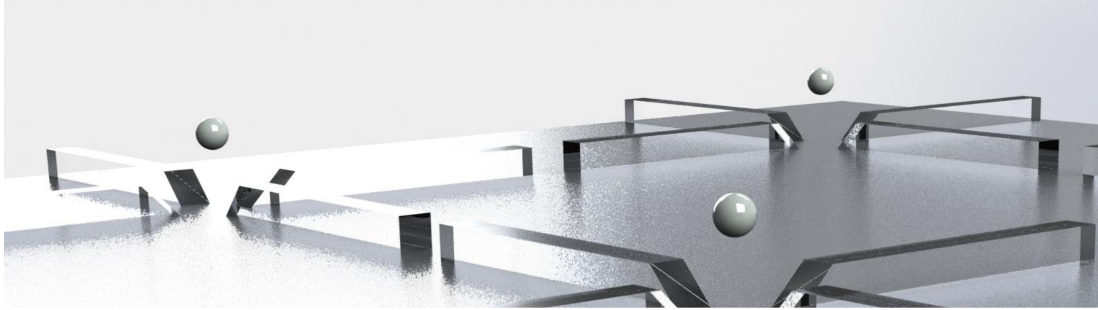
CERN

Ideas

**IdeaSquare**

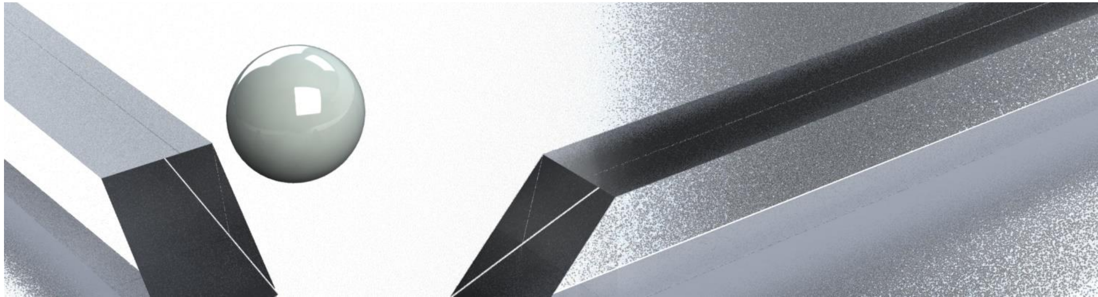
The innovation space at CERN

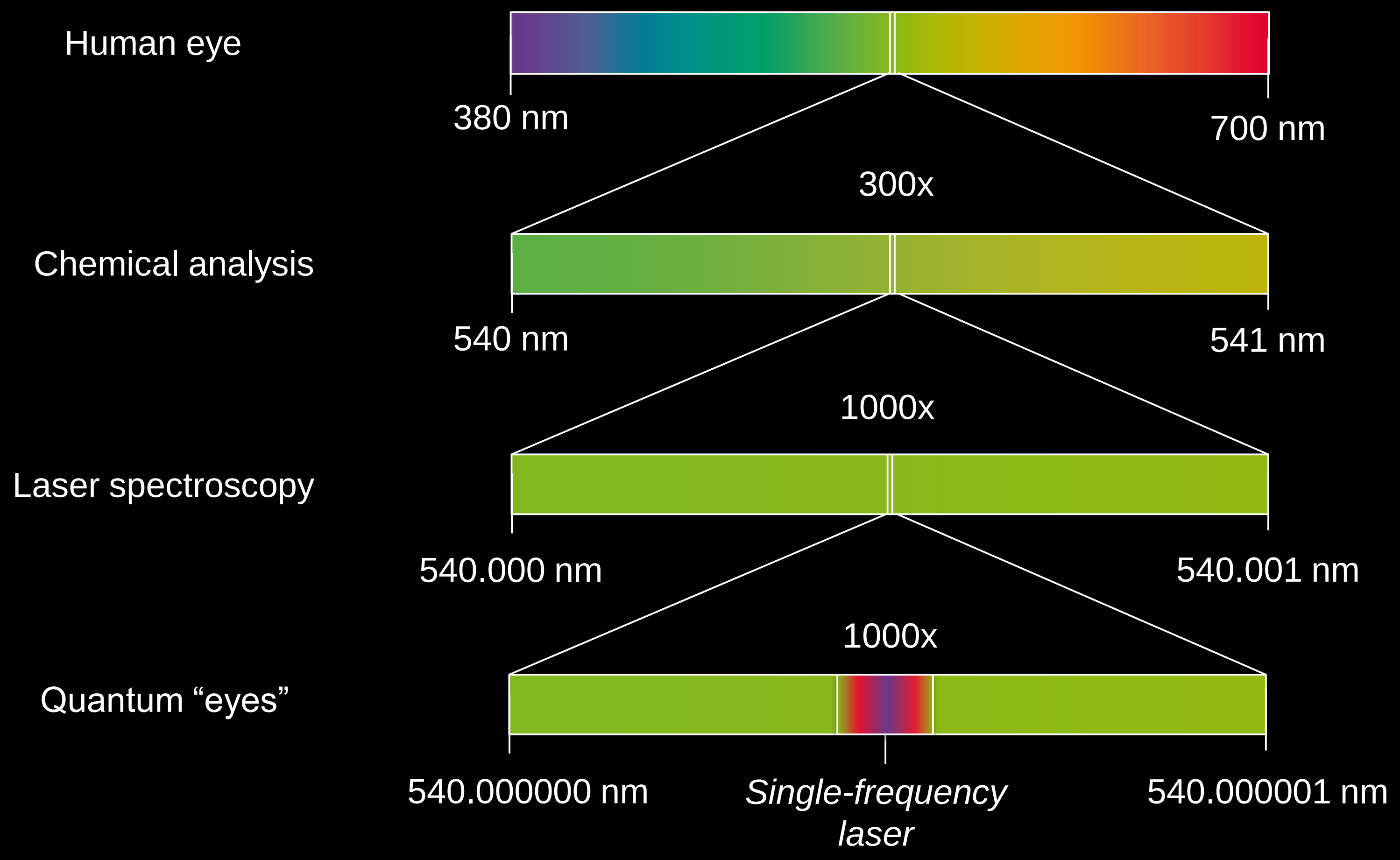


# QubikPhoton

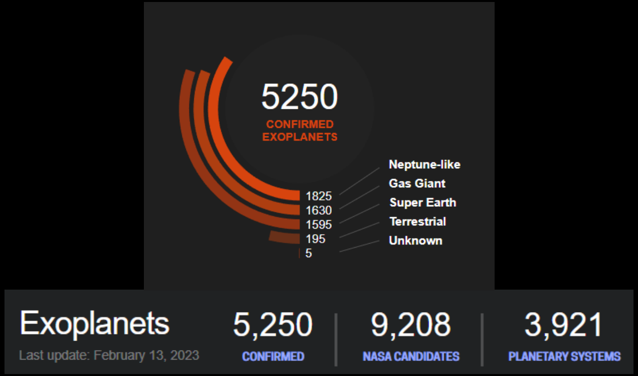
**Eduardo Granados**

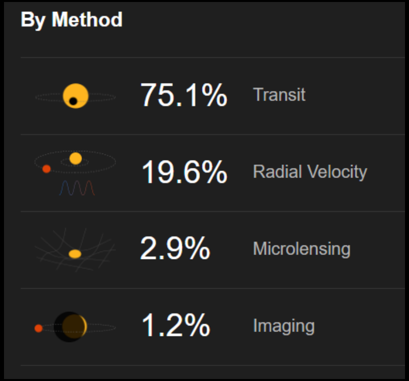
**16th February 2023**

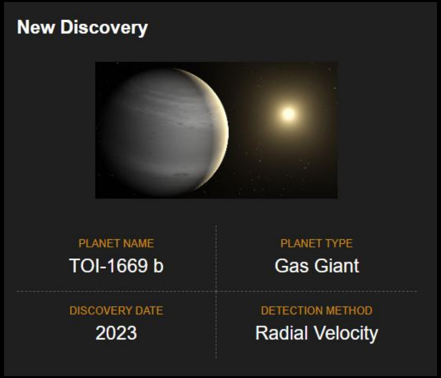



Human eye
380 nm
700 nm
300x
Chemical analysis
540 nm
541 nm
1000x
Laser spectroscopy
540.000 nm
540.001 nm
1000x
Quantum “eyes”
540.000000 nm
Single-frequency laser
540.000001 nm

# Exoplanet hunting

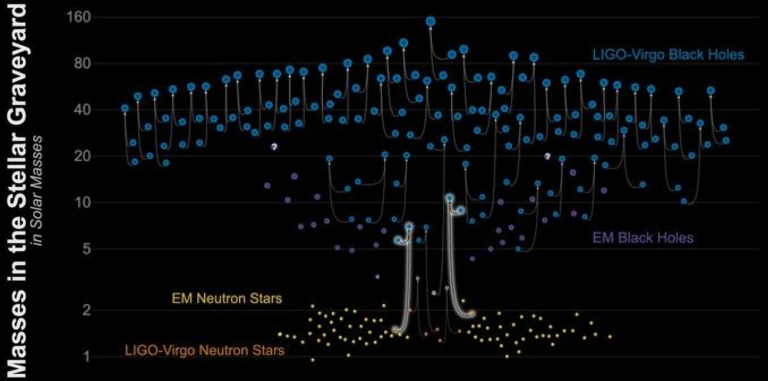


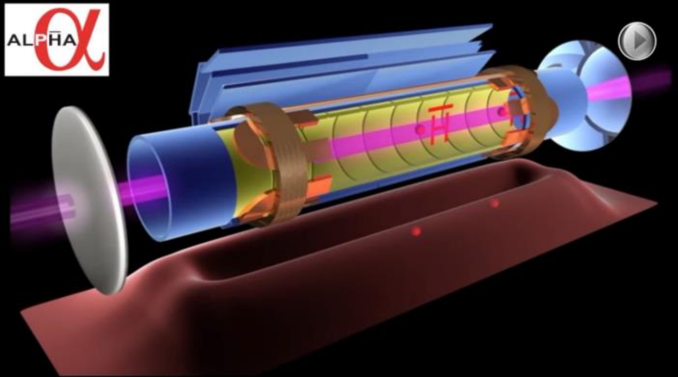

Source: NASA

## Gravitational wave surfing




Source: LIGO - Caltech/MIT

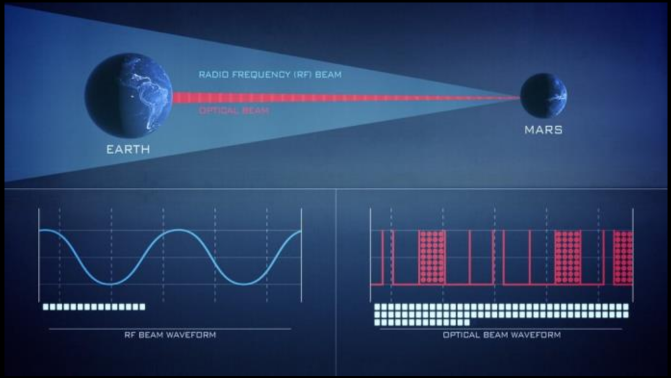
## Anti-matter




Source: CERN

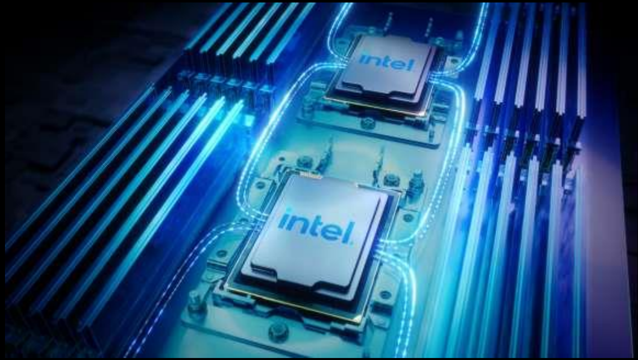
## Data links

Source: SpaceNews



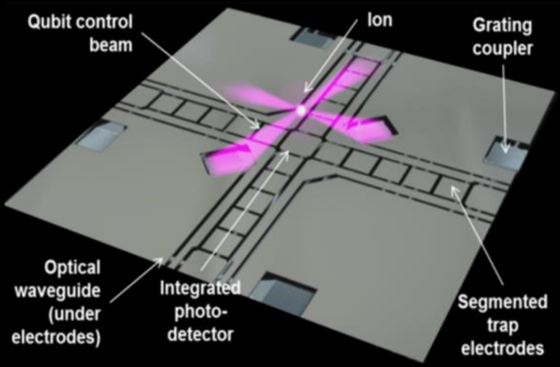

Source: NASA

## Photonic Integrated Circuits



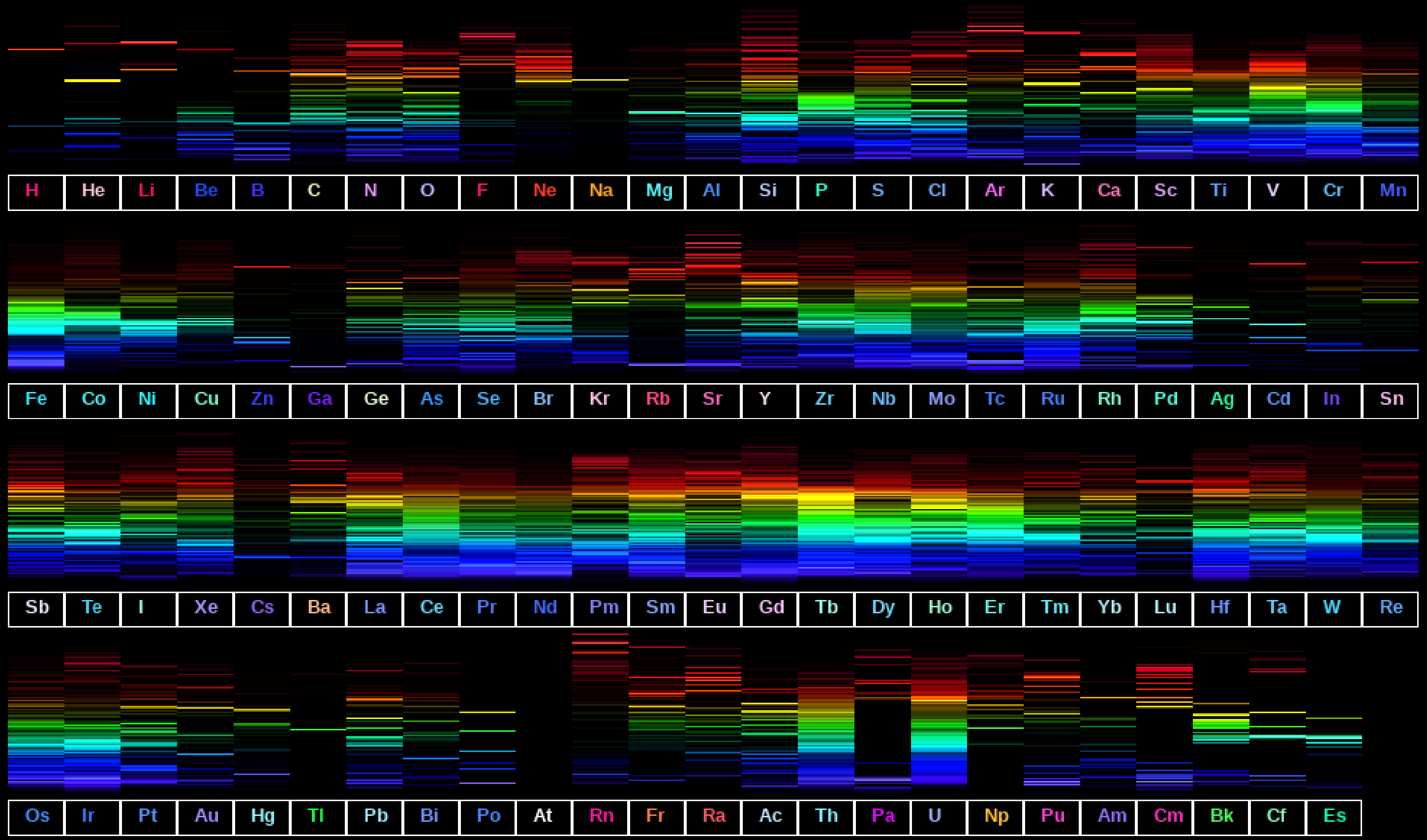

Source: Intel

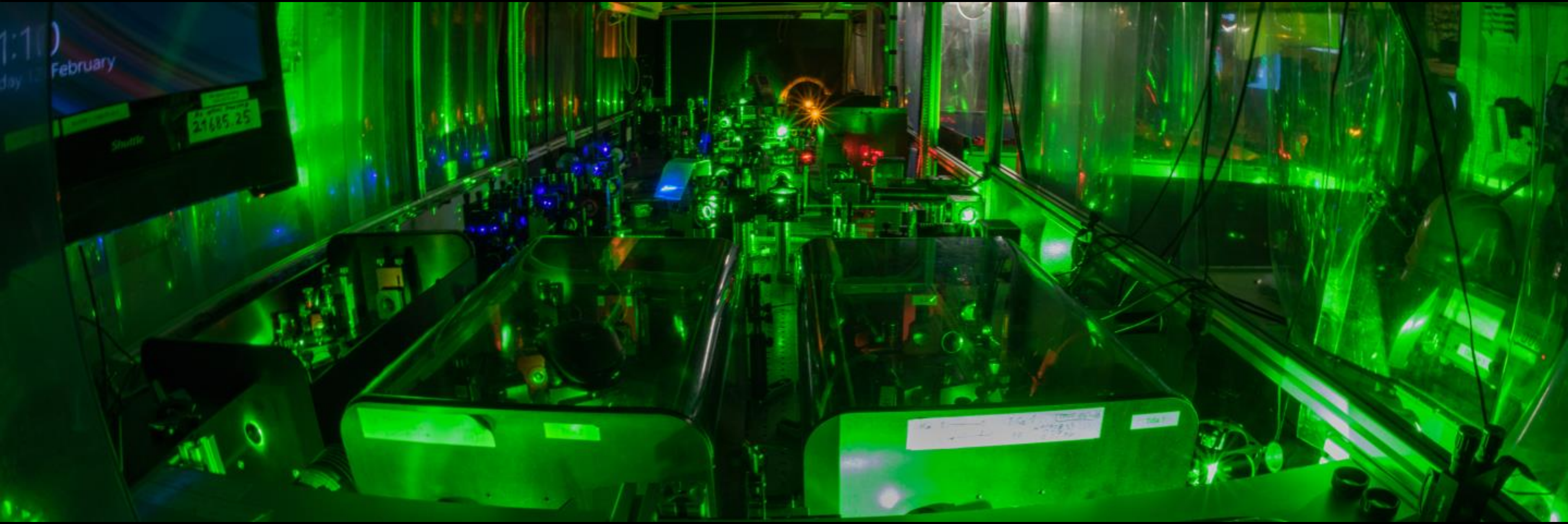
## Quantum computing




Source: MIT LL

# Playing the music of the atoms…






*Can we produce light in the visible part of the spectrum in a different way?*

RILIS - CERN

nature photonics

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > nature photonics > news & views > article

Published: April 2010

Yellow lasers

## A little diamond goes a long way

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > news > article

Published: 15 July 2011

## Diamond disappears in sunlight

nature astronomy

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > nature astronomy > letters > article

Letter | Published: 21 August 2017

## Formation of diamonds in laser-compressed hydrocarbons at planetary interior conditions

nature photonics

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > nature photonics > editorials > article

Published: April 2010

## Carbon optimism

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TECHNOLOGY

## Diamonds Lose Mass in Sunlight

Carbon atoms set free by ultraviolet light.

July 15, 2011

POPULAR MECHANICS HOME NEW TECH SCIENCE MILITARY POP MECH PRO SUBSCRIBE SIGN IN

Science > Energy

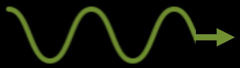
## New Laser Burns Hotter Than the Sun And Creates Mini-Stars in the Lab

Paired with the Linac Coherent Light Source, the new laser can create planet cores, repair airplane parts, and push the frontiers of particle science.

Why not using diamond again?

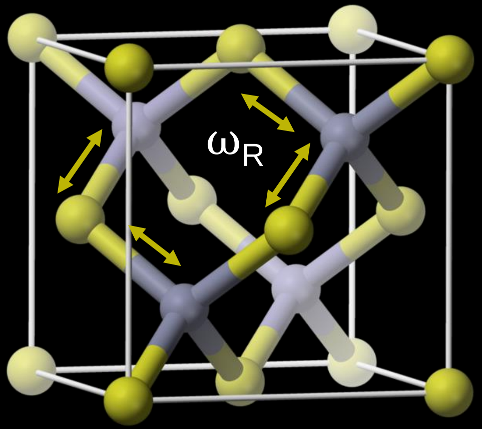
# The stimulated Raman effect

Incoming photon



$\omega_p$

crystal

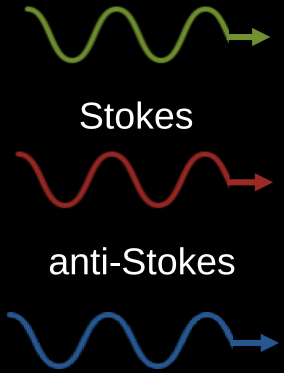



Possible outcomes

transmission

Stokes

anti-Stokes

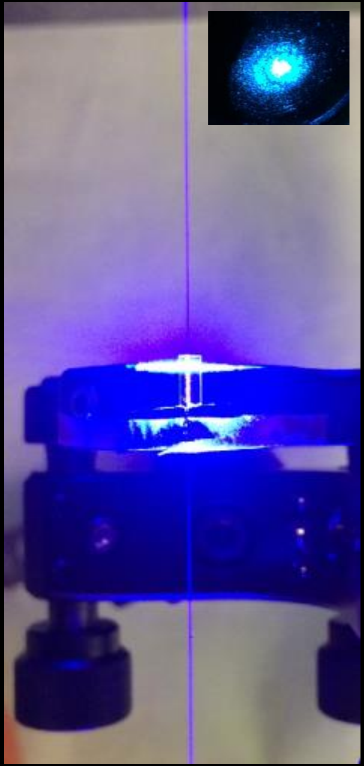


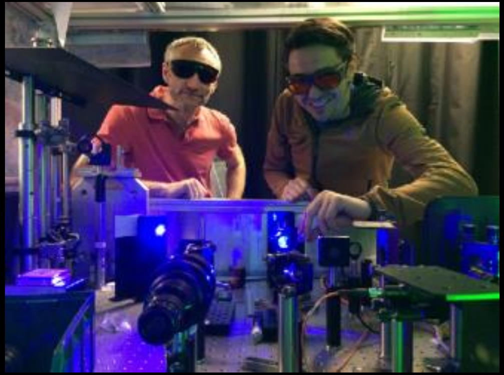

- The Raman shift ($\omega_R$) depends on the crystal
- The Raman gain depends on the crystal
- The spectral range also depends on the crystal

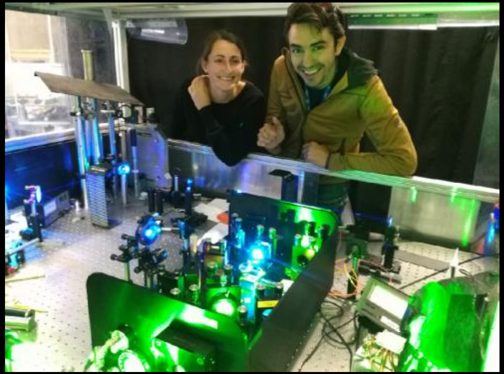
The "*best one*" overall is:
**DIAMOND**

But can be exploited in nearly all solids…

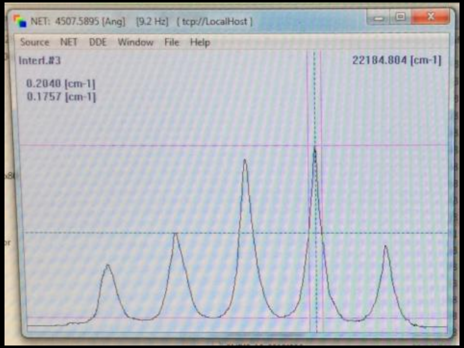
## Circa October 2018



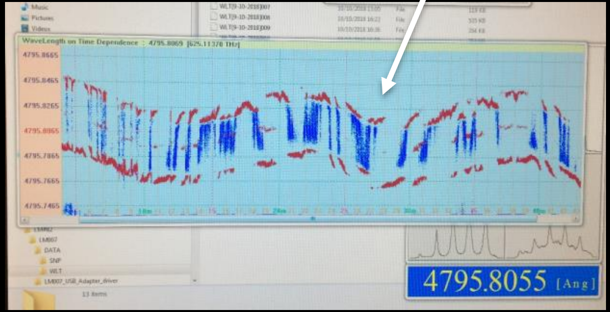




## The unexpected happens…

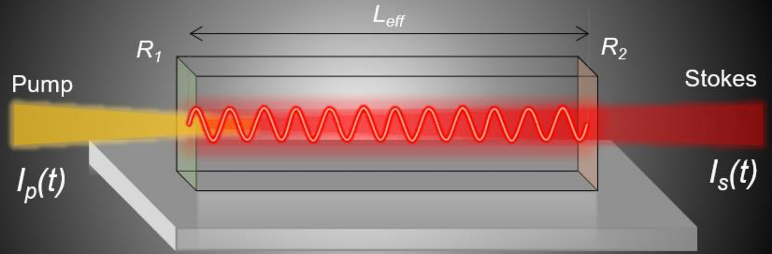



Malfunctioning AC



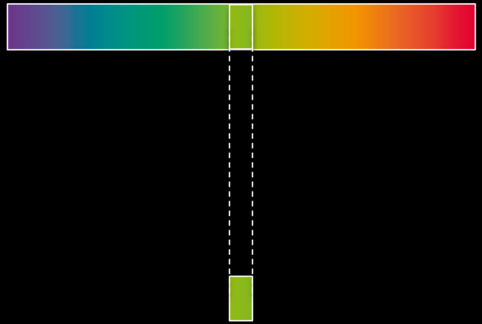

We produced for the 1st time tunable single frequency light using an integrated Raman laser

The device is *incredibly* simple

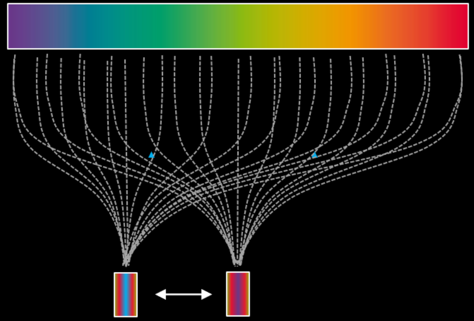



Works at any wavelength from the UV to THz
-> **NEW** and **UNIQUE** device for integrated photonics circuits toolbox

***Filtering***



***"Funneling"***



*Increased the brightness by 50x*
*Reduced the bandwidth by 100x*

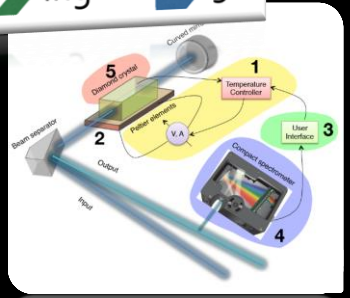
# The journey

October 2018

| | |
|---|---|
| 8th Oct 2018 | 1st contact CERN KT |
| 6th Nov 2018 | CERN KT Fund drafted |
| 7th Dec 2018 | KT project presented: “Singular Light” |
| 11th Jan 2019 | KT Funds confirmed: 117,500 CHF |
| 31st Jan 2019 | Technology description sent to KT |
| 14th Feb 2019 | IP agreement between CERN and Macquarie University prepared |
| 4th Apr 2019 | Singular Light featured in KT website |
| Jun-Jul 2019 | 2 students start working on “Singular Light” funded by KT |
| 14th Feb 2019 | IP agreement with Macquarie University signed |
| 4th Mar 2020 | First draft of patent completed |
| 12th Oct 2020 | European patent office - disclosure submitted |
| 17th Dec 2021 | PCT patent application was filed after patent search |
| Jun 2022 | Agreement CERN – Enigmedia to test the tech |
| 7th Feb 2023 | Follow up from the European patent office |

Now

SingularLight



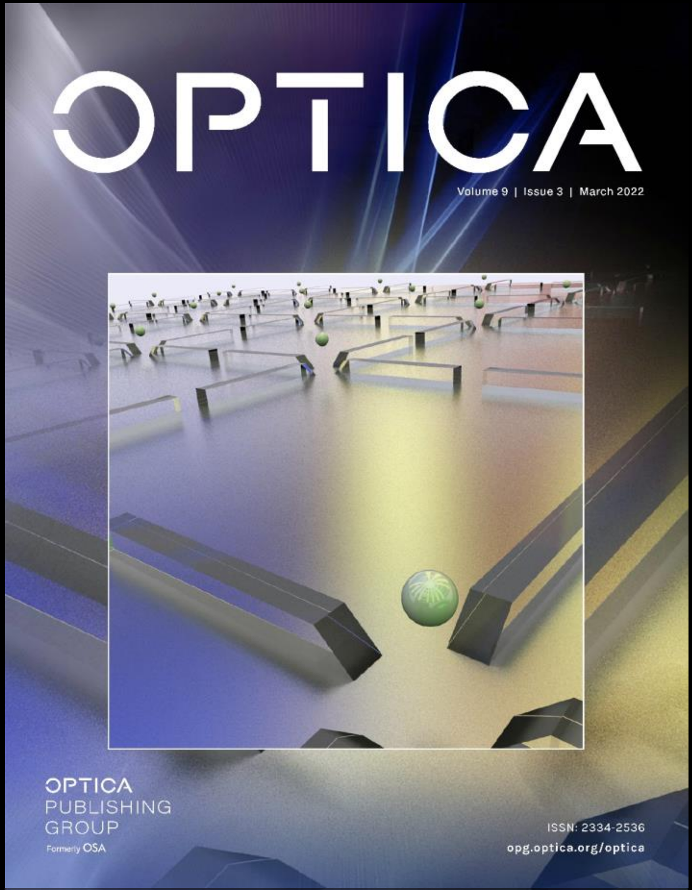


Europäisches Patentamt
European Patent Office
Office européen des brevets

**Acknowledgement of receipt**

We hereby acknowledge receipt of your request for the processing of an international application according to the Patent Cooperation Treaty as follows:

| | |
|---|---|
| Submission number | 10500063 |
| PCT application number | PCT/EP2021/086640 |
| Date of receipt | 17 December 2021 |
| Receiving Office | European Patent Office, The Hague |
| Your reference | SAH11514WO |
| Applicant | CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH |
| Number of applicants | 1 |
| Country | CH |
| Title | DEVICE, SYSTEM AND METHOD FOR PRODUCING A SINGLE LONGITUDINAL MODE LASER OUTPUT |




Research Article
Vol. 9, No. 3 / March 2022 / Optica 317
OPTICA

# Spectral synthesis of multimode lasers to the Fourier limit in integrated Fabry–Perot diamond resonators

EDUARDO GRANADOS,[1,*] CAMILO GRANADOS,[2] RIZWAN AHMED,[1] KATERINA CHRYSALIDIS,[1] VALENTIN N. FEDOSSEEV,[1] BRUCE A. MARSH,[1] SHANE G. WILKINS,[1] RICHARD P. MILDREN,[3] AND DAVID J. SPENCE[3]

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**Fourier-limited nanosecond pulses featuring narrow spectral bandwidths are required for applications in spectroscopy, sensing, and quantum optics. Here, we demonstrate a direct and simple route for the generation of single-frequency light relying on phonon-resonant Raman interactions within a monolithic diamond resonator. The technique enables the production of nearly Fourier-limited nanosecond optical pulses (15 ns), with an overall spectral bandwidth of down to 180 MHz, which is nearly two orders of magnitude narrower than the pump laser linewidth used (12 GHz). The power conversion efficiency was 47%, yielding a power spectral brightness enhancement of >50× compared to the pump. Our results pave the way to the integration of pulsed widely tunable, power scalable, narrow linewidth light sources into integrated photonic platforms. Furthermore, the device does not need elaborate mechanical feedback loops for cavity length or frequency stabilization, or any additional optical components.** 

https://doi.org/10.1364/OPTICA.447380

## 1. INTRODUCTION

The frequency synthesis and spectral content of lasers have been topics of investigation since the invention of the laser. Narrow linewidth and single longitudinal mode (SLM) lasers have become the prime tools for modern applications where high stability and precision are required. These include the development of atomic clocks [1], atomic matter and antimatter cooling [2], high-resolution spectroscopy [3], physics beyond the standard model [4], or lidar [5], to name a few. Applications on laser spectroscopy of radioactive elements [6–8] and the increasing interest for the study of chemical elements where no atomic information is known [9], is just another example where SLM laser sources with MHz-class linewidths are of imperative importance.

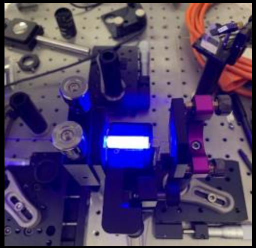
The advent of quantum-technology-based sensing and photonic sources has increased the interest in producing and integrating pulsed narrow linewidth lasers [10]. Here, the main challenge is in the complexity of producing widely tunable, high-performance narrowband lasers (in the kHz to hundreds of MHz) at a range of wavelengths that are used to cool, trap, and manipulate ions [11]. Eventually, photonic integrated circuits (PICs) are expected to provide the scalability and simplicity required to enable quantum-technology-based sensing systems and applications, but multiple advances are still needed. Among these, improvements in active materials (e.g., direct gain and laser output in the green-yellow spectral range) and passive materials (low-loss waveguides, especially in the UV blue range) could enable a viable path for wafer-scale integration [12].

While many methods to generate a stable phase-coherent train of ultrafast laser pulses are available now [13–15], these methods only provide limited access to the generation of stable coherent nanosecond pulses. By using injection-locking in Ti:sapphire [16], VCSEL [17], and fiber-based [18] lasers or external electro-optic modulation of single-frequency fibers [19], nearly Fourier-limited ns pulses have been achieved with flexible pulse durations, repetition rates, and tunability ranges. However, such schemes are usually associated with significant experimental complexity and cost, typically produce outputs with high noise figures and no pulse-to-pulse temporal coherence, and are usually not integrable on a chip.

Alternatively, taking advantage of the traditionally superior noise characteristics of passive mode-locking techniques, graphene-based saturable absorbers have been used for mode-locking ns pulses [20–22]. However, these systems produced chirped pulses with linewidths in the few-GHz range, caused mainly by the disadvantageous operation timescales of saturable absorbers, as well as by the low strength of the nonlinear effects reachable through ns pulses with moderate energies. More recently,

# Testing…

Mk 2

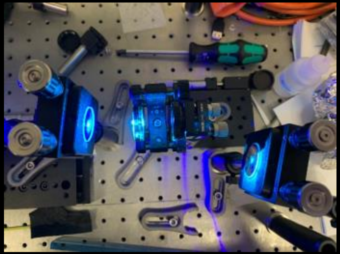


Jan 2019

Mk 3

Feb 2019

Mk 4

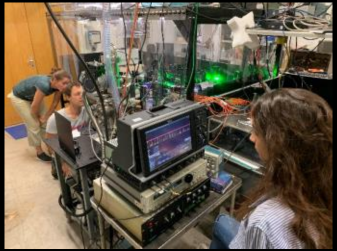


Feb 2019

Mk 5

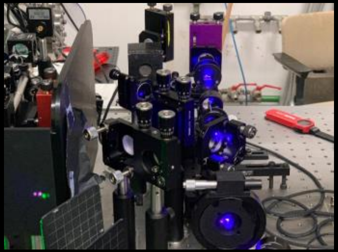
Mar 2019

Mk 6



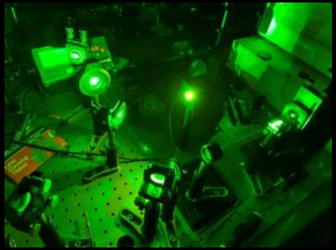
Jul 2019

Mk 7



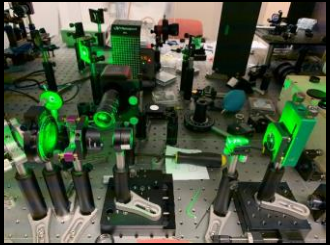
Sep 2019

Mk 8



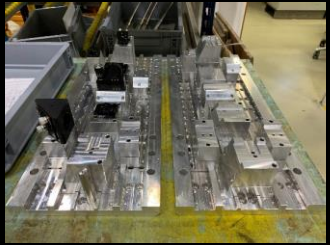
Jan 2020

Mk 9



Feb 2020

Mk 10

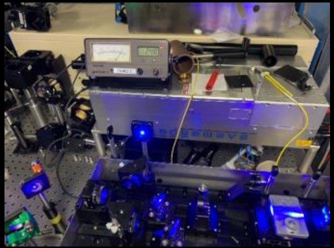


Aug 2020

Mk 11

Oct 2020

Mk 11



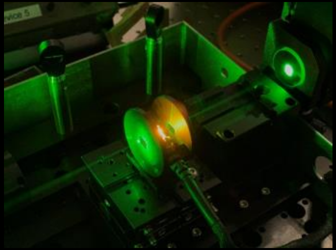
Nov 2020

# And more testing…

Mk 12

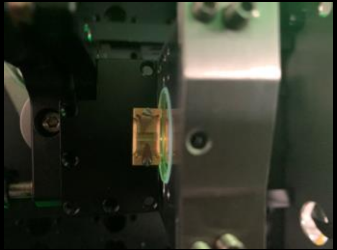
Feb 2021

Mk 11



Apr 2021

Mk 13



Jun 2021

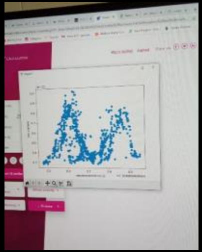
Mk 13


Oct 2021

Mk 14

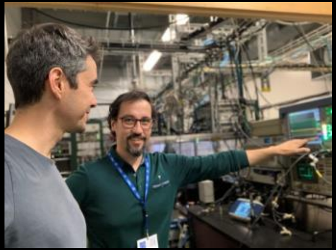
Dec 2021

Mk 14



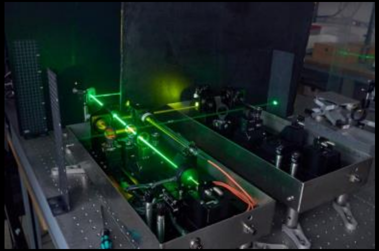
Mar 2022

Mk 15



May 2022

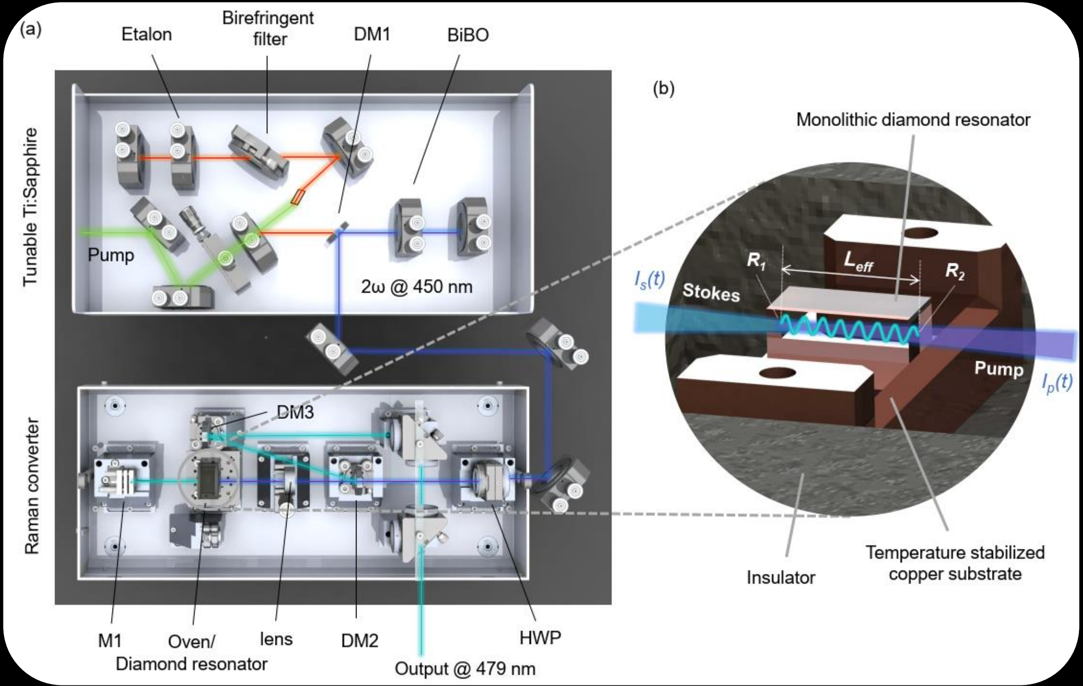
Mk 16

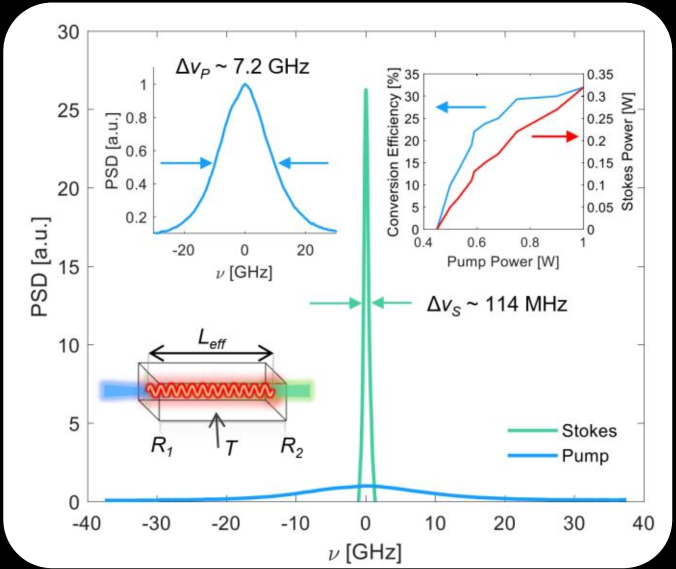


Jan 2023

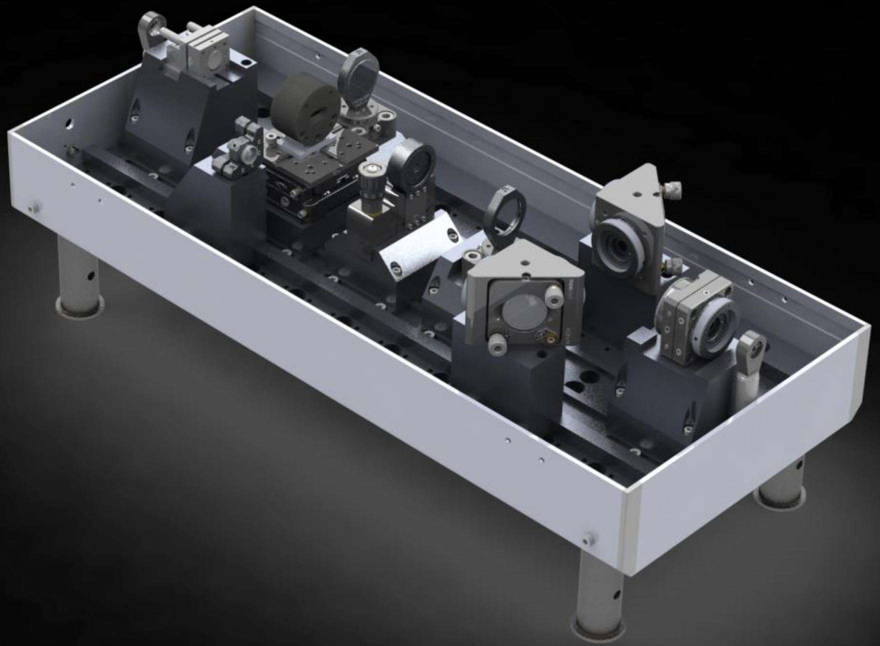
…

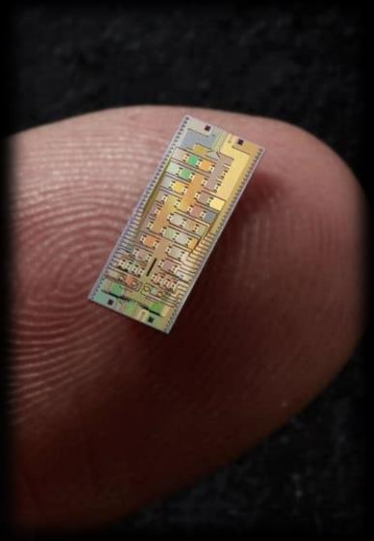
# “Singular Light” provided a working solution for single frequency light generation for scientific applications, what about outside the lab?



# The dream



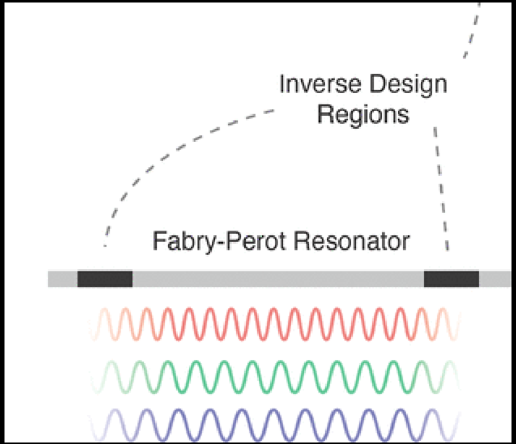


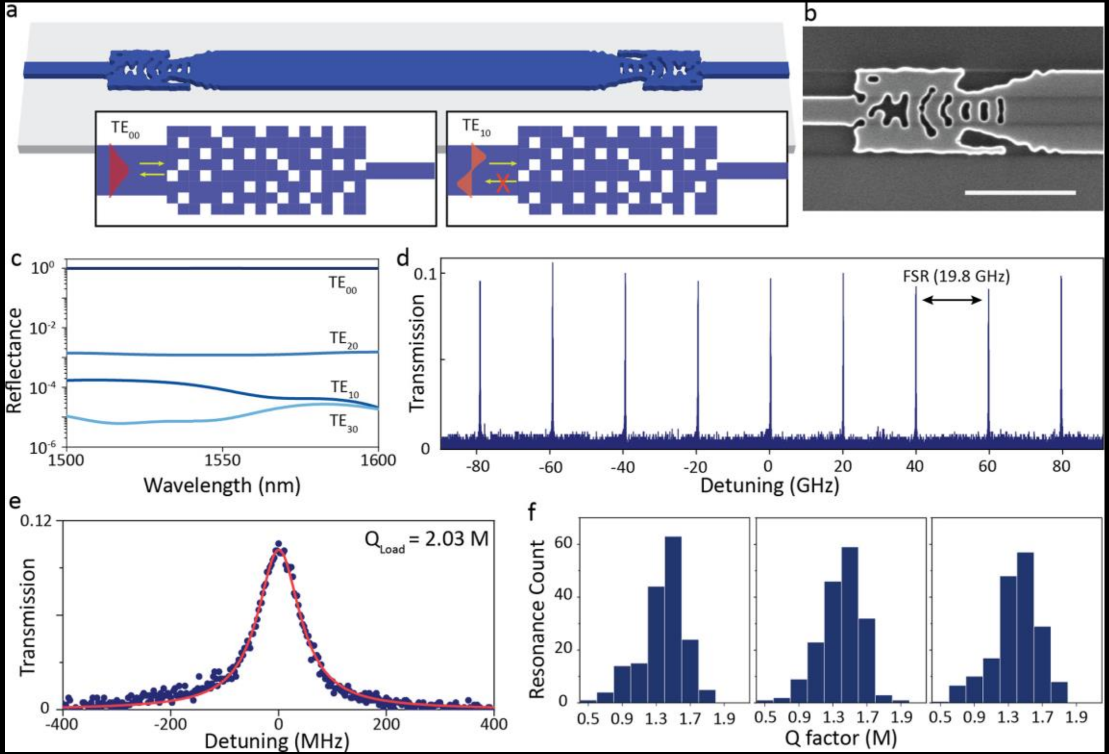
?

Revolutionary for optical communications, sensing and quantum computing

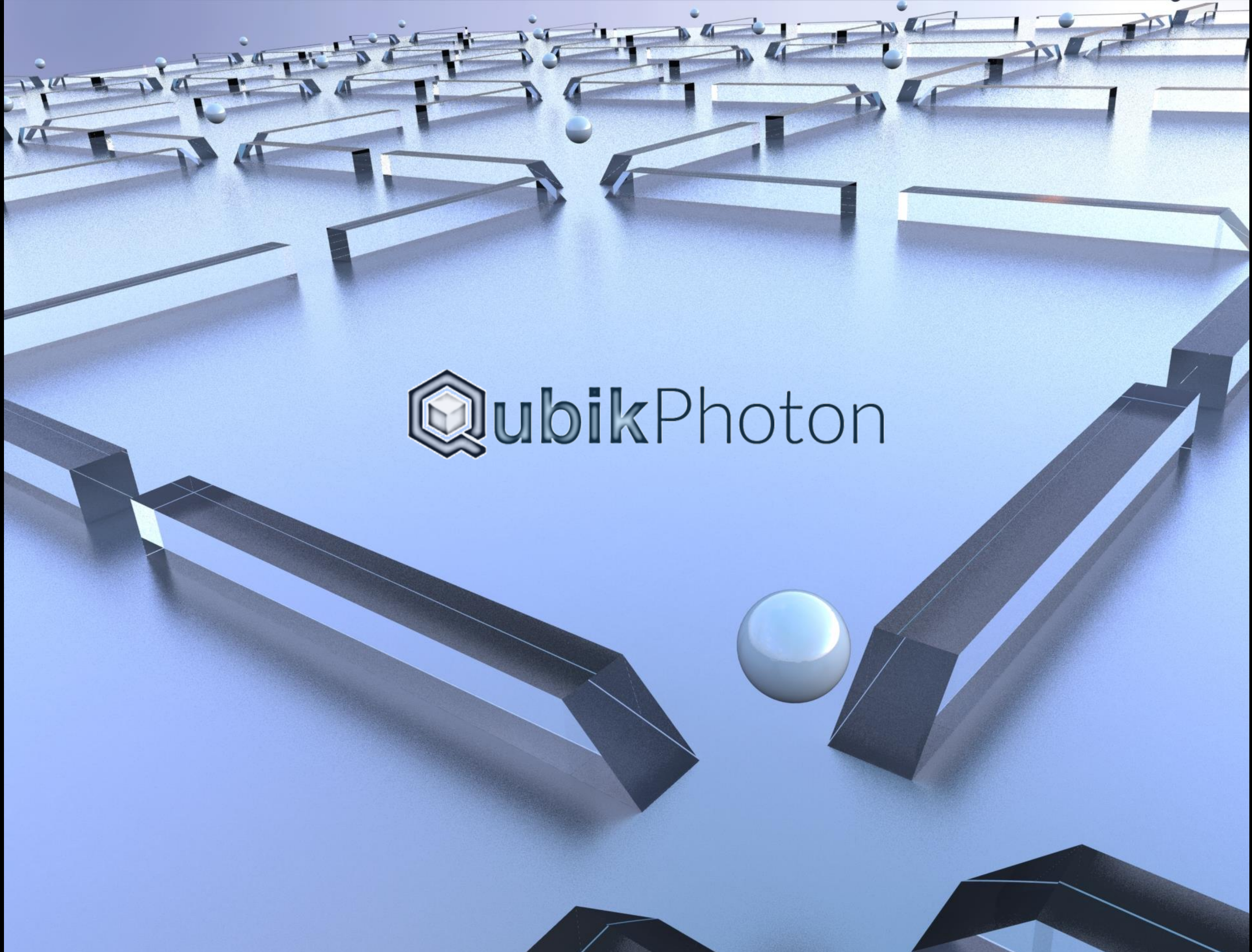
This is what QubikPhoton is about

# Can Photonic Integrated Circuit *inverse* design be the path forward?




*ACS Photonics* 2022, 9, 6, 1875–1881


QubikPhoton