \frac{8\pi^4 \alpha^2}{\lambda^4 R^2}(1 + \cos^2\theta)$$

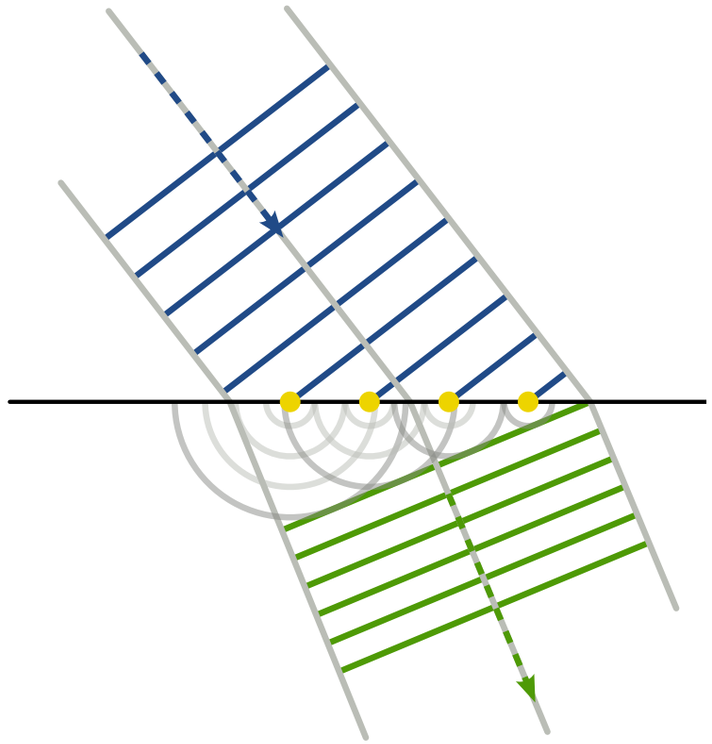
Scatterer < 0.1 wavelength



Huygens' Principle







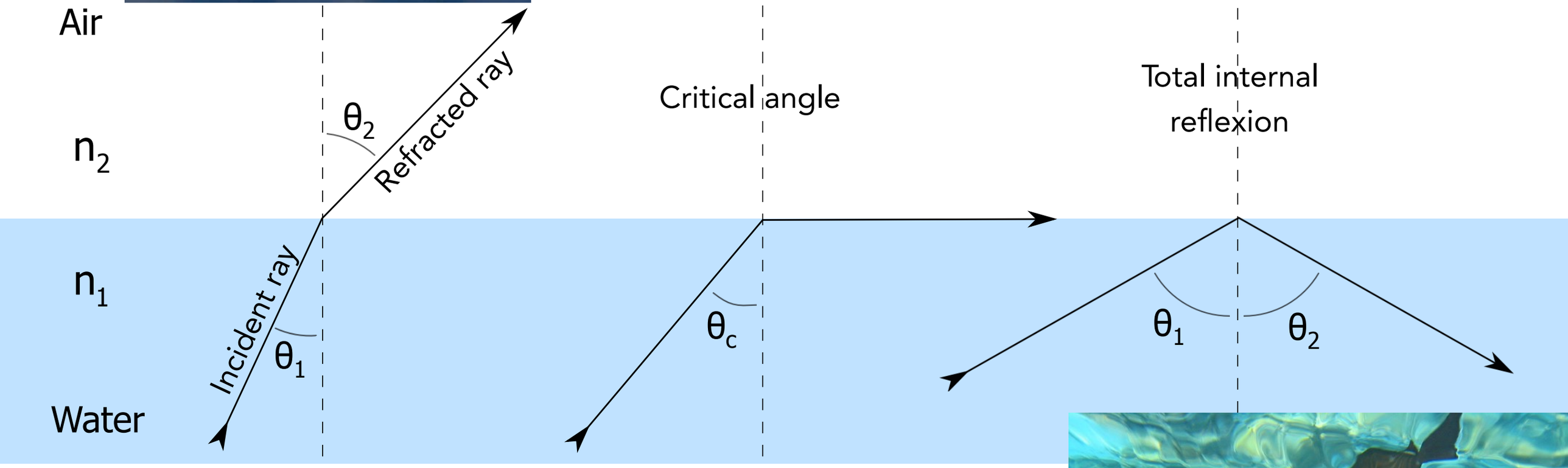
Refraction

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Interfaces are defects that scatter.

Every point on wavefront is the source of spherical wavelets that interfere with each other.

Optical Illusions by Refraction and Reflection



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_1 \sin\theta_c = n_2 \sin(90^\circ)$$

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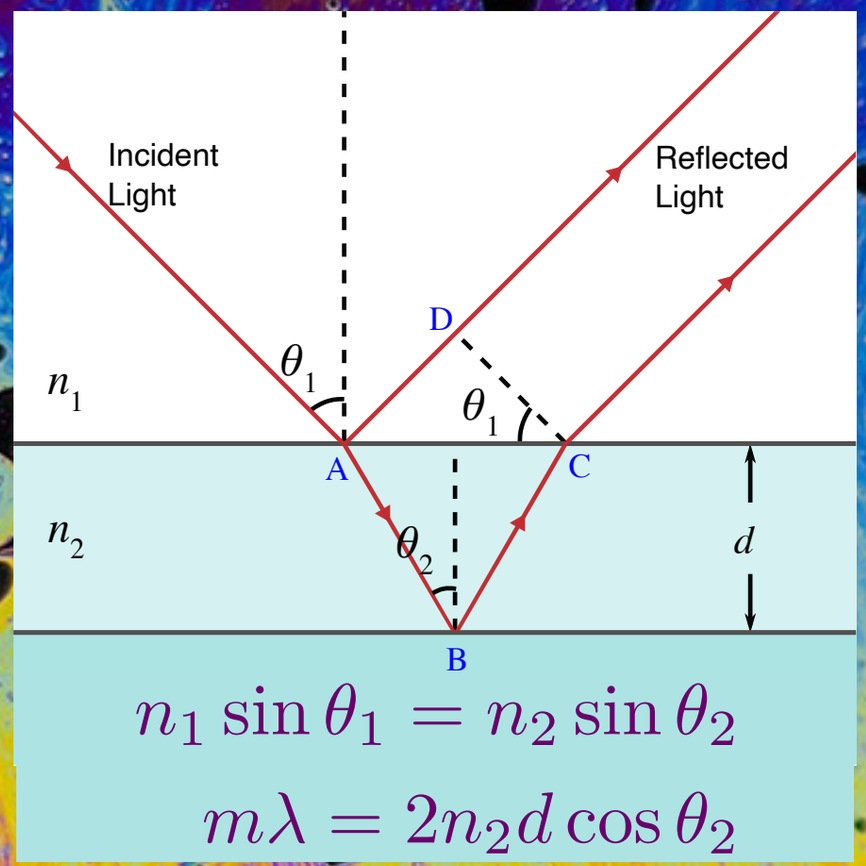
[1] https://phys.org/news/2011-08-wrong.html

Thin-Film Interference



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$m\lambda = 2n_2 d \cos\theta_2$$

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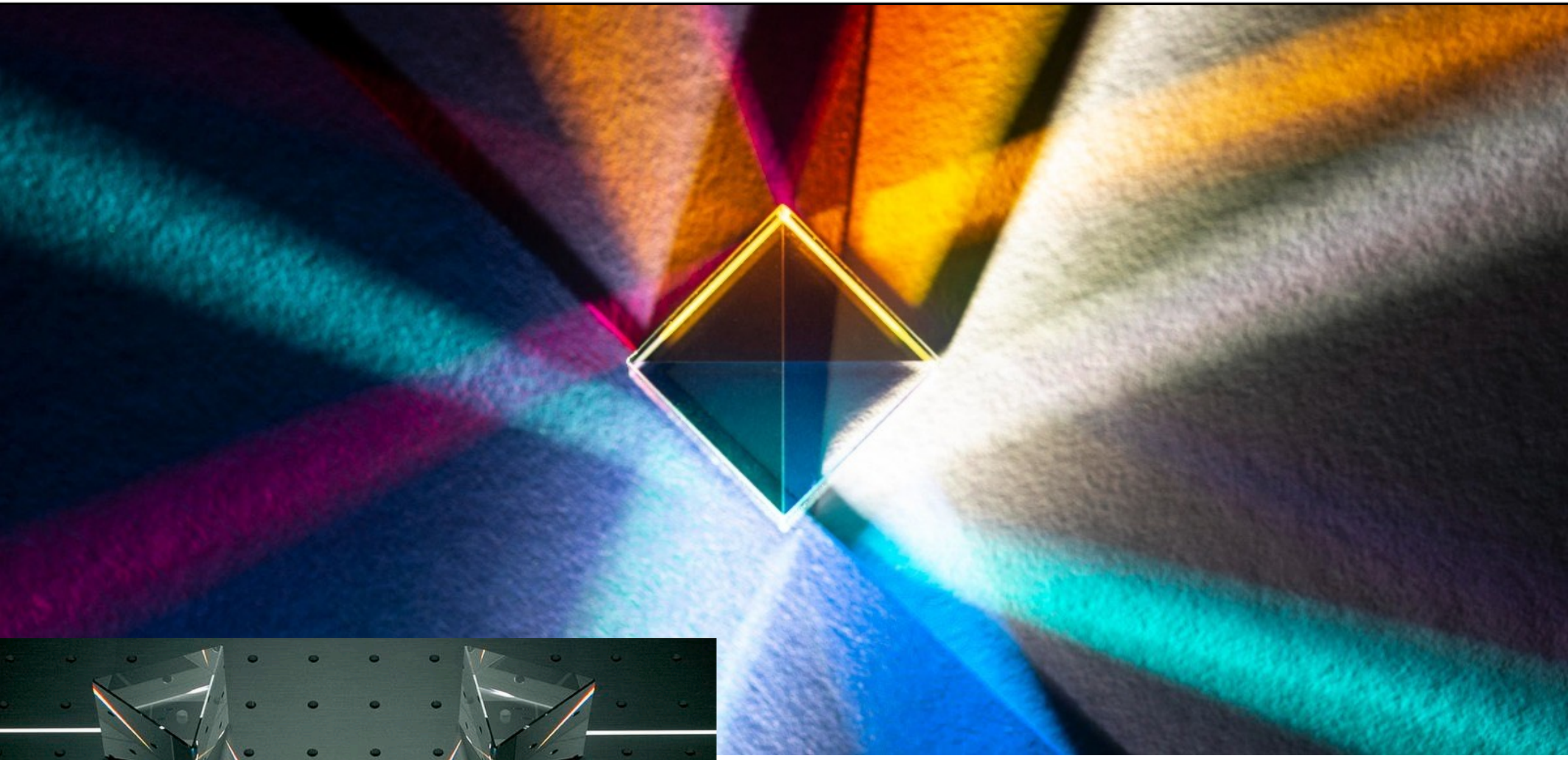
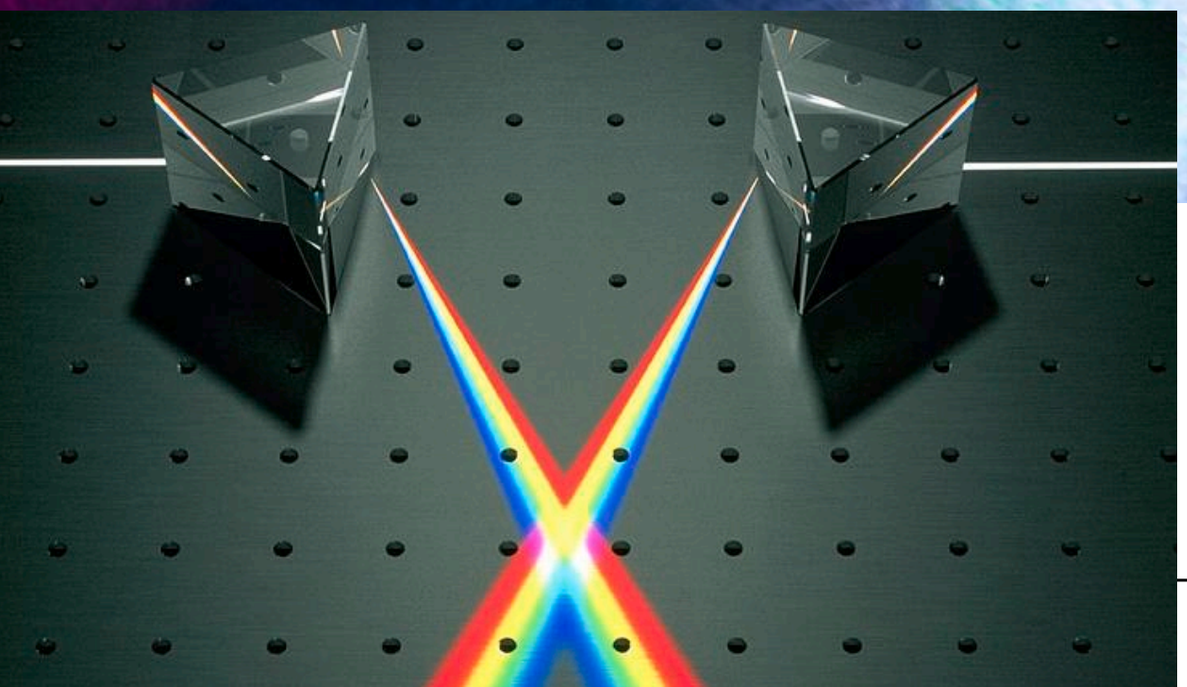
Prism Refraction





Wavelength dependent refraction (dispersion)

$$\delta \approx [n(\lambda) - 1]\alpha$$

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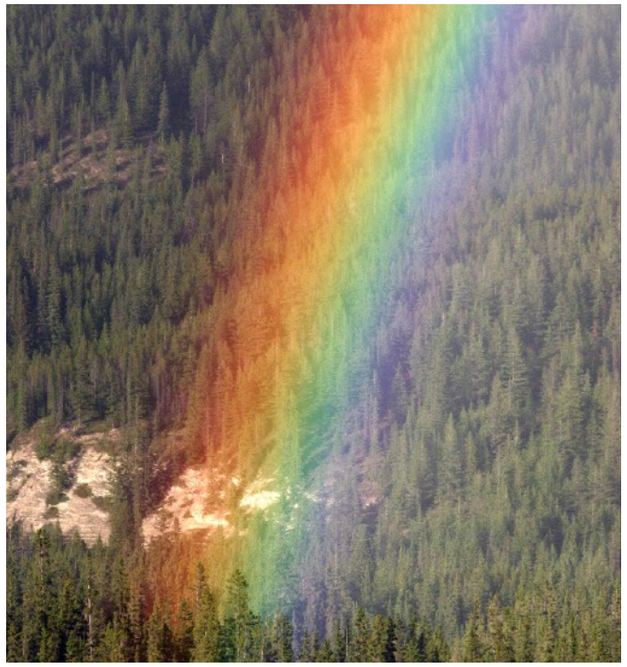
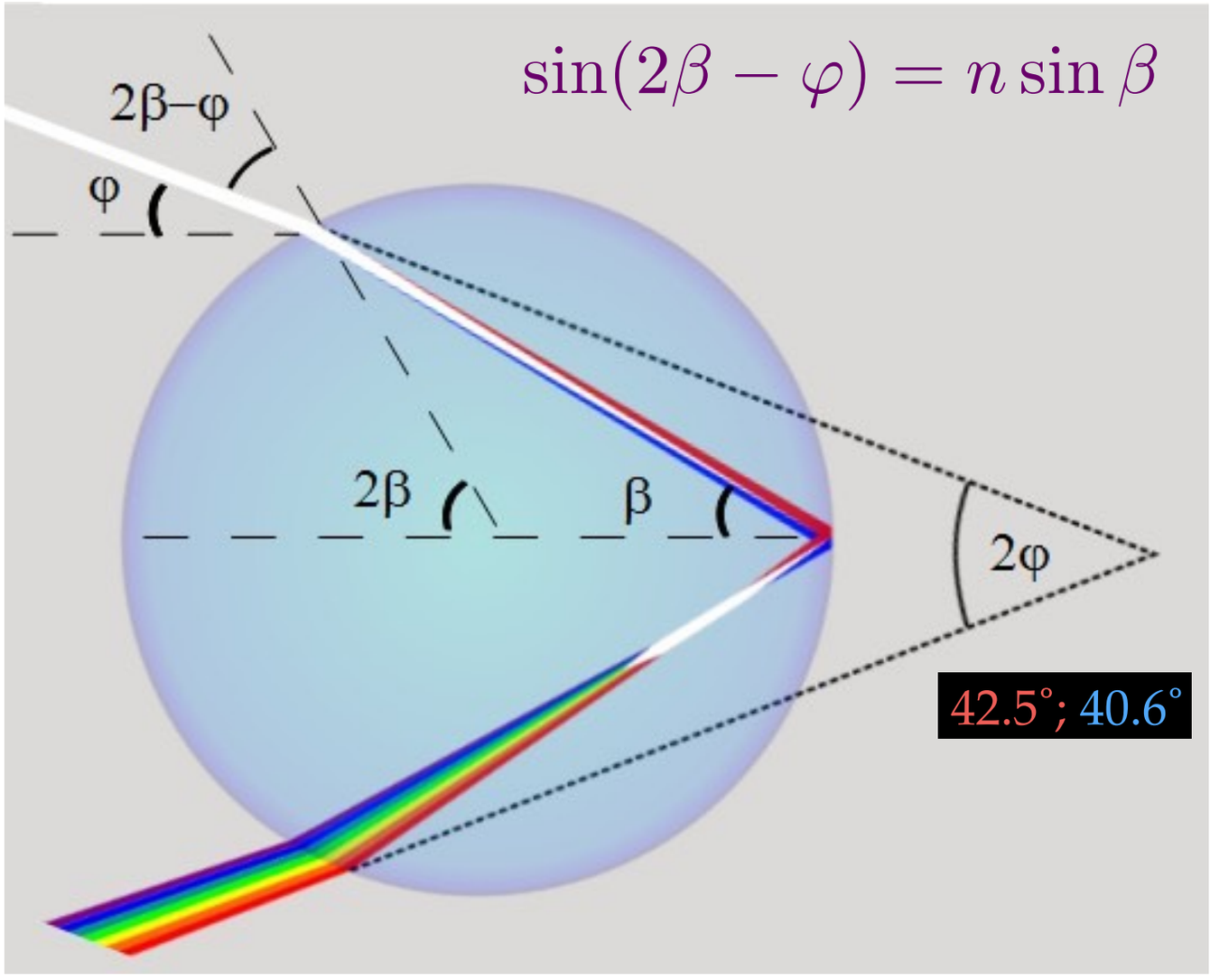
Rainbow Formation by Droplet Refraction



$$\beta_{\max} = \arccos\left(\frac{2\sqrt{n^2-1}}{\sqrt{3}n}\right) \approx 40.2^\circ$$

Salt water and oil have a larger refractive index and cause smaller rainbows



Refractive index of water:
1.331; 1.332; 1.333; 1.335; 1.338; 1.342

Color of rainbow is caused by different droplets (red from higher or closer droplets)

Interference and Polarization Alternation by Crystals

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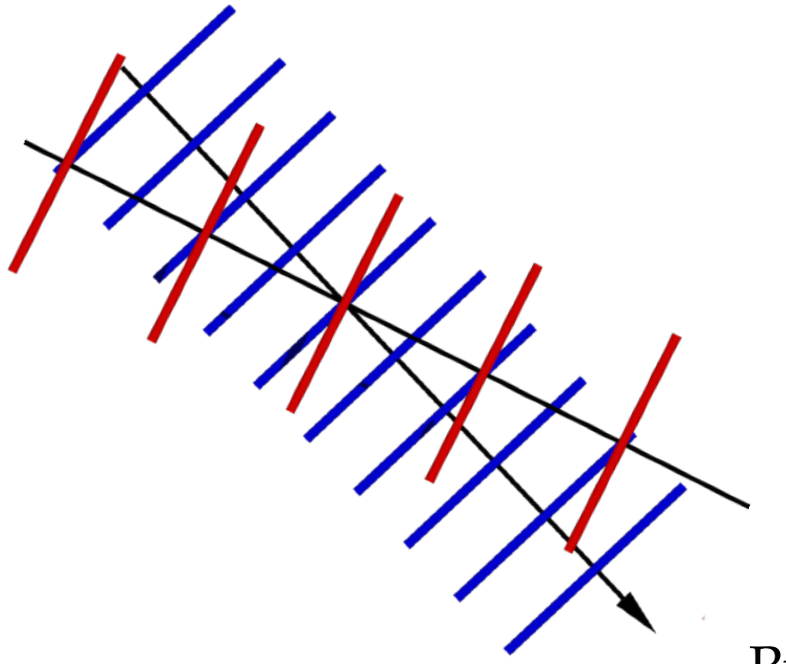
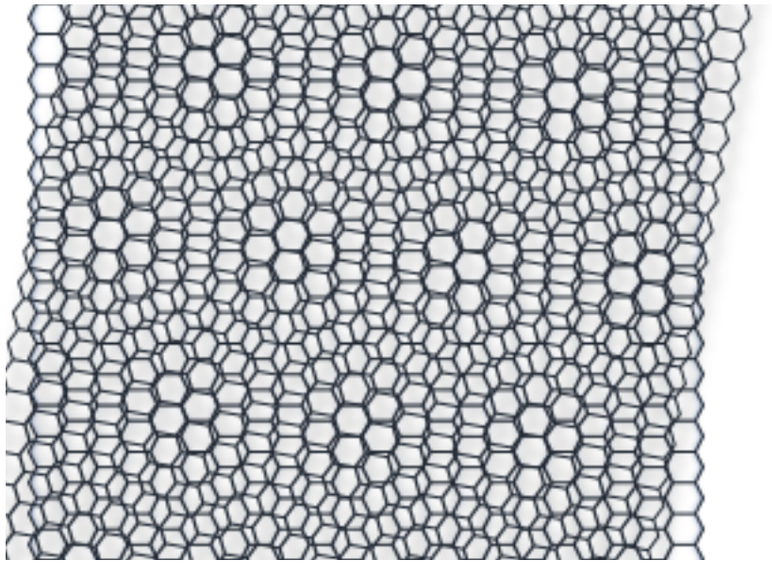
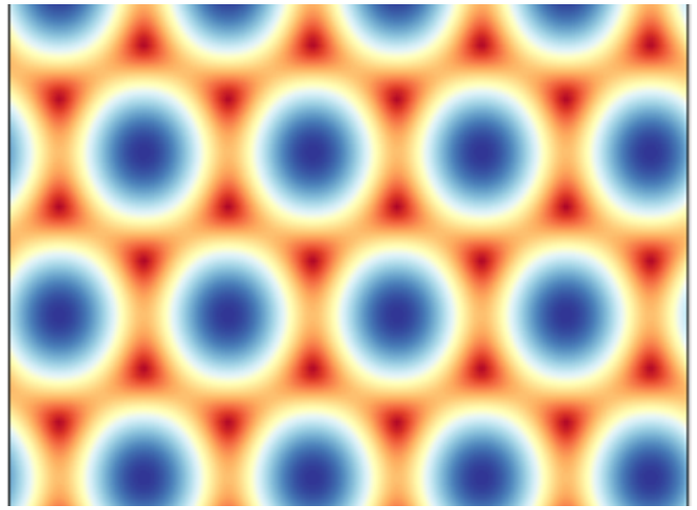
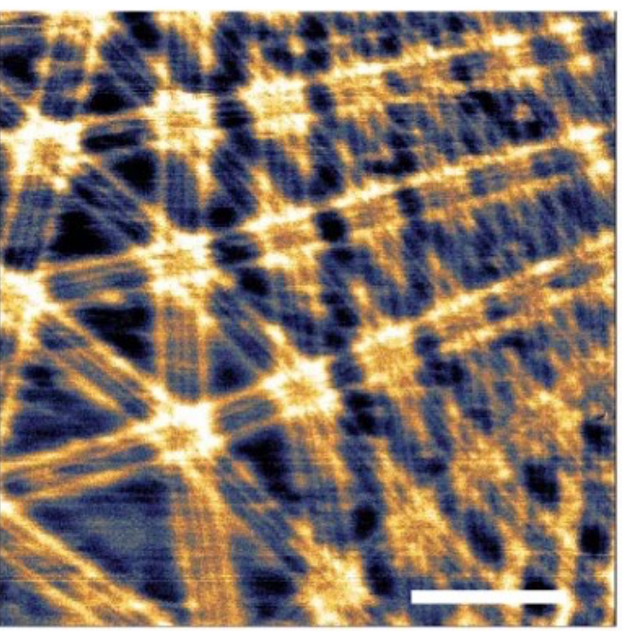
Moire Interference Pattern in Misaligned Lattices

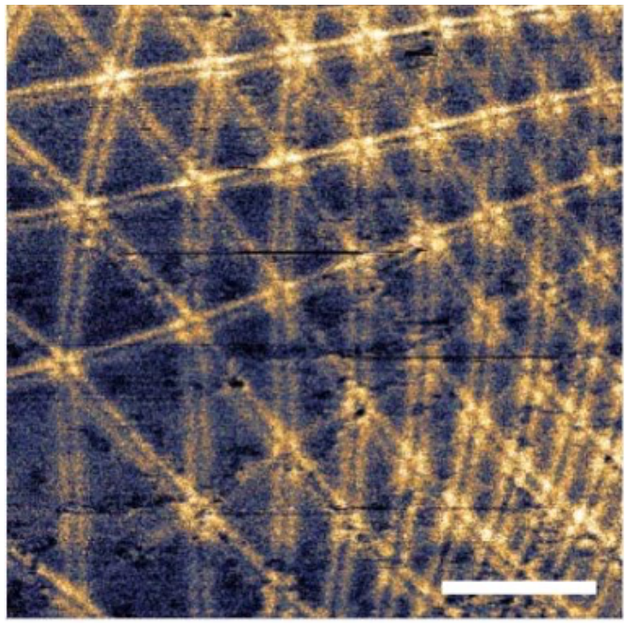


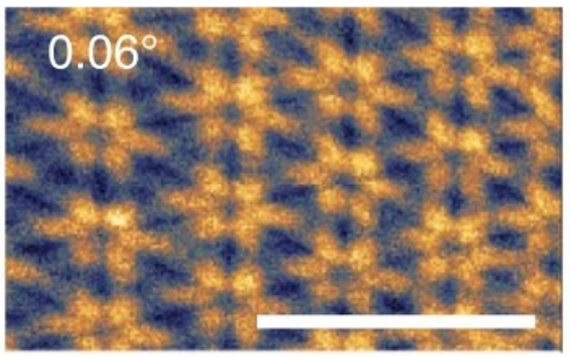


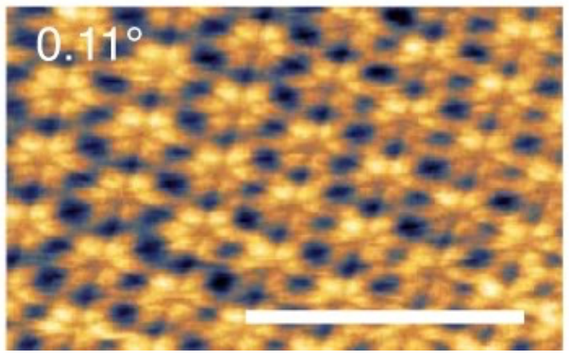


Proper electron orbital hybridization enhances conductivity



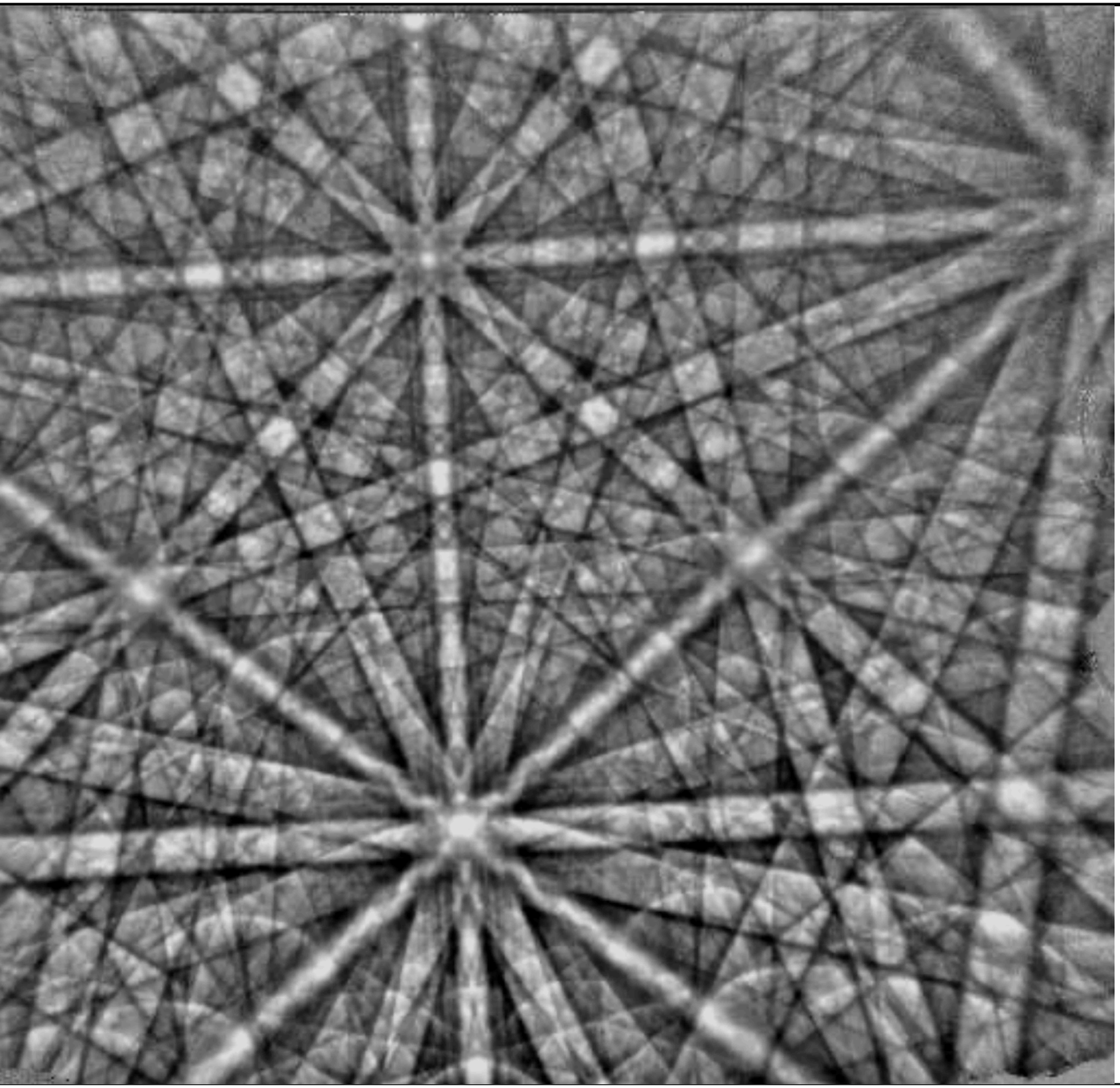






[1] K. Tran et al., Nature 567, 71 (2019); Y. Luo et al., Nat. Commun. **11**, 4209 (2020).

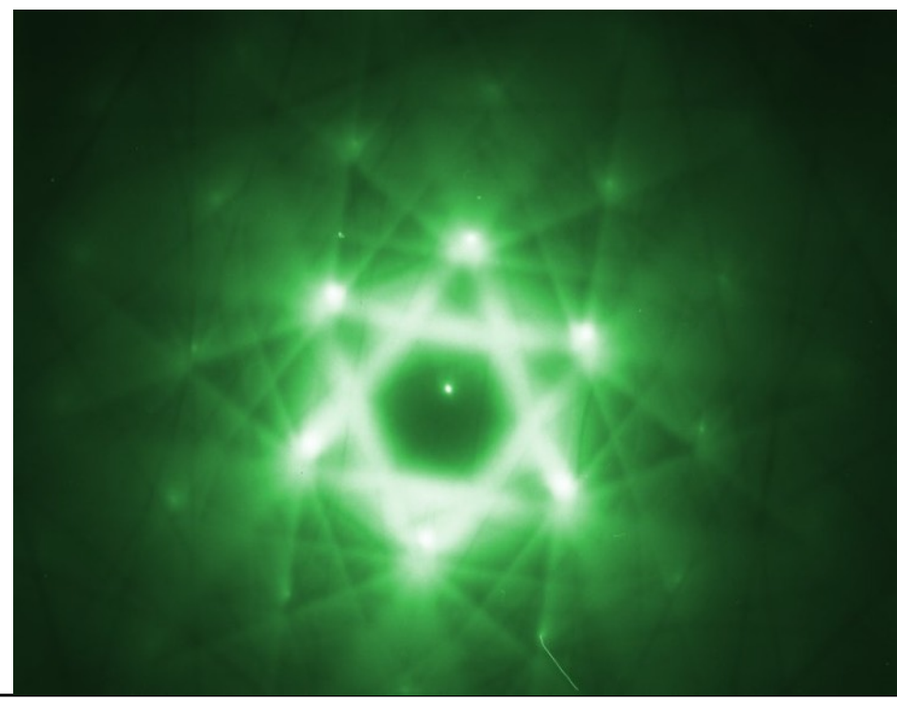
Kikuchi Pattern by Electron Backscatter Diffraction



Multiple inelastic scattering events in thick crystals

Diffuse scattering due to phonons

Intersections indicate crystal axes



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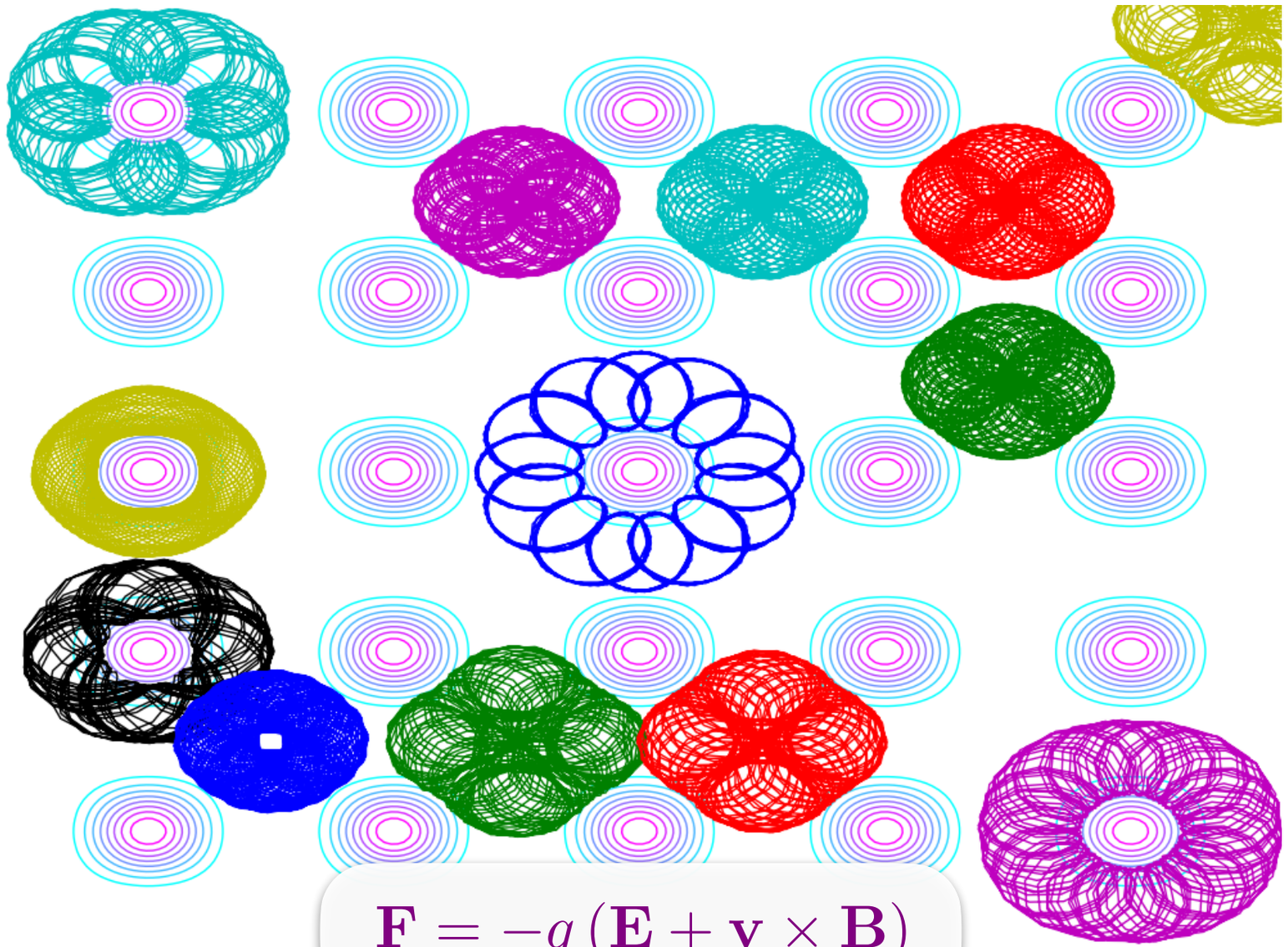
Electromagnetic Waves

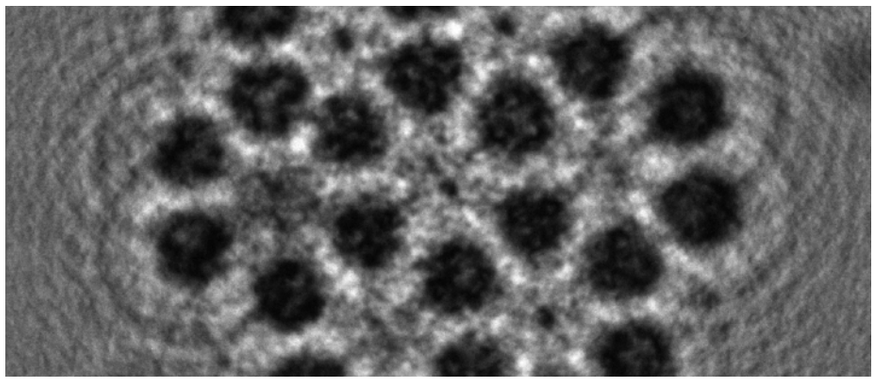
Dualism

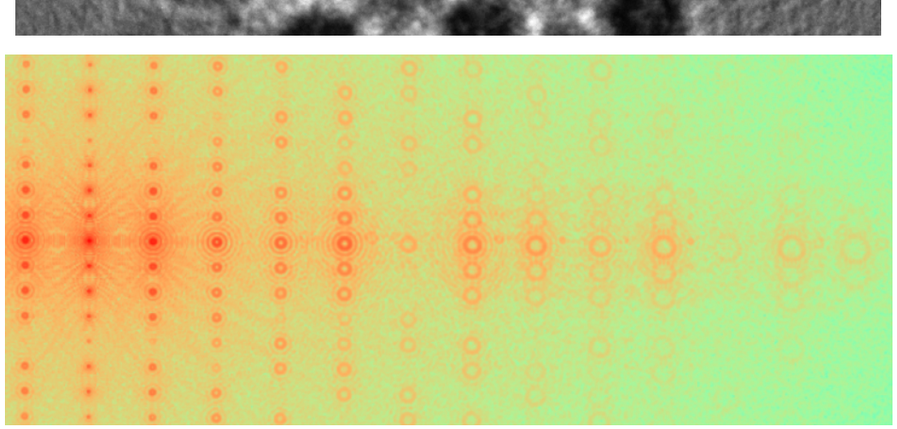
Particle ⟷ **Wave**

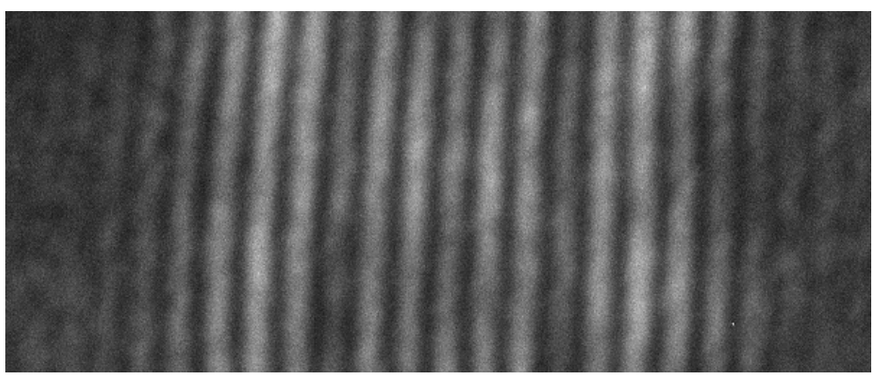
$$\lambda = \frac{h}{p}$$



$$\mathbf{F} = -q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$$







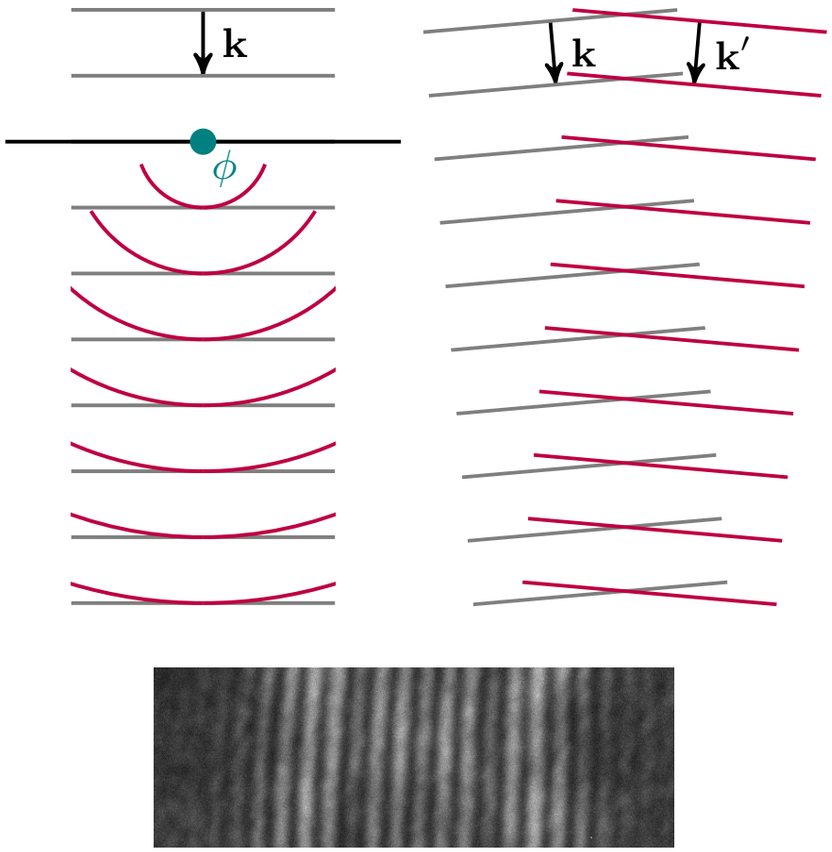
Interference

Superimposition of *coherent* waves causes interference fringes

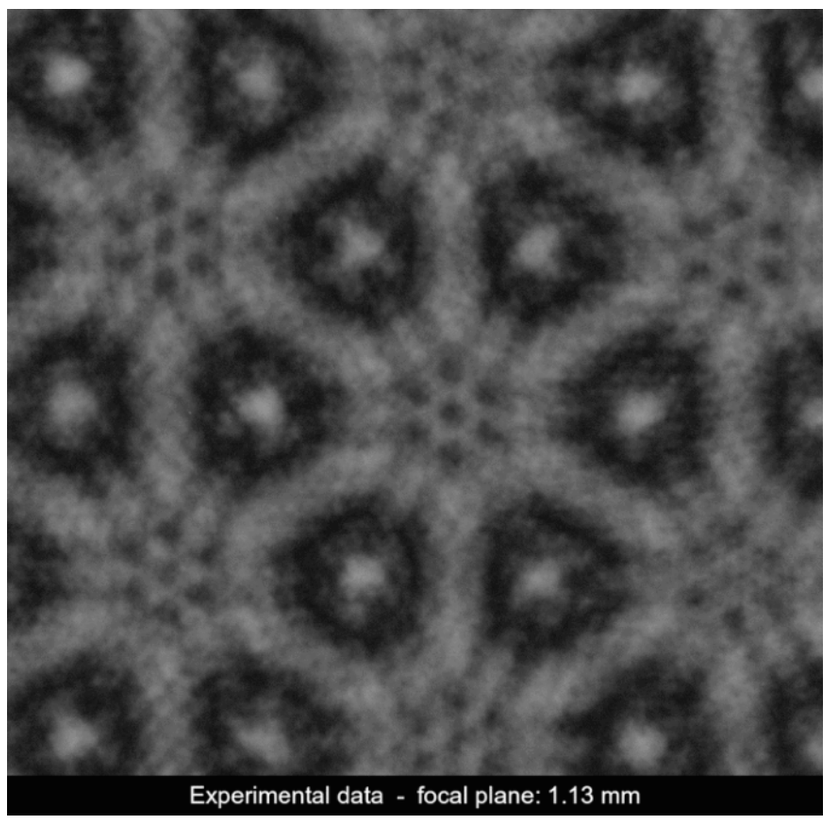
Temporal coherence

Spatial coherence

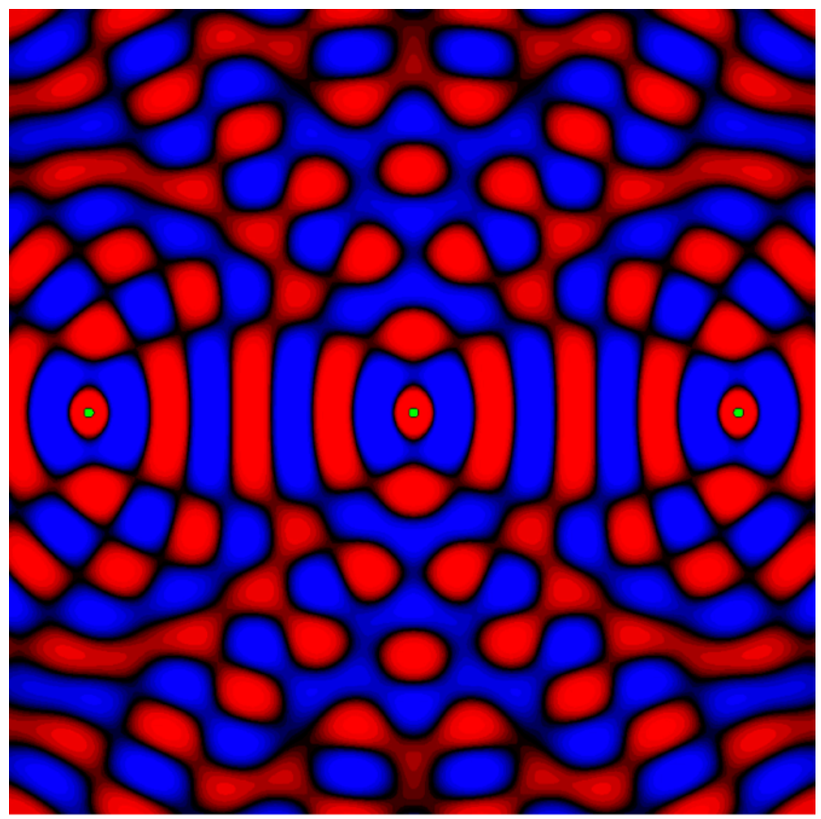
In-line and off-axis holography



Scattered and *un-scattered* waves



Multiple coherent sources



Electron intensity of nanodisk lattices

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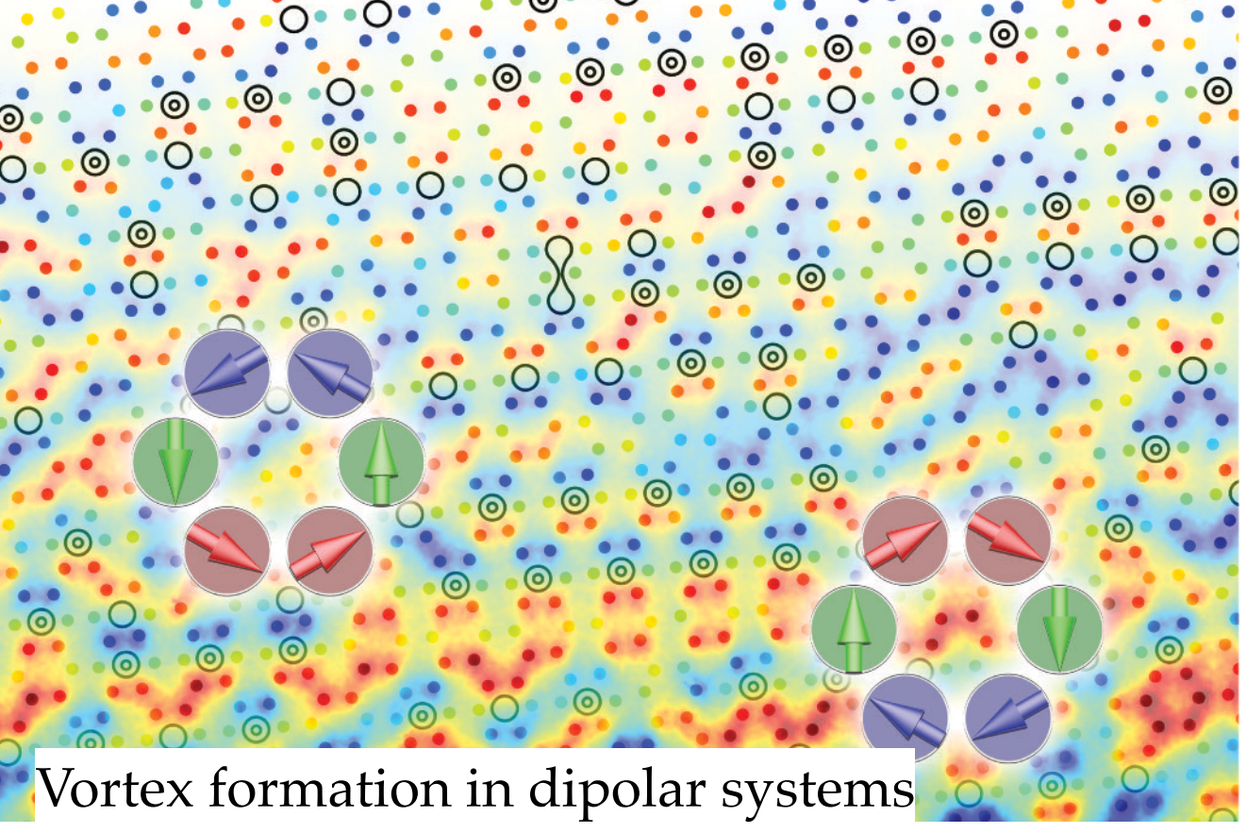
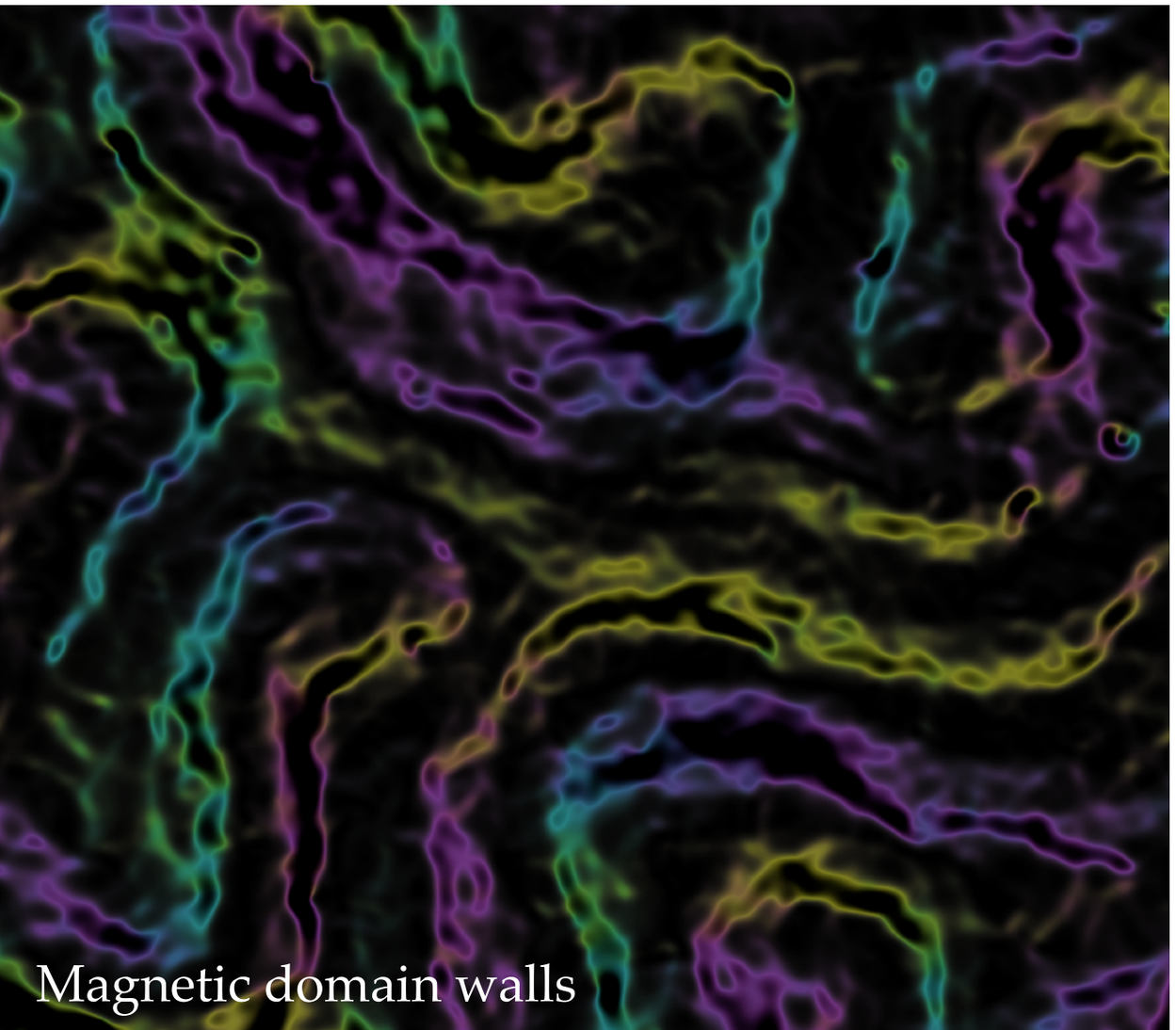
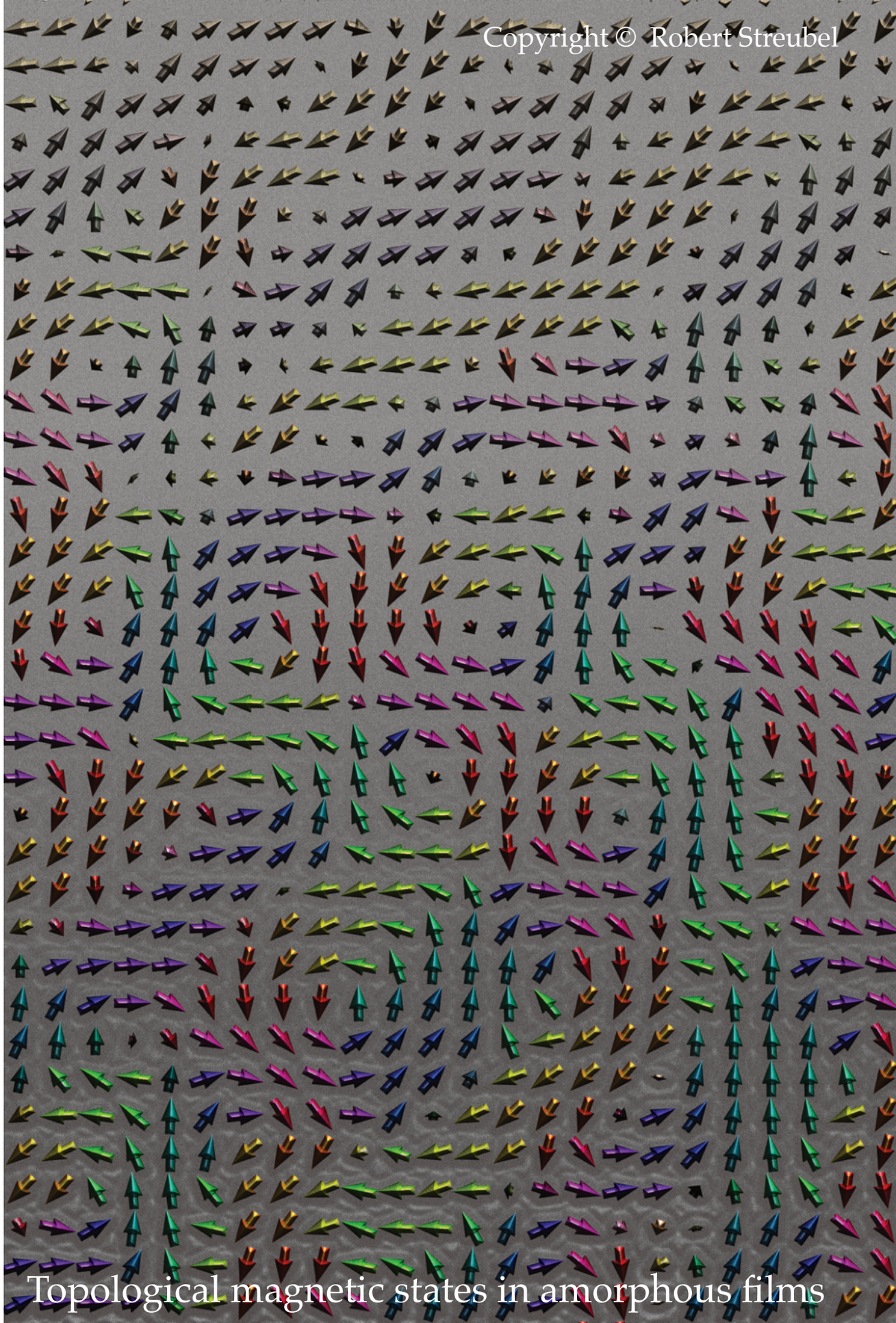


Vortex formation in dipolar systems



Magnetic domain walls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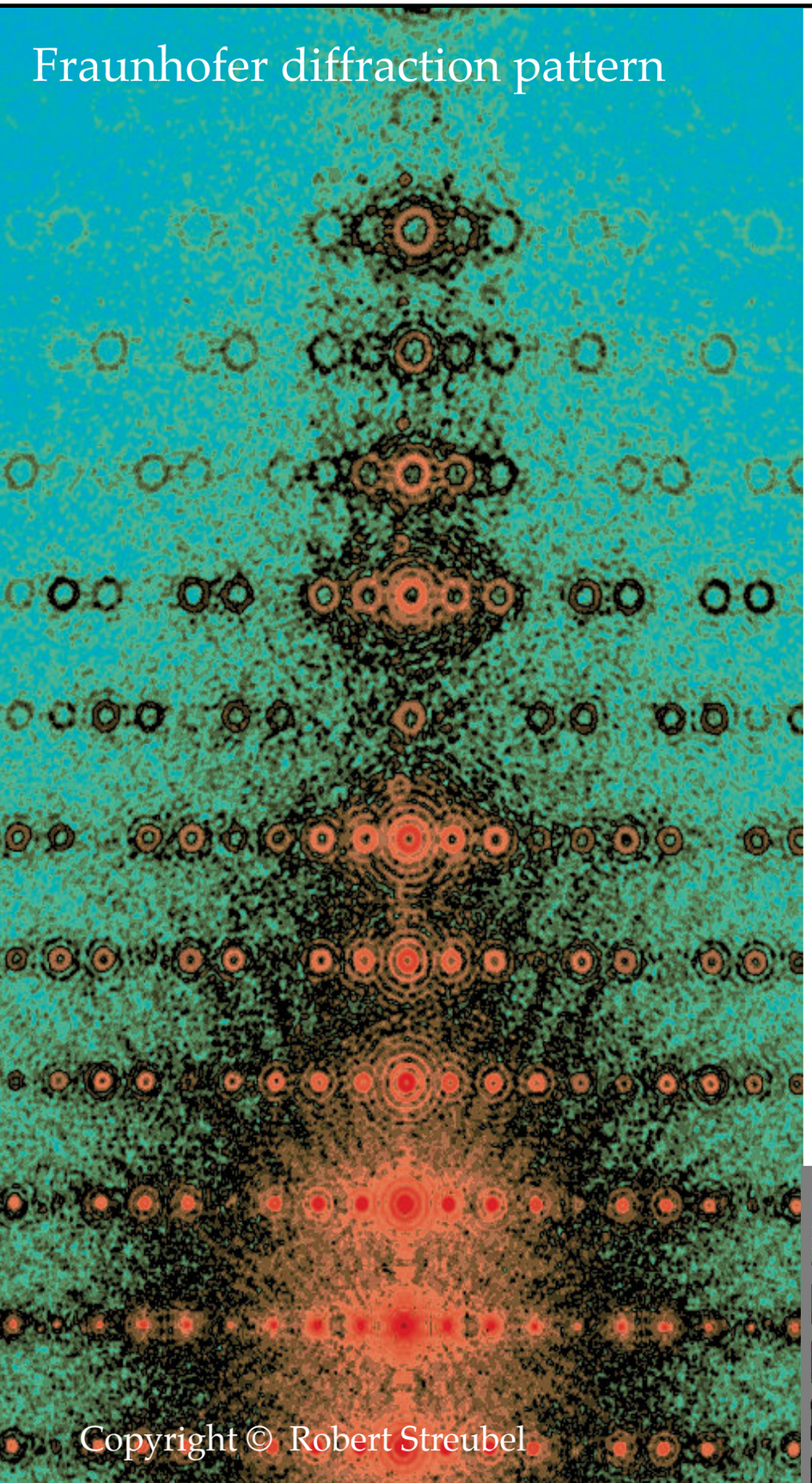
Topological magnetic states in amorphous films

Vortex Beams with Orbital Angular Momentum



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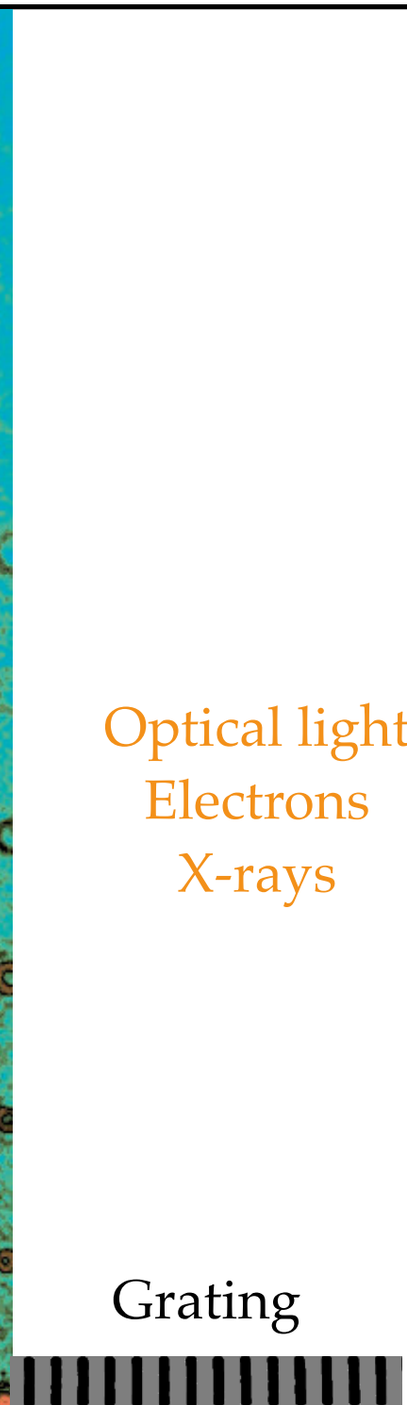
Optical light
Electrons
X-rays

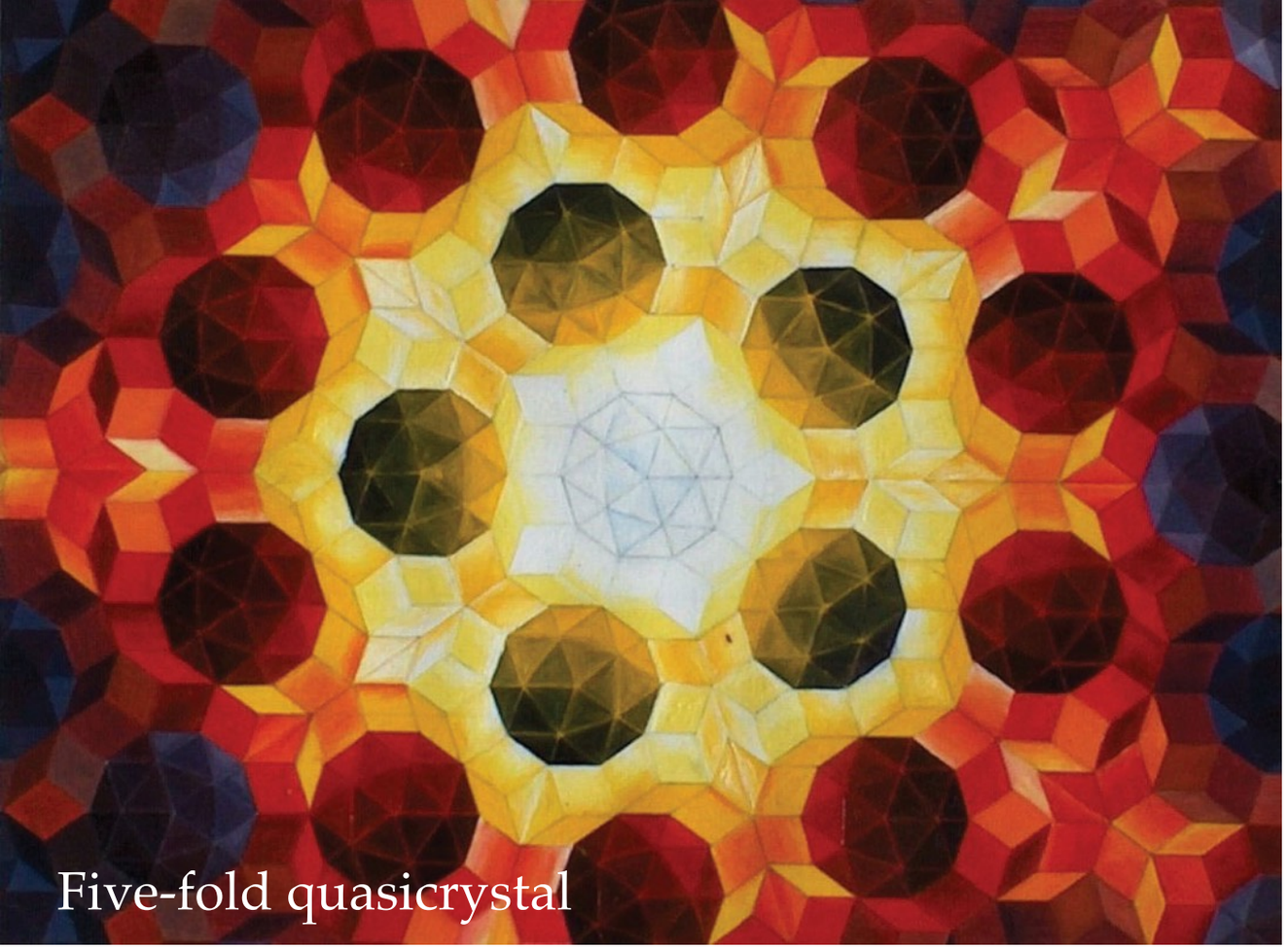
Grating



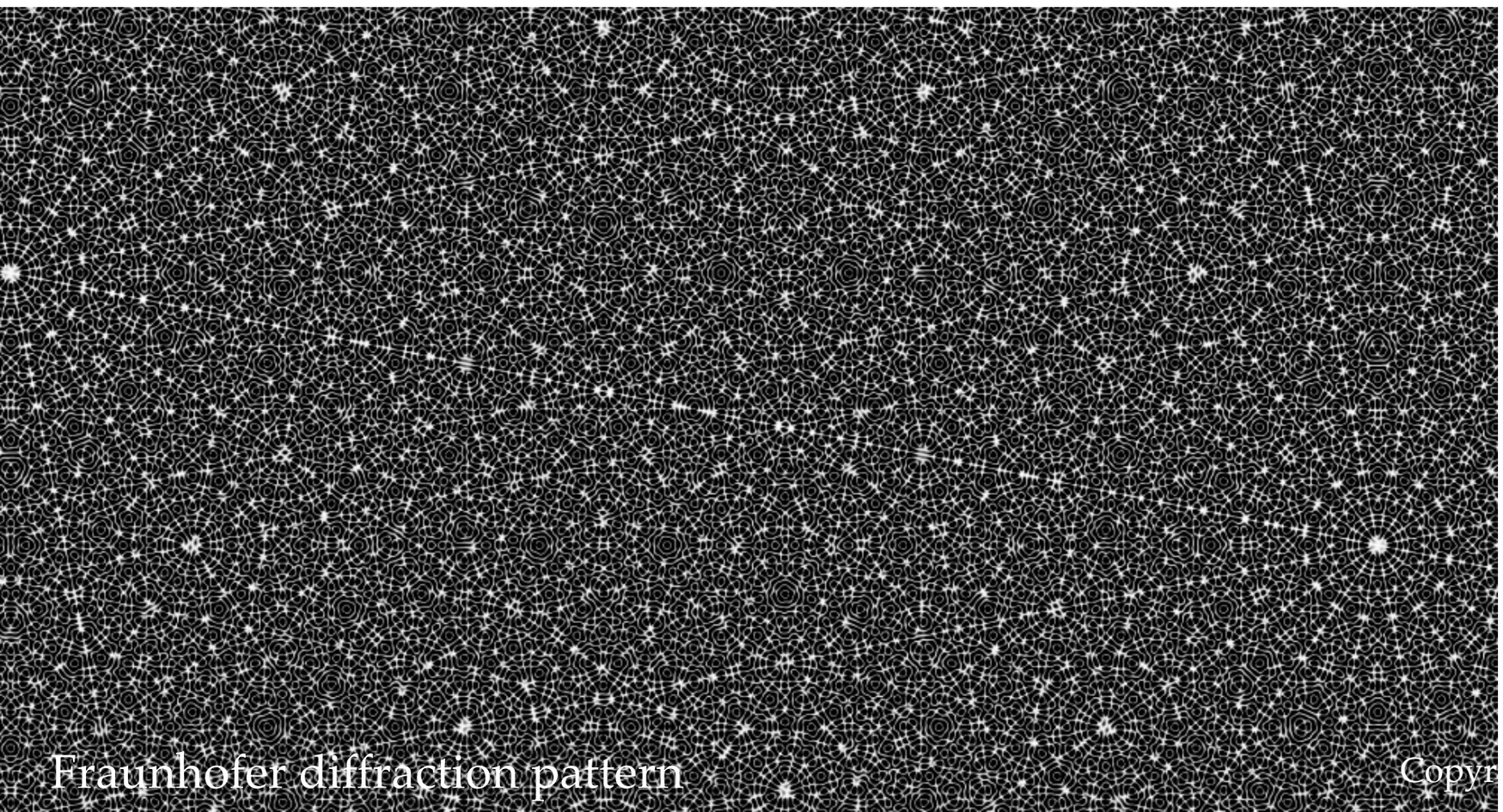
Integrated intensity

Momentary intensity

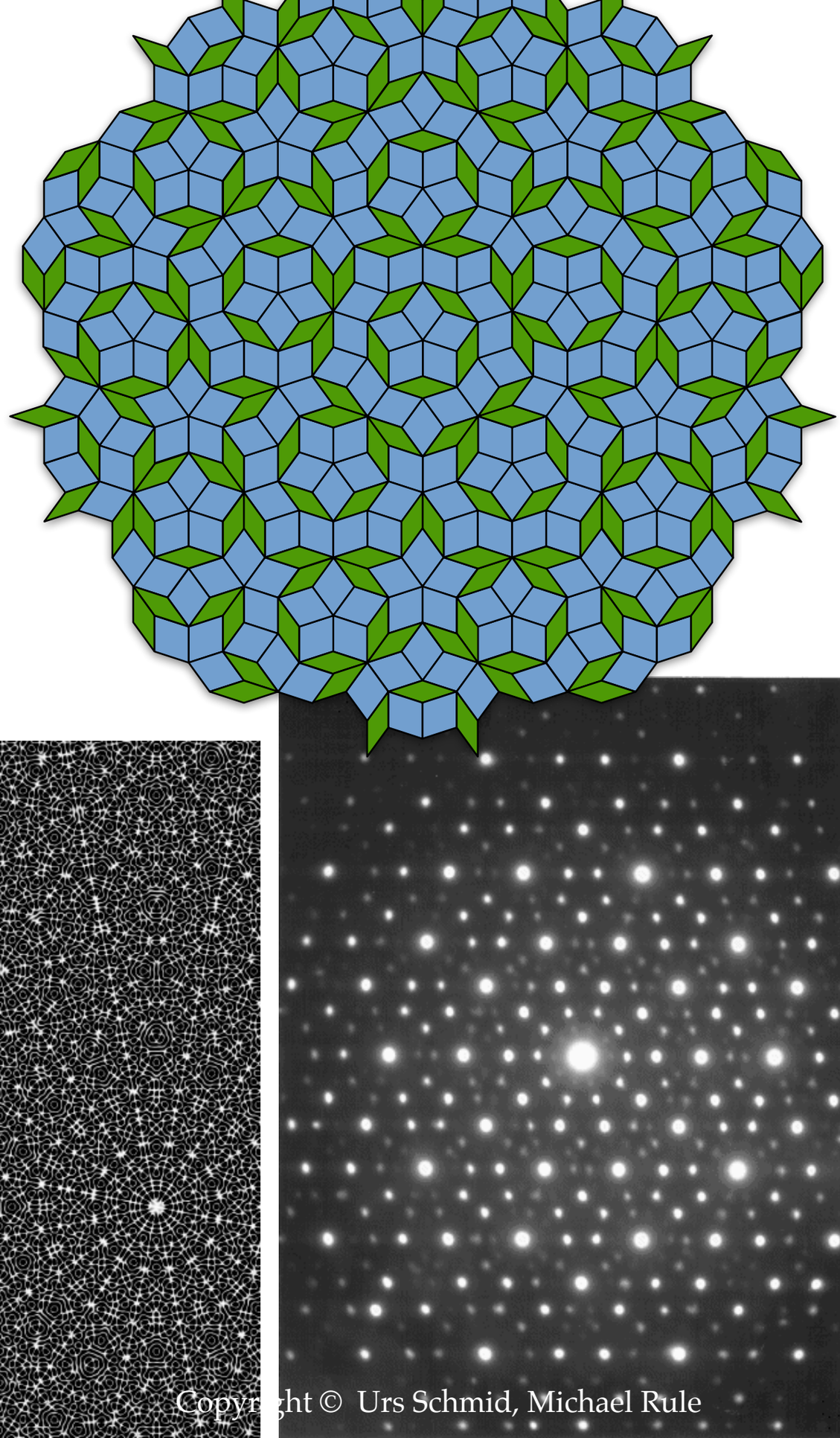
[1] M. Padgett et al., Physics Today **57**, 5, 35 (2004).



Five-fold quasicrystal



Fraunhofer diffraction pattern



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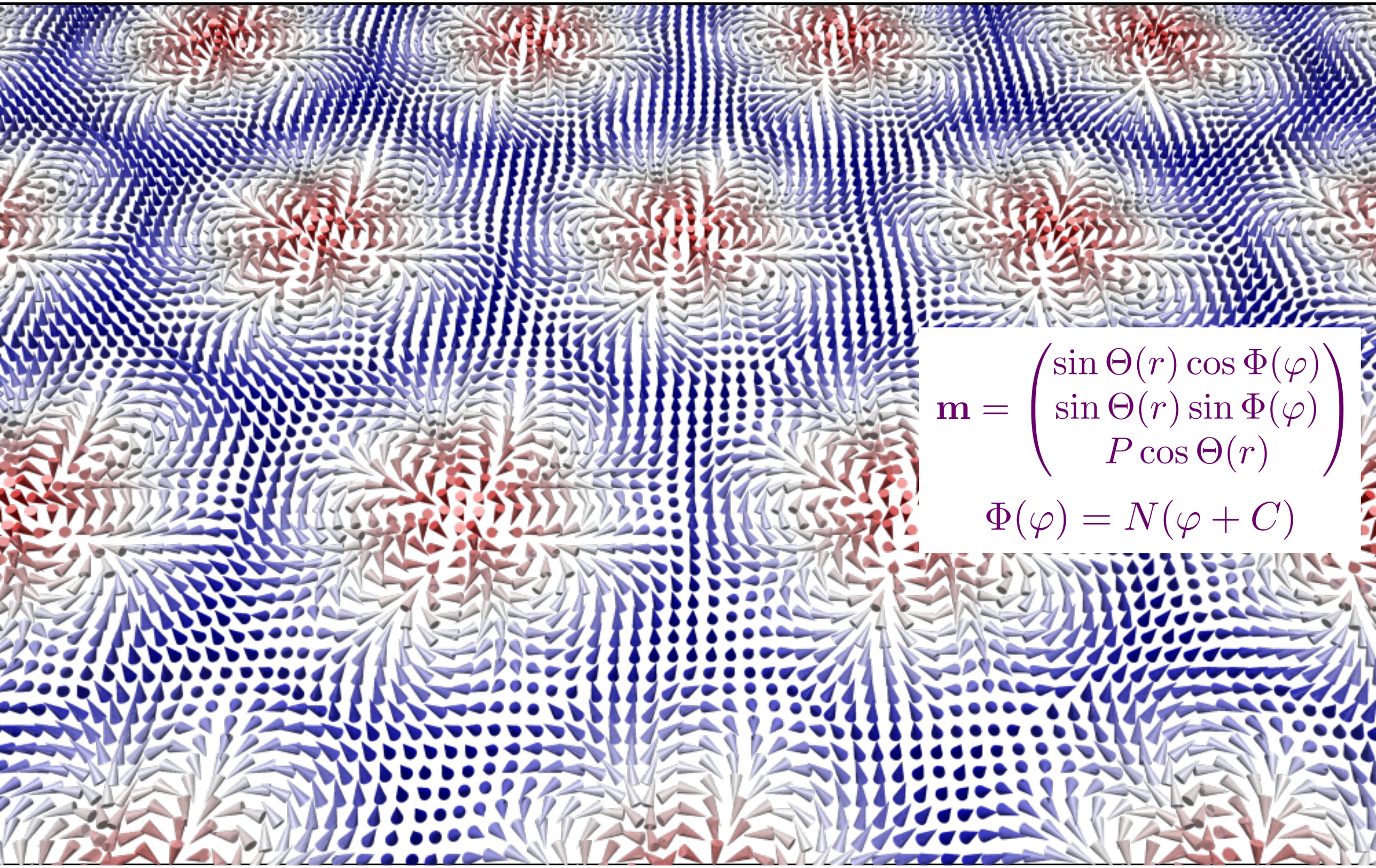
Topological Magnetic States



$$\mathbf{m} = \begin{pmatrix} \sin\Theta(r)\cos\Phi(\varphi) \\ \sin\Theta(r)\sin\Phi(\varphi) \\ P\cos\Theta(r) \end{pmatrix}$$

$$\Phi(\varphi) = N(\varphi + C)$$

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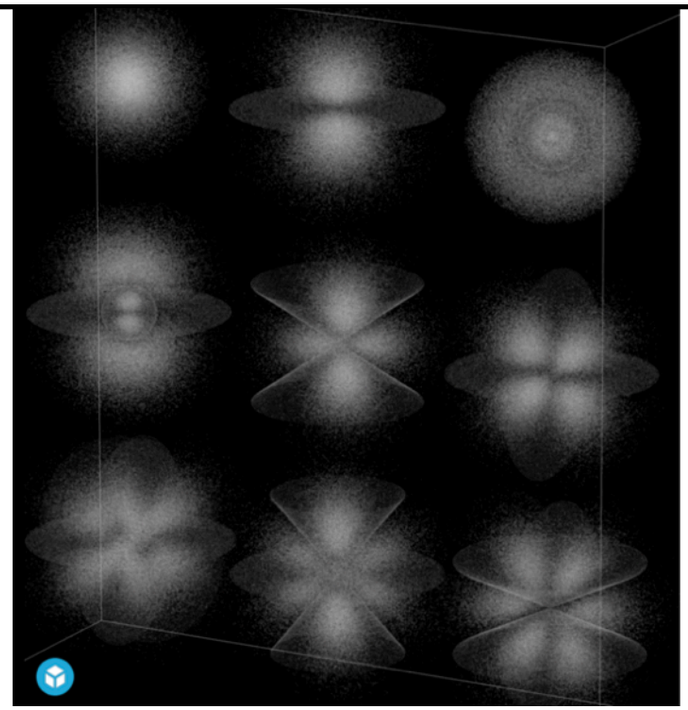
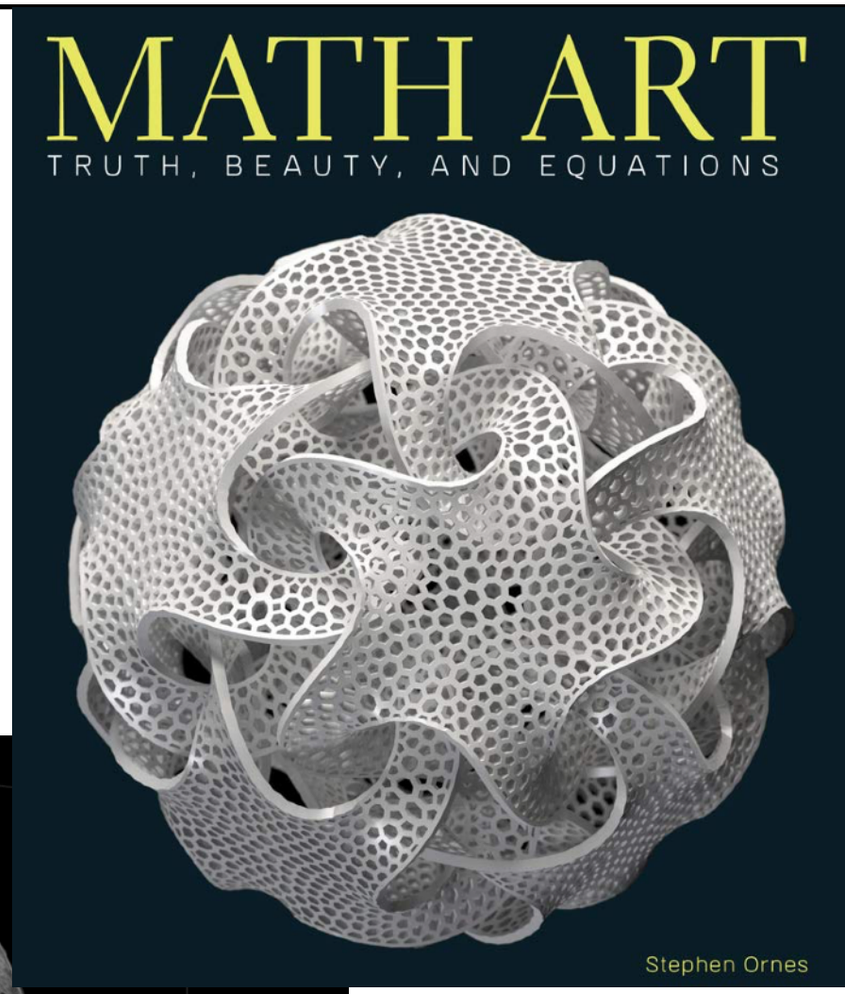
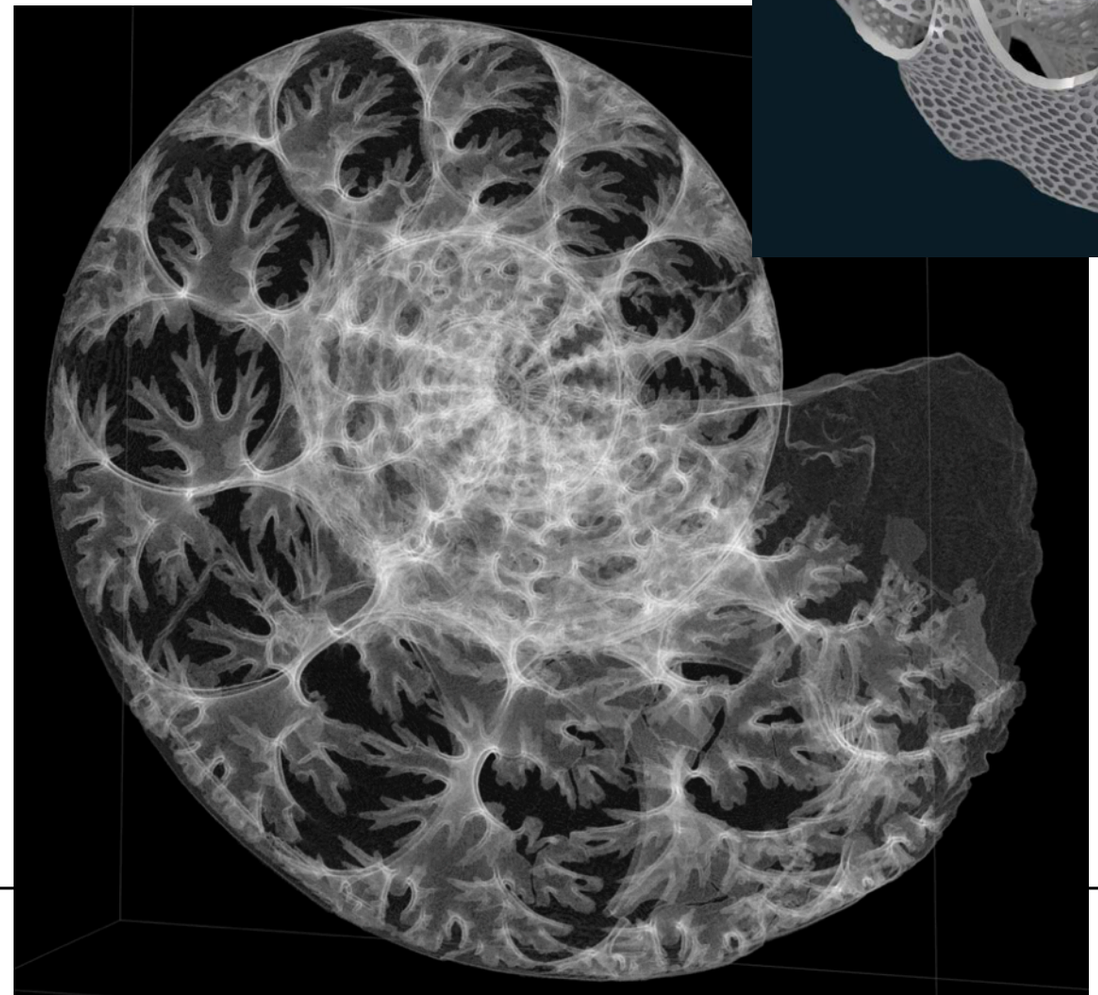
3D Printed Mathematical Art







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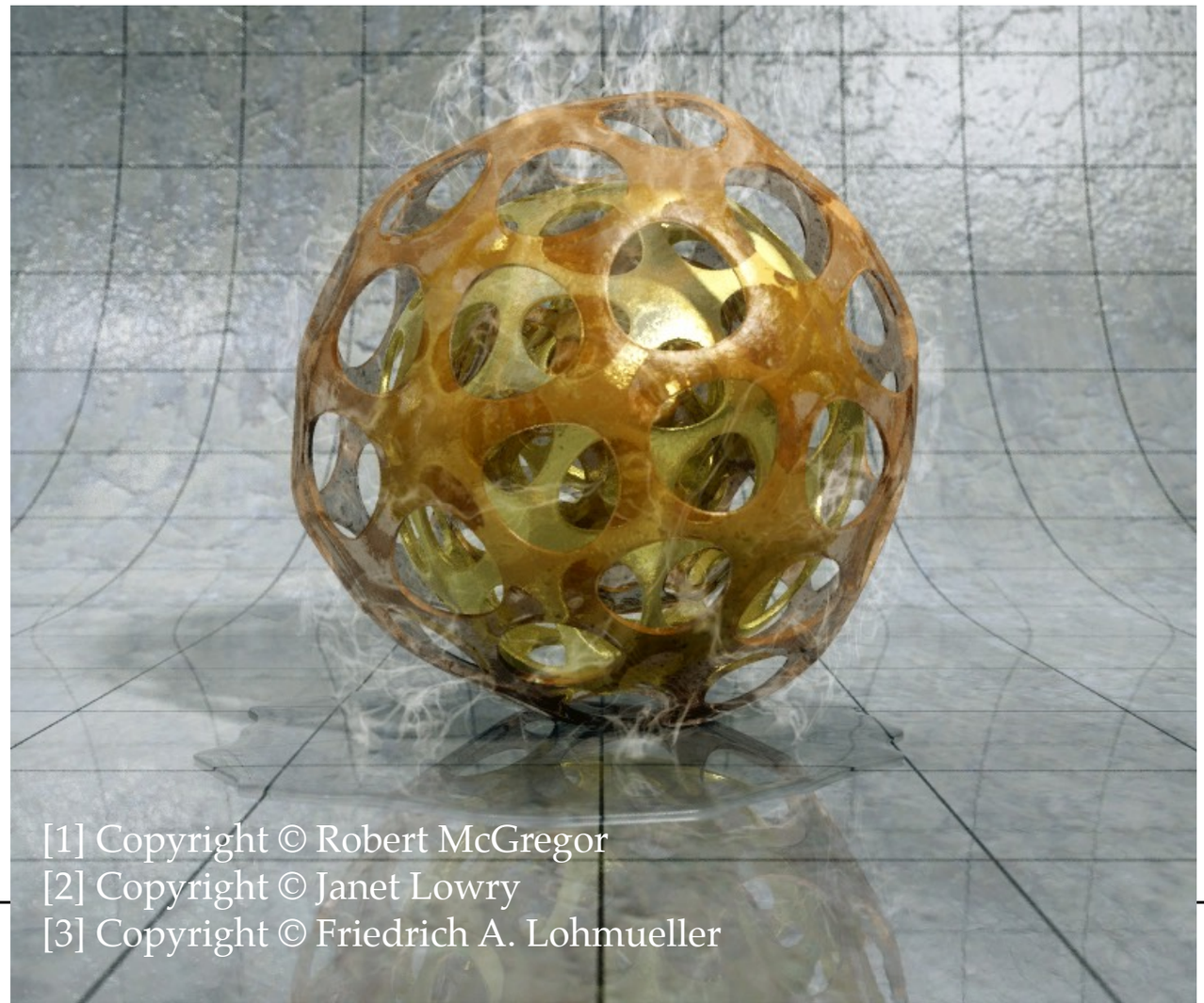
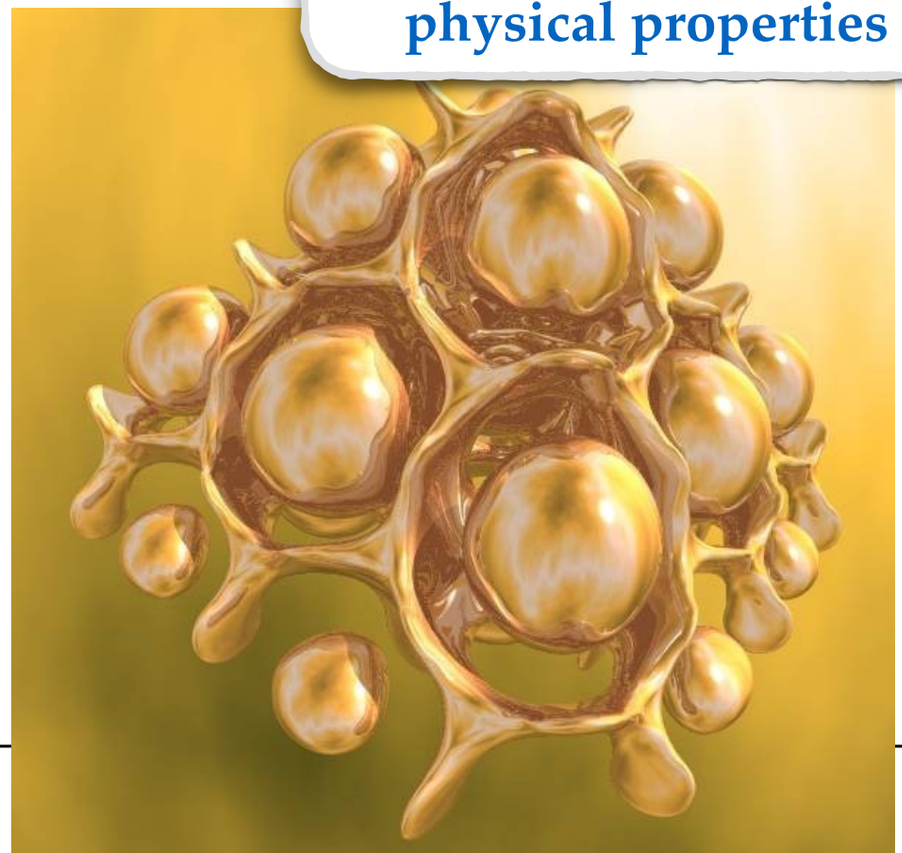
The Persistence of Vision Raytracer

Mathematical equations and physical properties of light





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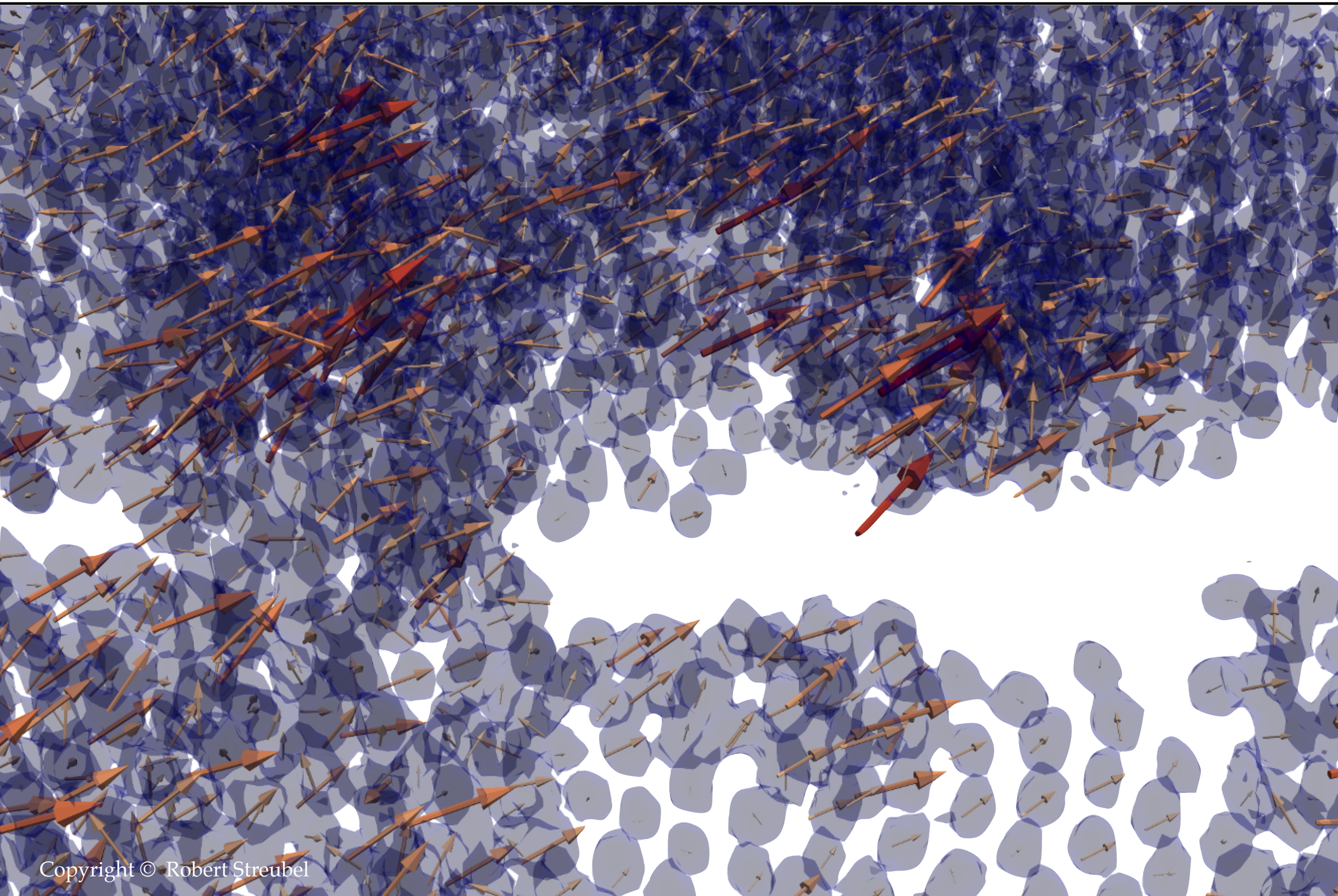
Magnetization in Superparamagnetic Nanoparticles



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Focused ion beam etching of semiconductors

Wet chemical etching of chromium

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Coexistence of Regular and Chaotic Motion

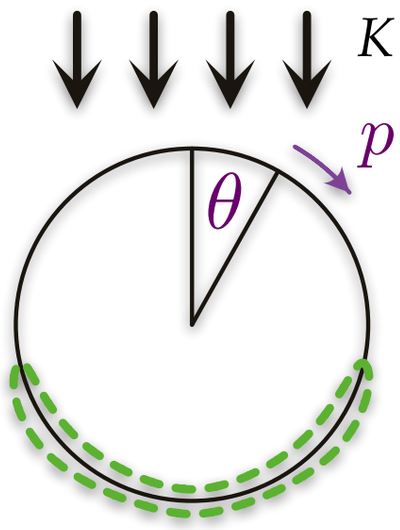
Circular motion experiencing a constant force K

Angular dependent torque

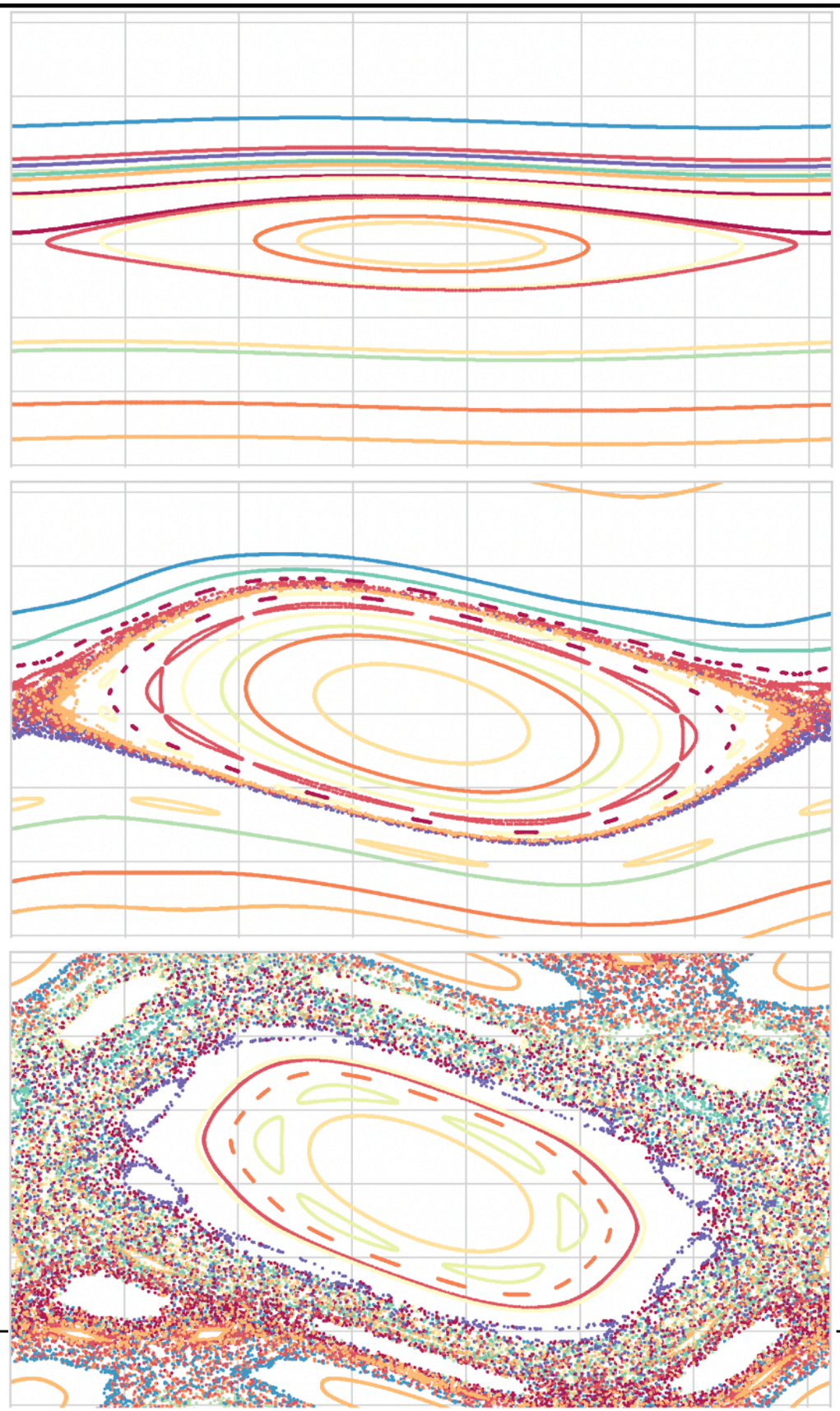
Phase space representation (theta, p)

$$\theta_{n+1} = \theta_n + p_n$$

$$p_{n+1} = p_n + K \sin \theta_{n+1}$$



K could be air flow or gravitation.



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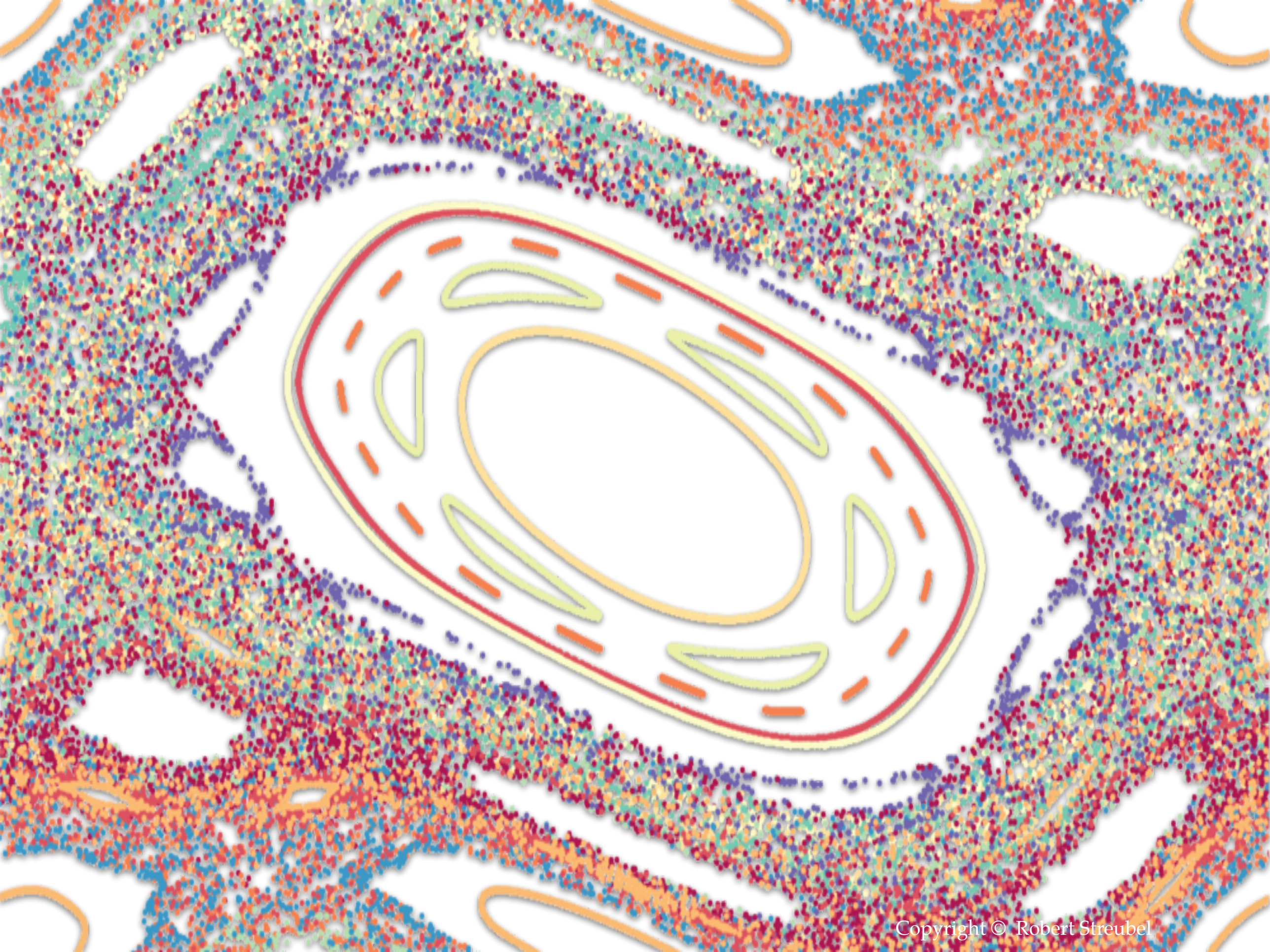

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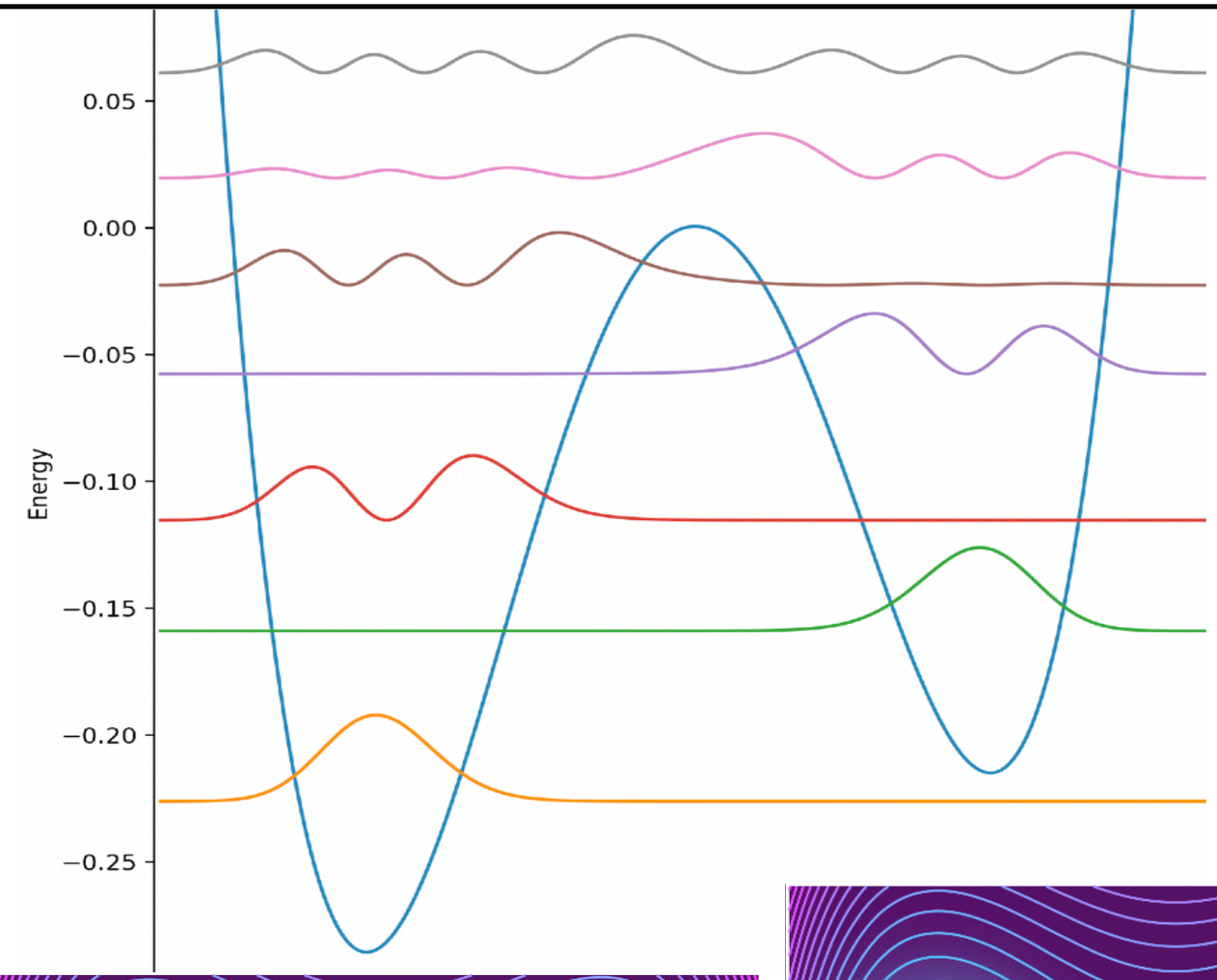
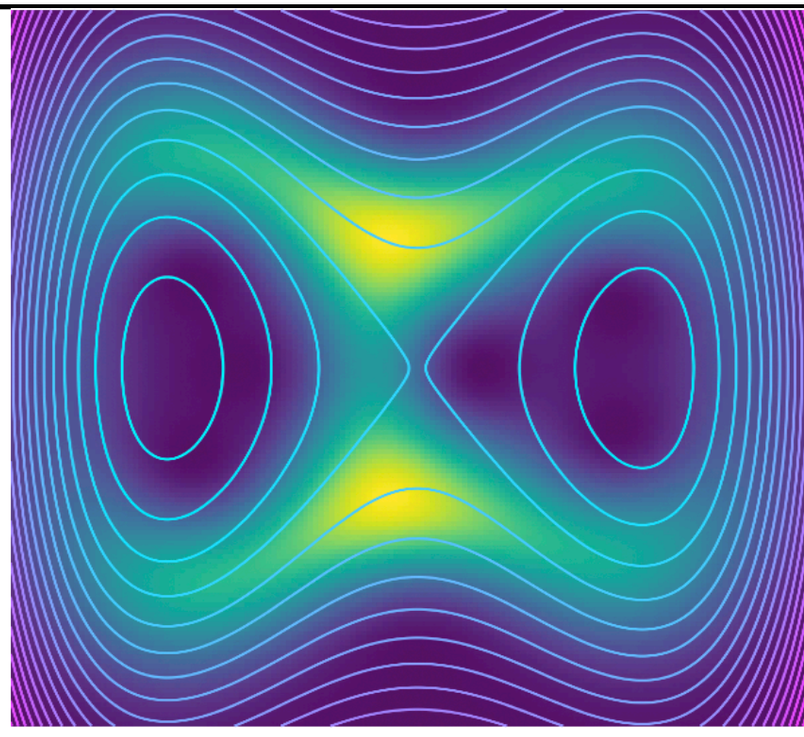
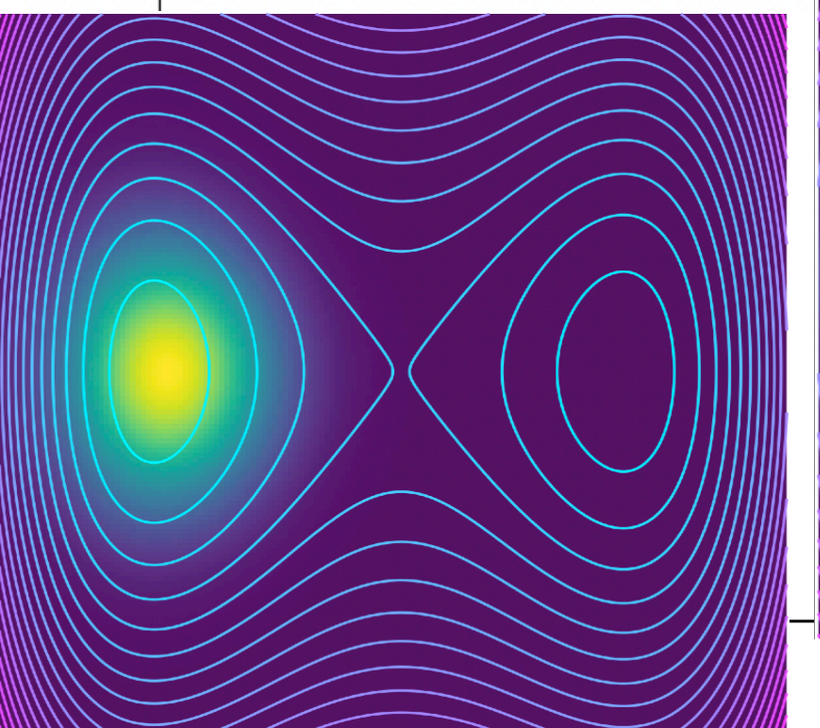
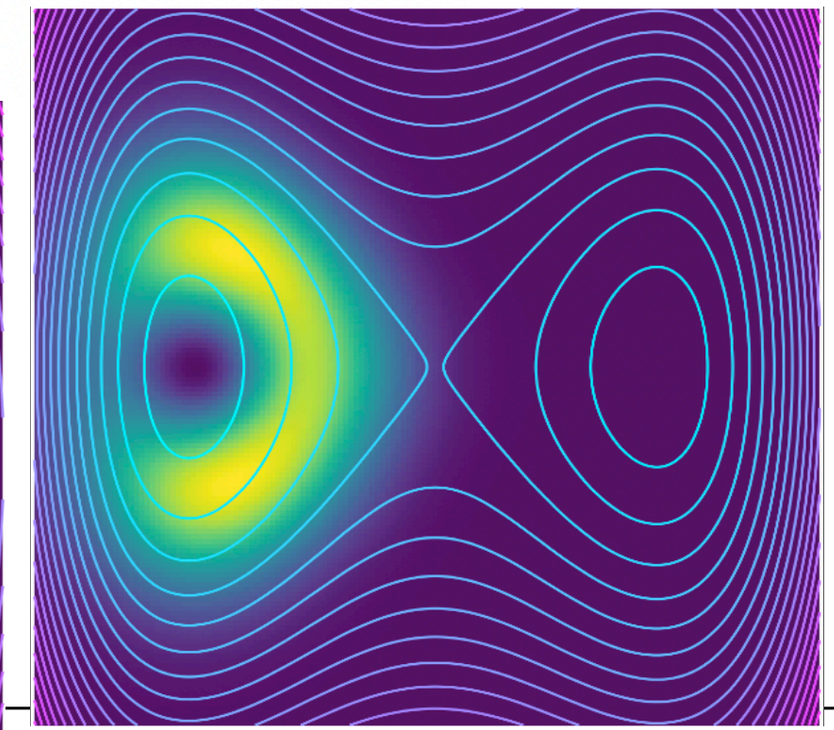
Quantum-Mechanical Oscillator

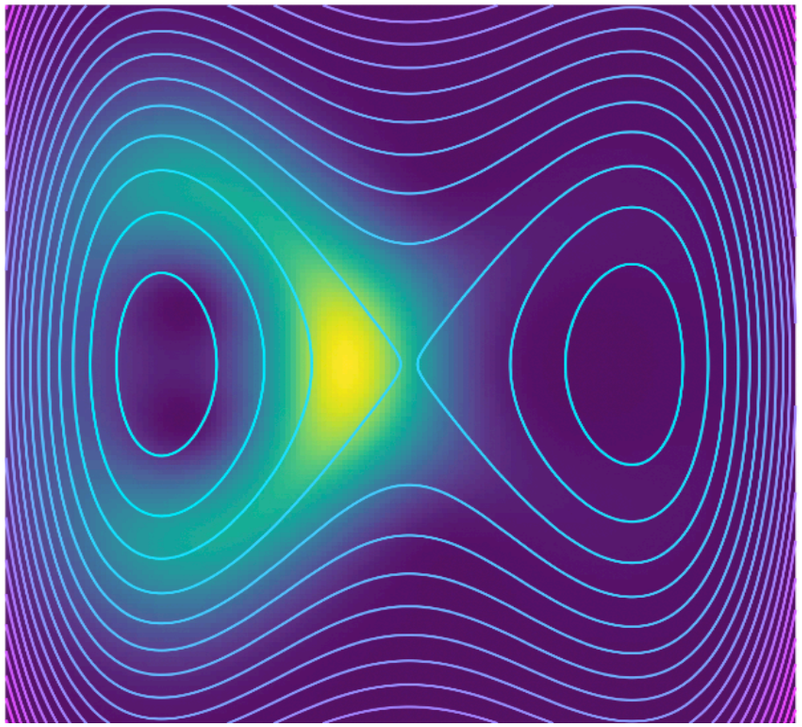


Probability density of particle in phase space









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Air Vortices

Turbulences form at edge and move faster for small separation.

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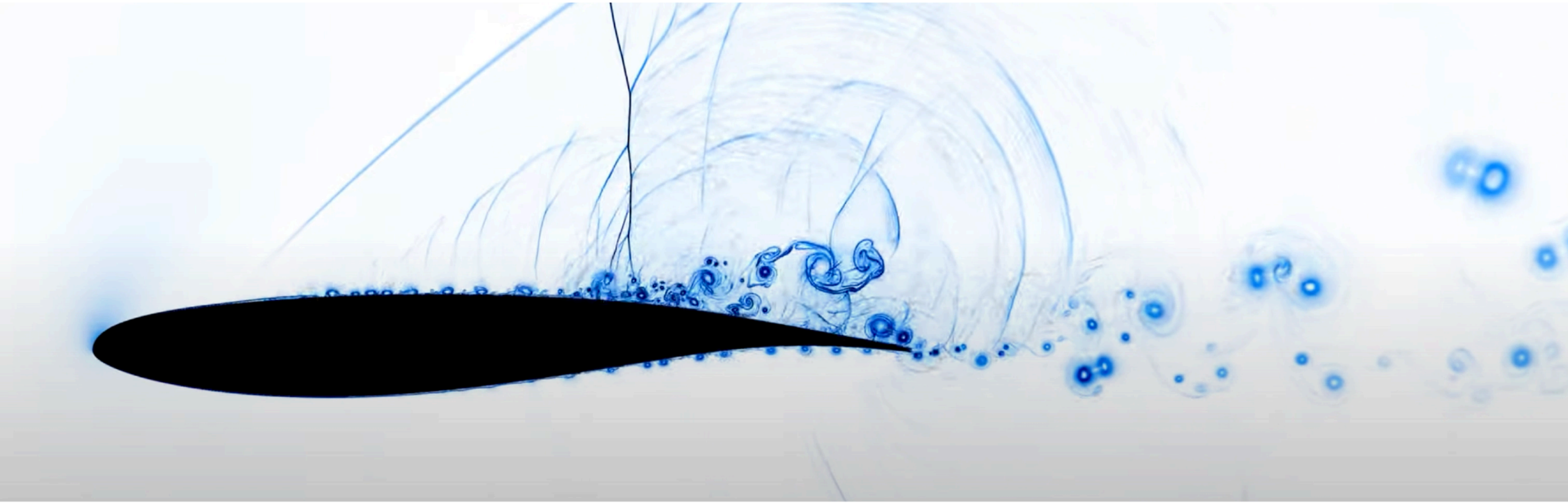
Air Turbulences Around Wings

Static pressure — Geodetic pressure — Hydrodynamic pressure

$$p_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = p_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

$$Re = \frac{r\rho v}{\eta} \approx \frac{\text{Inertia}}{\text{Friction}}$$



Reynold's number is about 3 million.
Vortices with opposite circulation form on opposite sites and bound or annihilate.

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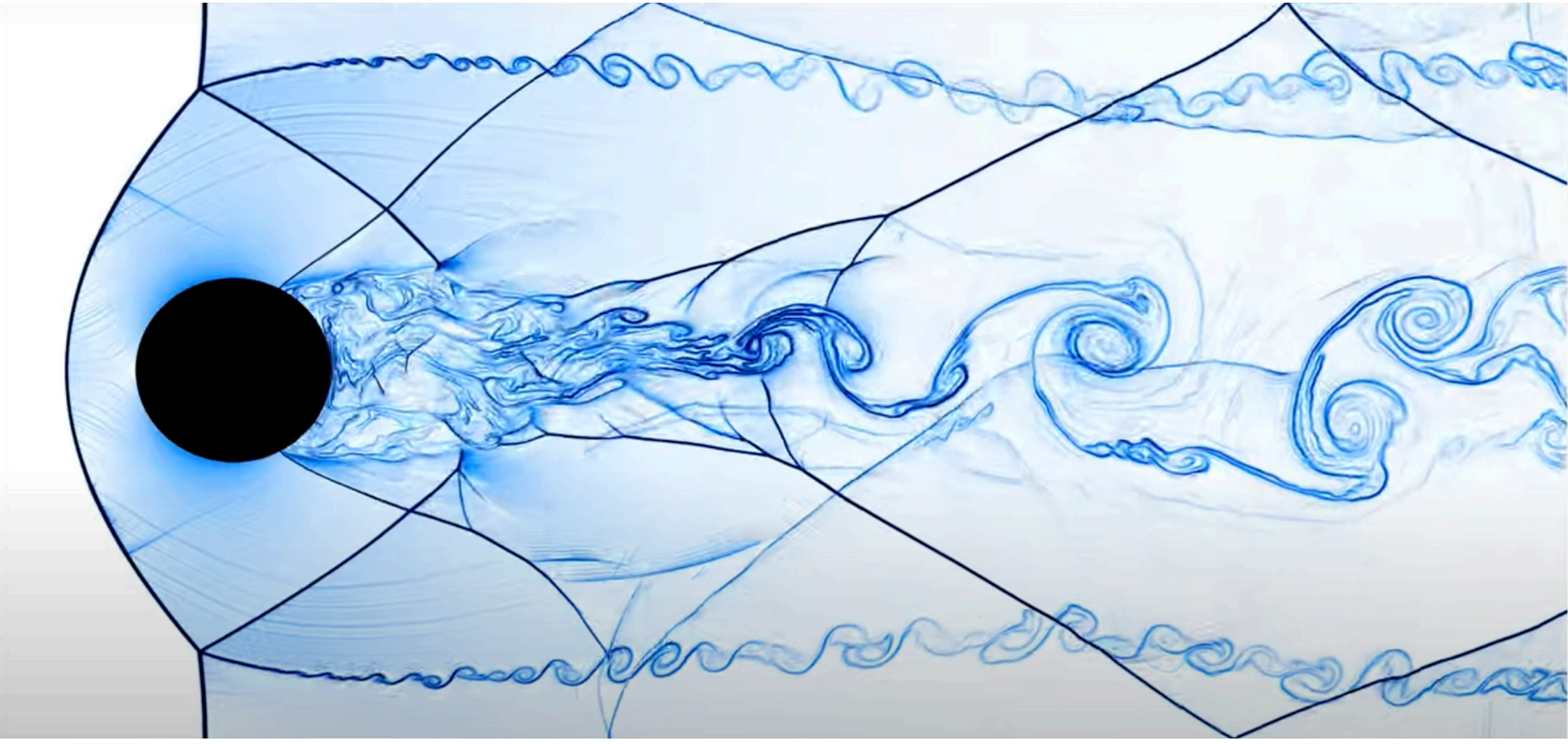
Water Turbulences Around Cylinder



Reynold's number is about 10 thousand.

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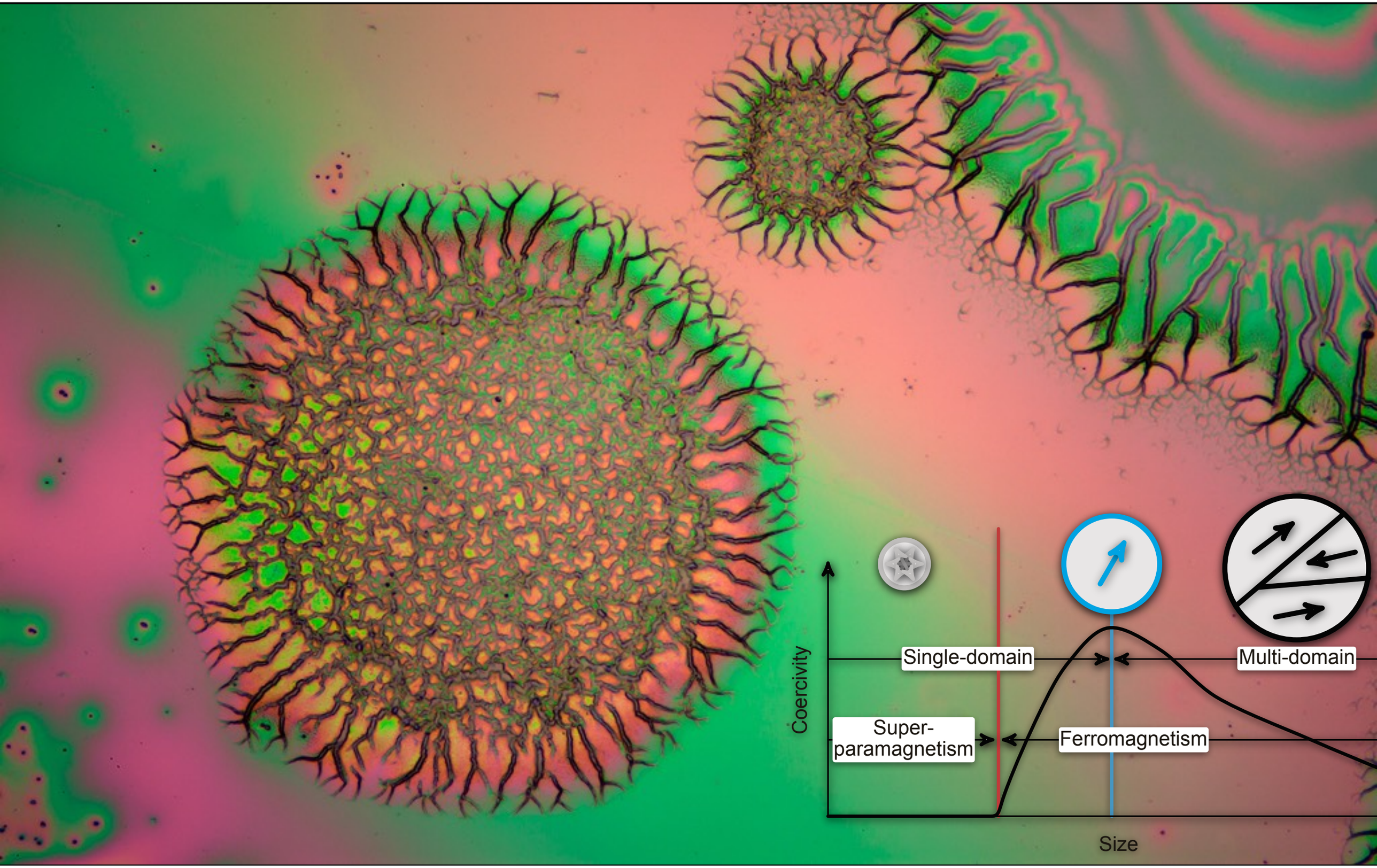
Ferrofluids



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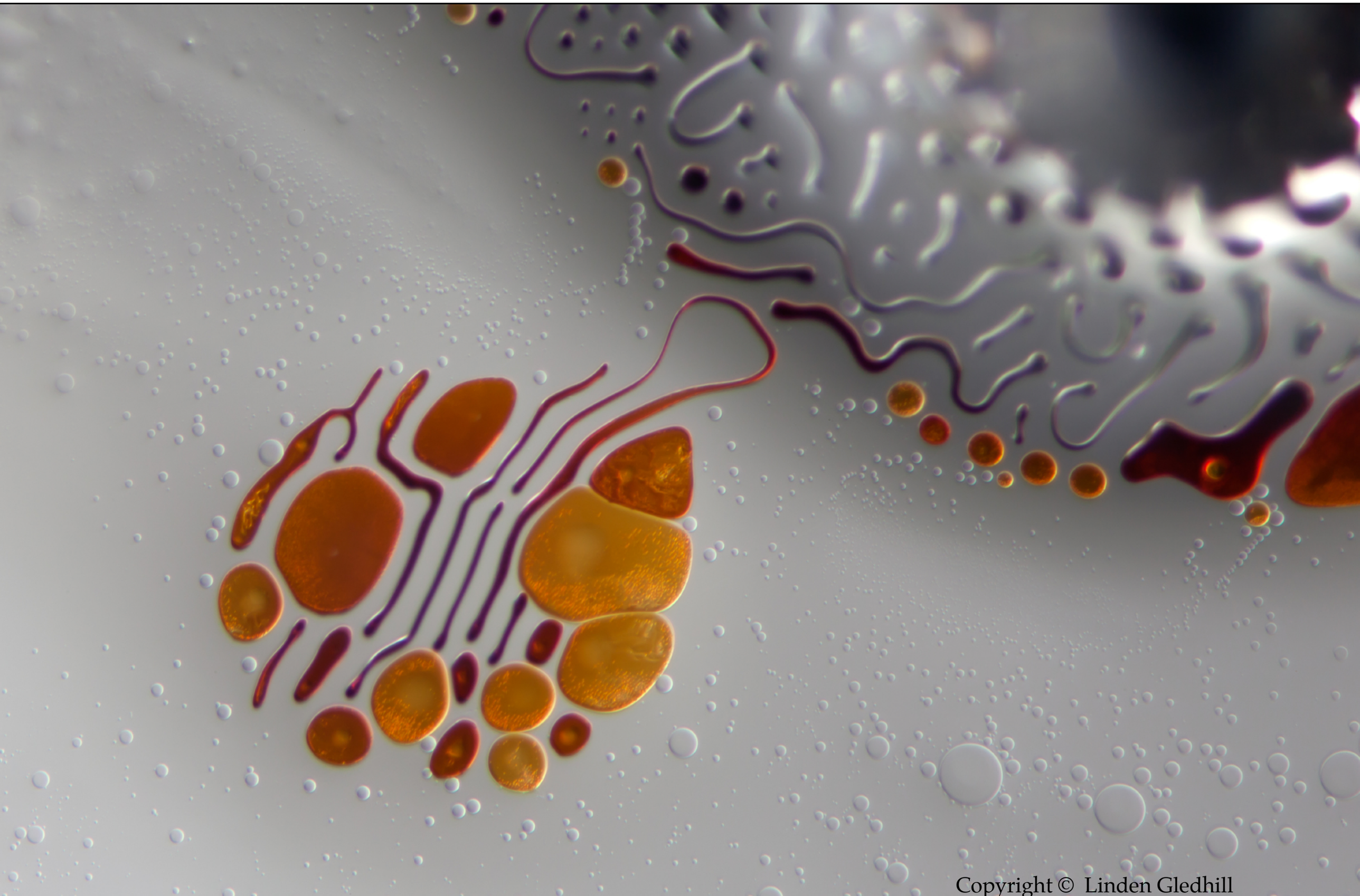
Oil and water containing superparamagnetic nanoparticles are immiscible.

[1] https://pinterest.com/Spikeartc/cool-ferrofluid-pictures/
[2] https://fractalenlightenment.com/14637/artwork/fractal-sculptures-with-magnetic-ferrofluid
[3] https://pinterest.com/Spikeartc/cool-ferrofluid-pictures

Ferrofluids



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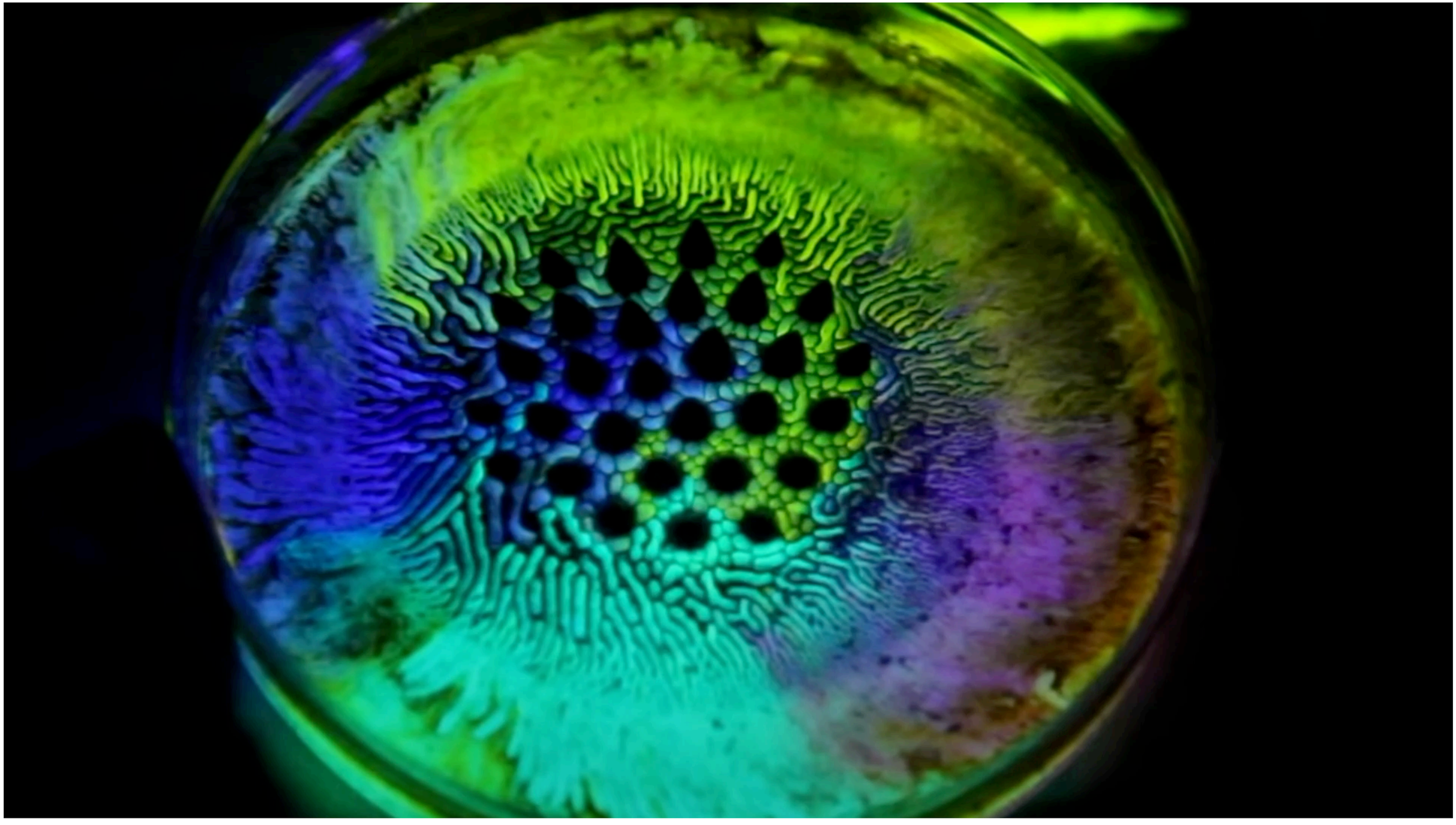
Ferrofluids



Interplay between reducing surface tension (sphere) and Zeeman energy (chain).

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Ferrofluids in Motion

Shape and size of droplets depends on magnetic field direction, strength, and gradient.

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Let's Make a Splash

Robert Streubel | streubel@unl.edu

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