WORKSHOP · FIRST EDITION

CARNOT

PHOTONIC HEAT ENGINES

24–25 October 2026

University of New Mexico
Albuquerque

Technical Program

Dedicated to the memory of
Mansoor Sheik-Bahae

carnot.unm.edu

FOREWORD

From the Organizing Committee

Welcome to Albuquerque, and welcome to the first Carnot.

As active members of the laser-cooling and adjacent communities, we used SPIE Photonics West as the annual meeting of our small field. We started there in 2004, as *Laser Cooling of Solids* and later *Laser Refrigeration of Solids*. To widen the scope beyond rare-earth crystals and semiconductors — to nanostructures, radiation-balanced lasers and the thermodynamics behind all of them — the chairs then, Mansoor Sheik-Bahae, Richard Epstein and Denis Seletskiy, renamed the symposium *Photonic Heat Engines*, and we met under that name for another six years.

Then we lost Mansoor, who had held us together for nearly thirty years. In 2024 we ran the symposium as a memorial to him. There was no 2025. Registration at Photonics West had passed a thousand dollars by then, research funding was unsettled, and the geopolitics kept people home, so we could not bring SPIE the attendance it expected, and SPIE canceled us.

So we built our own, and we run it ourselves. We are glad the first one is in New Mexico, where both of this field's firsts happened: Richard's group cooled a solid with light at Los Alamos in 1995, and Mansoor's group cooled one to cryogenic temperatures at UNM in 2010.

We kept it small deliberately. Everyone sits in one room for two days, nobody has to choose between parallel sessions, and the gaps between talks are long enough to finish an argument. **Maxwell Labs** underwrites Carnot as principal sponsor: they cover your registration, the food, the swag and the workshop dinner, and most of all they let us sit together in a small room and argue about the subject we love. We intend to keep future editions free, or close to it. **SELA Photonics**, **Triton Photonics** and the **UNM Department of Physics and Astronomy** pay for the student poster prizes. We applaud the students too, but a prize is a better reason for a young scientist to stay with this field.

A room this size lets us be wrong out loud, which a large conference never does. Bring the result you cannot yet explain. Argue about it here. We would rather hear what is uncertain than what is already in print.

We intend to run Carnot every year, and to move it — South Bend and Seattle are the likely next two. Between meetings we keep carnot.unm.edu alive: post what you are doing there, not only what you will present next October. There is more to come.

We dedicate this first edition to Mansoor. The pages that follow say why better than we can.

The Carnot 2026 Organizing Committee

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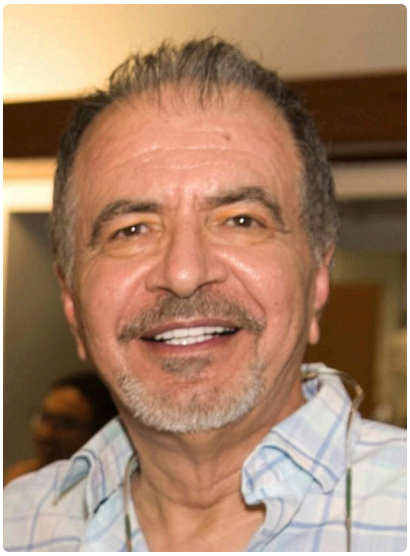
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IN MEMORIAM

Mansoor Sheik-Bahae

1956–2023



Mansoor Sheik-Bahae

Carnot 2026 is dedicated to Mansoor Sheik-Bahae, who passed away in July 2023, aged 67. Born in Isfahan, a descendant of the seventeenth-century polymath Sheikh Bahāʾi, Mansoor came to the United States to study electrical engineering, taking his doctorate at SUNY Buffalo in 1987. He joined CREOL in its founding year and moved to the University of New Mexico in 1994, rising to Distinguished Professor — the highest honor UNM gives its faculty — and becoming the first director of its Optical Science and Engineering program.

With Eric Van Stryland and colleagues, Mansoor invented the Z-scan, which gives both the magnitude and the sign of a material's third-order optical nonlinearity from a single-beam experiment with a moving sample and a detector. It remains the standard measurement, and the two of them shared Optica's R. W. Wood Prize for it in 2012. He then found a link that had been thought impossible — Kramers–Kronig relations are linear, so they ought not to connect nonlinear quantities. The way through was to linearize the problem by treating nondegenerate absorption, two photons of different frequency, which made nonlinear refraction predictable from two-photon absorption. A Fellow of Optica and of SPIE, he was also a senior member of the IEEE.

In 1995 Mansoor began working with Richard Epstein on cooling solids with light, and led that effort for the next twenty-seven years, directing the Consortium for Laser Cooling in Solids from 2004 to 2022. The group established Yb:YLF as the material the field now builds on, and in 2022 cooled a load to 125 K. He worked out the theory of radiation-balanced lasers, and his group built the first ones; others carried it from there to the first cooling of Yb-doped silica. Thinking about heat management also led him to a new semiconductor laser geometry, now called the MECSEL, designed to allow high-power operation of optically pumped semiconductor lasers — the technology behind today's laser sodium guide stars, and the core technology behind UNM's spinout SELA Photonics.

Cooling a semiconductor was something he was deeply passionate about seeing, and he never got the chance. His co-authors called it his unfulfilled dream. One session of this workshop goes straight at that problem. Another continues his work on radiation-balanced lasers. A deep thinker, Mansoor never stopped pondering the fundamental limits of noise, entropy and engine efficiency. He would have loved to be at this workshop with all of us. His presence is missed dearly!

Richard Epstein, Denis Seletskiy and Eric Van Stryland, "Mansoor Sheik-Bahae (1956–2023)," *Nature Photonics* **17**, 833–834 (2023).

Selected works

1990	**Sensitive measurement of optical nonlinearities using a single beam** M. Sheik-Bahae, A. A. Said, T.-H. Wei, D. J. Hagan and E. W. Van Stryland, *IEEE J. Quantum Electron.* **26**, 760–769 (1990)
1991	**Dispersion of bound electronic nonlinear refraction in solids** M. Sheik-Bahae, D. C. Hutchings, D. J. Hagan and E. W. Van Stryland, *IEEE J. Quantum Electron.* **27**, 1296–1309 (1991)
1999	**Quantum interference control of current in semiconductors: universal scaling and polarization effects** M. Sheik-Bahae, *Phys. Rev. B* **60**, R11257 (1999)
2000	**Observation of anti-Stokes fluorescence cooling in thulium-doped glass** C. W. Hoyt, M. Sheik-Bahae, R. I. Epstein, B. C. Edwards and J. E. Anderson, *Phys. Rev. Lett.* **85**, 3600–3603 (2000)
2004	**Can laser light cool semiconductors?** M. Sheik-Bahae and R. I. Epstein, *Phys. Rev. Lett.* **92**, 247403 (2004)
2007	**Optical refrigeration** M. Sheik-Bahae and R. I. Epstein, *Nature Photonics* **1**, 693–699 (2007)
2010	**Complementary ultrashort laser pulse characterization using MOSAIC and SHG FROG** D. A. Bender and M. Sheik-Bahae, *Opt. Lett.* **35**, 2191–2193 (2010)
2010	**Laser cooling of solids to cryogenic temperatures** D. V. Seletskiy, S. D. Melgaard, S. Bigotta, A. Di Lieto, M. Tonelli and M. Sheik-Bahae, *Nature Photonics* **4**, 161–164 (2010)
2013	**Development of high quantum efficiency GaAs/GaInP double heterostructures for laser cooling** D. A. Bender, J. G. Cederberg, C. Wang and M. Sheik-Bahae, *Appl. Phys. Lett.* **102**, 252102 (2013)
2015	**Broadband field-resolved terahertz detection via laser induced air plasma with controlled optical bias** C.-Y. Li, D. V. Seletskiy, Z. Yang and M. Sheik-Bahae, *Opt. Express* **23**, 11436–11443 (2015)
2015	**Optically pumped DBR-free semiconductor disk lasers** Z. Yang, A. R. Albrecht, J. G. Cederberg and M. Sheik-Bahae, *Opt. Express* **23**, 33164–33169 (2015)
2016	**Classical trajectories in polar-asymmetric laser fields: synchronous THz and XUV emission** A. Gragossian, D. V. Seletskiy and M. Sheik-Bahae, *Sci. Rep.* **6**, 34973 (2016)
2018	**First demonstration of an all-solid-state optical cryocooler** M. P. Hehlen, J. Meng, A. R. Albrecht, E. R. Lee, A. Gragossian, S. P. Love, C. E. Hamilton, R. I. Epstein and M. Sheik-Bahae, *Light: Science & Applications* **7**, 15 (2018)
2019	**Radiation-balanced Yb:YAG disk laser** Z. Yang, J. Meng, A. R. Albrecht and M. Sheik-Bahae, *Opt. Express* **27**, 1392–1400 (2019)
2020	**Optimum operation of radiation-balanced lasers** M. Sheik-Bahae and Z. Yang, *IEEE J. Quantum Electron.* **56**, 1000109 (2020)
2022	**Optical refrigeration of payloads to $T < 125$ K** J. L. Kock, A. R. Albrecht, R. I. Epstein and M. Sheik-Bahae, *Opt. Lett.* **47**, 4720–4723 (2022)
2022	**Semiconductor sodium guide-star source** M. Zhang *et al.*, *Opt. Express* **30**, 42470–42479 (2022)

CONTINUING THE WORK

The Sheik-Bahae Dissertation Prize

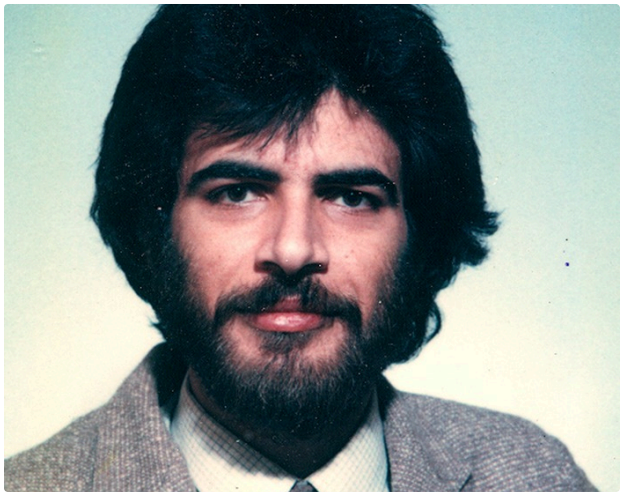
The Optical Science and Engineering program at UNM awards a dissertation prize in Mansoor's name, to a graduating student whose thesis does the kind of work he valued: careful, physical, and unafraid of a hard measurement. The prize is endowed, so a gift now pays a student every year.

Gifts go through the UNM Foundation to the **Physics & Astronomy Chair's Fund**. Please mention **"Mansoor Sheik-Bahae's Dissertation Prize"** when you make your donation.

CHAIR'S FUND



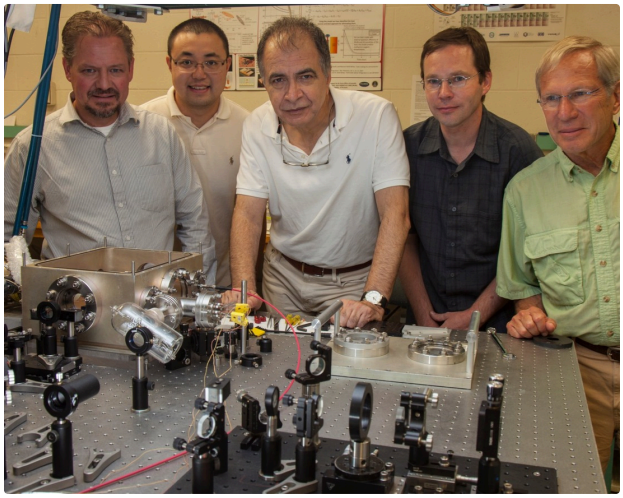
On the Great Wall, 2022



Early career



Mansoor and Richard Epstein



The laser cooling group, UNM



OSE Commencement

INAUGURAL AWARD

The Pringsheim Medal

The Pringsheim Medal recognizes a career that has shaped the physics of photonic heat engines. It is awarded for the first time at this workshop.



2026

Richard I. Epstein

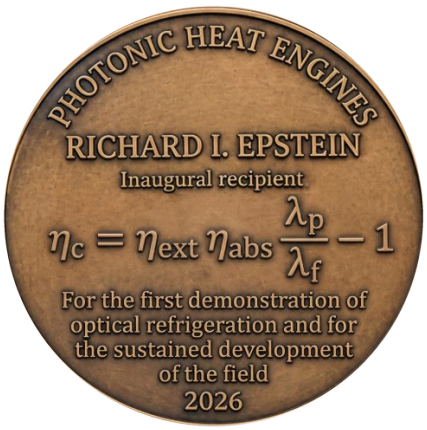
for the first demonstration of optical refrigeration and for the sustained development of the field

In 1929 Peter Pringsheim asked whether light could make a solid colder. The question stood open for sixty-six years. In 1995, at Los Alamos National Laboratory, Richard Epstein and his colleagues answered it: they pumped a sample of ytterbium-doped ZBLANP glass with a laser and measured it cooling. They had cooled a solid with light for the first time, and this field starts there.

What followed mattered as much as the demonstration. Richard did not publish the result and move on from it. With Mansoor Sheik-Bahae he built an argument, then a collaboration, and eventually an institution around it; the Consortium for Laser Cooling in Solids carried the problem from a fraction of a degree of cooling to a load held below 125 K, and from one material to a periodic table of candidates. Much of what will be presented over these two days descends directly from choices made in that collaboration.

It is a pleasure for the Organizing Committee to award Richard the first Pringsheim Medal.





THE INAUGURAL RECIPIENT

Richard I. Epstein

Los Alamos National Laboratory · University of New Mexico

Richard Epstein studied physics at Cornell and earned his doctorate at Stanford in 1972, under the plasma astrophysicist Peter Sturrock. For most of the years that followed the subject was the universe: the origin of deuterium in 1976, the structure of neutron star envelopes in 1983, the intrinsic luminosity of gamma-ray bursts and their host galaxies in 1993, what pulsar timing can say about the neutron star equation of state in 1999, ultra-high-energy cosmic rays from young neutron star winds in 2000. These all involve matter in conditions no laboratory will reproduce. They ask what a system must do before asking what it is made of.

He came at the problem as an instrument builder, not a spectroscopist. A refrigerator with no moving parts cannot vibrate and cannot wear out, and in orbit a mechanical cooler eventually does both and takes the detector with it. Epstein and his co-authors say so in the abstract of the 1995 paper: they propose a compact, all-solid-state optical cryocooler for cryogenic electronics and detectors, including in orbit. They measured about two percent efficiency, four orders of magnitude above anything Doppler cooling of a gas had reached.

That habit — asking first what a system must do — is still visible in how this community frames its questions, and the thermal axis along which the sessions of this workshop are arranged is an inheritance of it. The 1995 paper has since become the most cited of Richard's career, ahead of the astrophysics that preceded it.

Richard went on to direct the optical refrigeration effort at Los Alamos. He is a research professor at the University of New Mexico and runs ThermoDynamic Films in Albuquerque, a company that exists to turn optical refrigeration into an instrument. Thirty-one years after the demonstration, the field it opened fills the two days of this workshop, and Richard opens them with a talk on how it began.

Selected works

1976	**The origin of deuterium** R. I. Epstein, J. M. Lattimer and D. N. Schramm, *Nature* **263**, 198–202 (1976)
1993	**The intrinsic luminosity of γ-ray bursts and their host galaxies** E. E. Fenimore, R. I. Epstein, C. Ho *et al.*, *Nature* **366**, 40–42 (1993)
1995	**Observation of laser-induced fluorescent cooling of a solid** R. I. Epstein, M. I. Buchwald, B. C. Edwards, T. R. Gosnell and C. E. Mungan, *Nature* **377**, 500–503 (1995)
1999	**Pulsar constraints on neutron star structure and equation of state** B. Link, R. I. Epstein and J. M. Lattimer, *Phys. Rev. Lett.* **83**, 3362 (1999)
2000	**Ultra-high-energy cosmic rays from young neutron star winds** P. Blasi, R. I. Epstein and A. V. Olinto, *Astrophys. J. Lett.* **533**, L123–L126 (2000)
2004	**Can laser light cool semiconductors?** M. Sheik-Bahae and R. I. Epstein, *Phys. Rev. Lett.* **92**, 247403 (2004)
2007	**Optical refrigeration** M. Sheik-Bahae and R. I. Epstein, *Nature Photonics* **1**, 693–699 (2007)

THE MEDAL IS NAMED FOR

Peter Pringsheim

1881–1963 · a seventeen-year argument about the second law



Peter Pringsheim
1881–1963

In 1929 Peter Pringsheim asked whether a material could be made colder by shining light on it. The authoritative reference work of the day, the *Handbuch der Experimentalphysik*, had declared such cooling impossible. Pringsheim disagreed, and his argument was simple. If a substance absorbs a photon and emits one of higher energy, the difference must be paid for, and the only available account is the thermal energy of the material itself. The sample is not isolated. Energy enters from the pump and leaves with the fluorescence, so the second law of thermodynamics constrains the entropy of the whole process rather than the energy balance of the sample alone. Nothing in it forbids the material from cooling.

The question then remained in dispute for seventeen years.

The sharpest objection came from Sergey Vavilov in 1945. Suppose the fluorescence were collected and converted back into electricity to drive the pump. The emitted light carries more energy than the light absorbed, so the cycle would close with work to spare, and that work could have been drawn only from the thermal energy of the sample. The result is a perpetual motion machine of the second kind.

Pringsheim replied in 1946 that the cycle does not close, because the two radiation fields are not equivalent. The pump is narrow in spectrum and confined in direction; the fluorescence is broadband and emitted into the full solid angle. Energy is returned but entropy is not, since spontaneous emission is irreversible. Vavilov answered that lenses and mirrors could restore the directionality and recover what had been lost.

That answer is incorrect, although the reason was not available to either of them: the entropy of a beam depends on the product of its area and its angular spread, and Liouville's theorem forbids a passive optical system from reducing that product.

Lev Landau closed the question in 1946 by making the entropy of a radiation field a quantity that can be calculated. A beam carries entropy as well as energy and may be assigned a brightness temperature; the fluorescence discarded in such a cycle corresponds to a brightness temperature of order 10,000 K. Once radiation is entered on both sides of the entropy balance, the second law is satisfied and anti-Stokes cooling is permitted.

The experiment came forty-nine years after Landau, and sixty-six years after Pringsheim first asked the question: in 1995 Richard Epstein and his colleagues at Los Alamos cooled a solid with a laser. The first medal in Pringsheim's name goes to the man who answered it.

A life across two wars

Pringsheim was born in Munich on 19 March 1881, a son of the mathematician Alfred Pringsheim. He took his doctorate at Munich in 1906 under Wilhelm Conrad Röntgen, worked at Göttingen and then at Cambridge under J. J. Thomson, and joined the Institute of Physics at the University of Berlin in 1908.

In 1914 Pringsheim sailed to Melbourne for the conference of the British Association for the Advancement of Science. War broke out while the meeting was under way, and the next five years were spent interned as an enemy alien at Trial Bay, on the coast of New South Wales. They were not wasted. Colleagues in the southern hemisphere kept the current literature coming: Thomas Ranken Lyle in Melbourne, James Pollock and Edward Wellisch in Sydney, and Ernest Rutherford, who had been at the same conference. The manuscript finished in the camp was published in 1921 as *Fluoreszenz und Phosphoreszenz im Lichte der neueren Atomtheorie*, and it made him the authority on the subject. Rubens and Planck assessed it for his promotion in Berlin and the faculty vote was unanimous. The question he asked in 1929 came out of that book.

A full professorship in Berlin followed in 1925, and the chair was made permanent in January 1930. In September 1933 the law on the restoration of the professional civil service placed Pringsheim in retirement; the memorandum was signed by Wilhelm Stuckart, who later helped draft the Nuremberg laws. A position at the Université Libre de Bruxelles kept him teaching for nearly seven years, until German troops entered Brussels in May 1940 and he was sent to the camp at Gurs, in southern France. His sister Katia and her husband Thomas Mann, together with James Franck, secured a visa and a post at Berkeley; it was issued on 5 December 1940. Those held at Gurs who could not obtain help from abroad were deported to the extermination camps.

From 1942 Pringsheim worked with Franck at Chicago, then in industry in Pasadena, and from 1947 at Argonne, returning to Belgium in 1954 at the age of seventy-three. He died in Antwerp on 20 November 1963. Eight Nobel laureates had intervened on his behalf at one point or another: Röntgen, J. J. Thomson, Rutherford, Planck, von Laue, Nernst, Franck and Thomas Mann. None of it stopped the work: the internment produced the book, and the years after Gurs produced papers from Chicago, Pasadena and Argonne. The question he asked in 1929 outlived every institution that tried to be rid of him.

The medal

The Pringsheim Medal recognizes a career that has shaped the physics of photonic heat engines, and is awarded for the first time at this workshop. His 1929 question took seventeen years to be accepted as a question at all. We have written to the Humboldt-Universität zu Berlin, successor to the institute where he worked, to ask whether they will endorse a medal in his name.

THE EXCHANGE

1. P. Pringsheim, *Fluoreszenz und Phosphoreszenz im Lichte der neueren Atomtheorie* (Springer, Berlin, 1921). Written during his internment at Trial Bay.
2. P. Lenard, F. Schmidt and R. Tomaschek, *Handbuch der Experimentalphysik*, Band 23: *Phosphoreszenz und Fluoreszenz* (Akademische Verlagsgesellschaft, Leipzig, 1928).
3. P. Pringsheim, “Zwei Bemerkungen über den Unterschied von Lumineszenz- und Temperaturstrahlung,” Z. Physik **57**, 739–746 (1929).
4. S. Vavilov, “Some remarks on the Stokes law,” J. Phys. (Moscow) **9**, 68–72 (1945).
5. P. Pringsheim, “Some remarks concerning the difference between luminescence and temperature radiation: anti-Stokes fluorescence,” J. Phys. (Moscow) **10**, 495–498 (1946).
6. S. Vavilov, “Photoluminescence and thermodynamics,” J. Phys. (Moscow) **10**, 499–502 (1946).
7. L. Landau, “On the thermodynamics of photoluminescence,” J. Phys. (Moscow) **10**, 503–506 (1946).
8. H. E. D. Scovil and E. O. Schulz-DuBois, “Three-level masers as heat engines,” Phys. Rev. Lett. **2**, 262–263 (1959).

Biography drawn from J. N. Bade, *Hist. Rec. Aust. Sci.* **36**, HR24006 (2025).

THE PREMISE

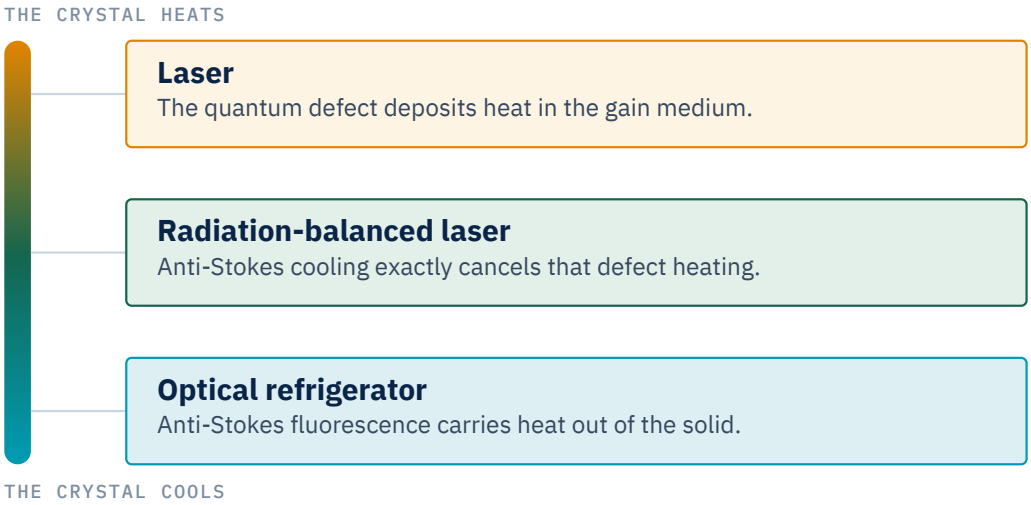
Why this is called Carnot

In 1824 a French military engineer named Sadi Carnot published a short book about steam engines and in doing so founded thermodynamics. His question was not how to build a better engine but how good any engine could be. The answer depended on nothing about the machine, neither its working fluid nor its mechanism, but only on the two temperatures between which it operated.

This field inherited that question. A photonic heat engine is a heat engine in the strict sense rather than by analogy. Its working fluid is light, its reservoirs are radiation fields, and the entropy of those fields decides whether a given device can run at all.

Scovil and Schulz-DuBois made the identification exact in 1959. Their subject was the three-level maser, in operation since 1954, and they showed that it is a heat engine running between a hot pump and a cold sink, with an efficiency bounded by the Carnot limit set by those two temperatures. The argument that began with Pringsheim asking whether light could cool a solid, and that Vavilov and Landau settled in terms of radiation entropy, arrives at a general statement: a coherent light source is a thermodynamic engine, and a Carnot bound applies to what it can do.

Optical refrigeration is the engine run in reverse. A pump photon is absorbed, a fluorescence photon of higher energy is emitted, and the difference is carried away from the lattice. The cooling efficiency depends on three quantities: the fraction of excitations that escape as light, the fraction of the pump that is usefully absorbed, and the ratio of the two wavelengths.



For any given material and pump, three operating points. The color of every session band and speaker mark in this book is taken from this axis.

How close to the limit?

Two kinds of temperature appear in the same expression. The first is the ordinary thermodynamic temperature of the solid, the quantity a thermometer reports. The second belongs to the light. Any beam can be assigned the temperature a blackbody would need in order to emit the same radiance, at that frequency, into that solid angle and polarization. This is its brightness temperature, and what it measures is the mean number of photons per mode. Broadband fluorescence leaving a sample in every direction sits at a brightness temperature of order 10^4 K. A laser beam carrying a thousand times less power, but concentrating it into a single mode, exceeds 10^9 K. The asymmetry is this. The pump arrives in one direction, in one mode, at one wavelength, and so carries almost no entropy with it. The fluorescence leaves in every direction, across a broad band, and carries a great deal. Landau's contribution was to assign that difference a number. This is the whole reason a solid can be cooled with light: the radiation that leaves can carry away more entropy than the radiation that arrived, and what pays the difference is the thermal energy of the lattice.

The Carnot bound applies to that device as directly as it applies to a steam engine. A laser pump photon carries essentially no entropy. A fluorescence photon carries $h\nu_f$ divided by the brightness temperature of the field it escapes into. Requiring that the entropy leaving be at least the entropy removed from the lattice turns into the Carnot coefficient of performance for a refrigerator working between the sample and the radiation. For a solid near room temperature radiating at a brightness temperature of order 10^4 K, that limit is about three percent, and the best laser-cooled materials reach about two. An optical refrigerator is not an inefficient machine. It is a machine running close to its thermodynamic limit, in a regime where the limit itself is small.

REFERENCES

1. S. Carnot, *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance* (Bachelier, Paris, 1824).
2. R. Clausius, "Über die bewegende Kraft der Wärme und die Gesetze, welche sich daraus für die Wärmelehre selbst ableiten lassen," Ann. Phys. **155**, 368–397 (1850). The temperature-ratio form of Carnot's result is due to Clausius and Thomson, not to Carnot, whose argument was framed in terms of caloric.
3. H. E. D. Scovil and E. O. Schulz-DuBois, "Three-level masers as heat engines," Phys. Rev. Lett. **2**, 262–263 (1959).

Color/shape code

A radiation-balanced laser operates at the point where anti-Stokes cooling exactly cancels the heat a laser deposits in its own gain medium. A high-power laser is the same engine with the balance deliberately on the other side. These are not three subjects but one engine at three operating points, and that is one axis of this book.

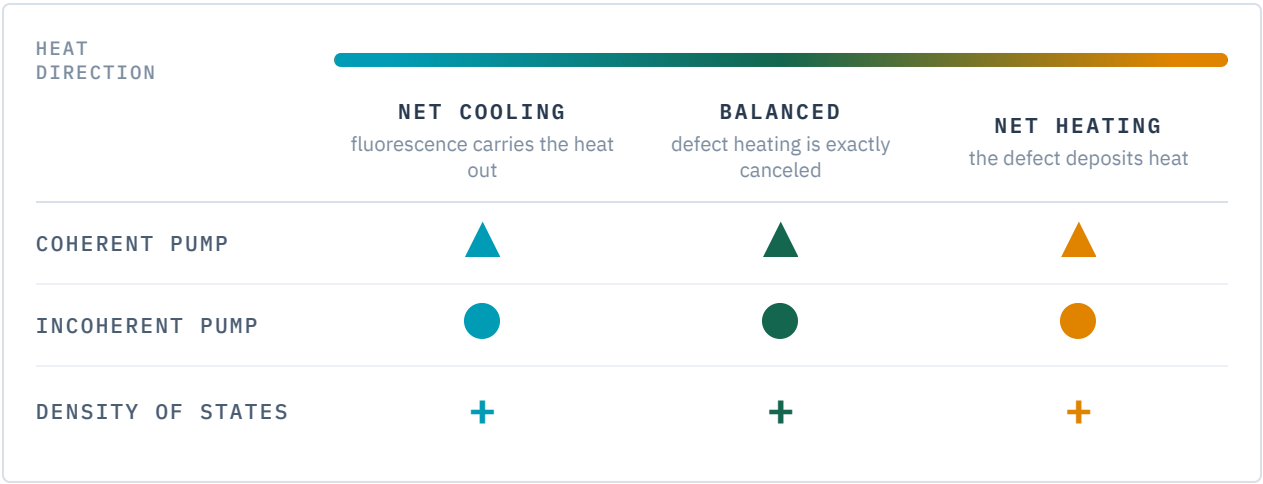
On its own the axis is not enough. Two experiments can both cool a solid and share almost none of their physics, because the direction of the heat flow says nothing about what is driving it. The pump is the second axis.

So every talk in this workshop is placed by two questions: which way does the heat go, and what drives it?

Those two questions are independent, so we have given each its own visual channel. **Color** carries the direction of heat flow: cooling, balanced, heating. **Shape** carries the pump: a **triangle** for a coherent pump, a **circle** for an incoherent one, and a **plus** where the work is done by engineering the density of states rather than by the pump at all.

Two speakers may both cool a solid and have almost nothing to say to each other, while a radiation-balanced laser and a solar-pumped one differ in exactly one coordinate. The matrix below is the field laid out along the two axes that separate the work.

Some cells have no speaker. That is also information: those cells are a combination nobody has made work yet, or one nobody has tried, and they are the places where the field has room to move.



> The second axis is the pump for a reason. Vavilov and Pringsheim were arguing about precisely whether a monochromatic unidirectional beam and a broadband isotropic one can be exchanged for one another; Landau's answer was that they cannot, with a number attached. A coherent pump is a low-entropy input; an incoherent one is not. A talk in this workshop that cools a solid with sunlight rather than a laser is working the near side of a question that has been open since 1946.

PROGRAM

Day One

Saturday 24 October

08:00	REGISTRATION, ARRIVAL, AND COFFEE	PAIS foyer

0 · Welcome ○

Lecture Hall · 1100 — 25 min

08:35 **Denis Seletskiy**
Meet CARNOT: 2026 and beyond
University of New Mexico

I · Optical refrigeration — rare earths ▲

Lecture Hall · 1100 — 3 × 30 min

09:00 **Richard Epstein** — I-1
Can you give me a second?
University of New Mexico

09:30 **Hiroki Tanaka** — I-2
Crystalline materials for optical refrigeration
Leibniz Institute for Crystal Growth

10:00 **Michel Digonnet** — I-3
Anti-Stokes fluorescence cooling in silicate fibers
Stanford University

10:30 COFFEE BREAK (30 MIN)

II · Optical refrigeration — semiconductors ▲

Lecture Hall · 1100 — 2 × 30 min

11:00 **Matt Sheldon** — II-1
Quantifying optical cooling in perovskite nanocrystal ensembles with photothermal deflection spectroscopy
University of California, Irvine

11:30 **Masaru Kuno** — II-2
Solid state laser cooling
University of Notre Dame

12:00 WORKSHOP PHOTOGRAPH (10 MIN) — Lecture Hall · 1100
In the Lecture Hall, PAIS 1100

12:10 LUNCH (60 MIN) — PAIS 1110
Catered on site

III · Nanostructures and engineered environments +

Lecture Hall · 1100 — 3 × 30 min

13:10 **Peter Pauzauskie** — III-1
Solid state laser refrigeration of nanoscale quantum sensors
University of Washington

13:40 **Christian Schmiegelow** III-2
Environment engineering and electrodynamic traps for laser cooling
Universidad de Buenos Aires

14:10 **Pengning Chao** III-3
Nanophotonic inverse design for optical refrigeration
Maxwell Labs

14:40 COFFEE BREAK (30 MIN)

IV · High-power and radiation-balanced lasers

Lecture Hall · 1100 Talk and panel

15:10 **Peter Dragic** IV-1
Fibers and fiber materials for power scaling of radiation balanced fiber lasers
University of Illinois Urbana-Champaign

15:40 PANEL DISCUSSION (60 MIN)
Where cryogenic optical refrigerators are actually needed, how far radiation-balanced and high-power lasers can be pushed, and what the two problems have in common

V · Flash talks

Lecture Hall · 1100 2 min each

16:45 FLASH TALKS (15 MIN)
Two minutes and one slide each — the posters follow at the restaurant

17:00 BUS TO THE RESTAURANT (20 MIN) Redondo Drive
Board outside PAIS on Redondo Drive at 17:00; a fifteen-minute ride to La Fonda del Bosque, arriving 17:20. Returns to the hotel and to PAIS after dinner

Evening

La Fonda del Bosque

17:20 POSTER SESSION AND RECEPTION (70 MIN) La Fonda del Bosque
At La Fonda del Bosque — the boards go up at the restaurant, with light refreshments

18:30 WORKSHOP DINNER La Fonda del Bosque
La Fonda del Bosque, National Hispanic Cultural Center · poster prizes and photographs

PROGRAM

Day Two

Sunday 25 October

08:00	REGISTRATION, ARRIVAL, AND COFFEE	PAIS foyer

VI · Thermodynamics and broadband sources — Lecture Hall · 1100 — 3 × 30 min

08:30	**Hanieh Fattahi** Solar-pumped radiation-balanced laser Max Planck Institute for the Science of Light	VI-1
09:00	**Eli Yablonovitch** Opto-electronic thermodynamics University of California, Berkeley	VI-2
09:30	**Sushrut Ghonge** Thermodynamics of photoluminescence-based cooling with incoherent photon sources Saint Mary's College	VI-3
10:00	COFFEE BREAK (30 MIN)	
10:30	TALKS FROM THE POSTER PRIZE WINNERS 10 minutes each	

VII · A roadmap for the photonic engine community — Rm 1140 & 1160

2 × 30 min + joint discussion

- **A** — **Laser cooling** — Moderators: Masaru Kuno, Peter Pauzauskie
- **B** — **Radiation-balanced and high-power lasers** — Moderators: Denis Seletskiy, Joel Bixler

11:00	WORKING GROUPS A AND B — FIRST ROUND (30 MIN) Running in parallel, in Rm 1140 and Rm 1160	
11:30	SECOND ROUND (30 MIN) Both groups run again — switch rooms, stay where you are, or sit this one out	
12:00	JOINT DISCUSSION WITH SUMMARY FROM MODERATORS (30 MIN) Each group reports, then the two halves meet	
12:30	LUNCH (60 MIN) Catered on site	PAIS 1110
13:30	LAB TOURS / ADJOURN Optional tours of UNM laboratories · the workshop ends at 15:00	

SPEAKERS

Invited speakers



Joel Bixler

Air Force Office of Scientific Research

Program Officer, High-Energy Radiation-Matter Systems (HERMES).

○ PANEL DISCUSSION



Pengning Chao

III-3

Maxwell Labs

Nanophotonics, computational inverse design, and high-power optical refrigeration.

\+ COOLING · DENSITY OF STATES



Michel Digonnet

I-3

Stanford University

Rare-earth-doped fiber lasers, amplifiers and sensors; radiation-balanced silica fiber lasers.

▲▲ COOLING AND BALANCED · COHERENT



Peter Dragic

IV-1

University of Illinois Urbana-Champaign

Optical fiber materials and glass science; Brillouin scattering; fiber laser design.

▲ BALANCED · COHERENT



Richard Epstein

I-1

University of New Mexico

First demonstration of laser cooling in a solid; rare-earth spectroscopy; cryogenic optical refrigerators.

▲ COOLING · COHERENT



Hanieh Fattahi

VI-1

Max Planck Institute for the Science of Light, Erlangen

Ultrafast and field-resolved optics; sun-pumped radiation-balanced lasers.

● BALANCED · INCOHERENT



Sushrut Ghonge

VI-3

Saint Mary's College

Thermodynamics of photoluminescent cooling; cooling with incoherent and broadband light.

● COOLING · INCOHERENT



Masaru Kuno

II-2

University of Notre Dame

Semiconductor nanostructures; single-particle spectroscopy; laser cooling of semiconductors.

▲ COOLING · COHERENT



Peter Pauzauskie

III-1

University of Washington

Laser refrigeration of nanomaterials; Yb-doped nanocrystals; nanoscale thermometry.

\+ COOLING · DENSITY OF STATES



Christian Schmiegelow

III-2

Universidad de Buenos Aires

Laser cooling of solids and nanoparticles in electrodynamic traps; cavity-modified electromagnetic environments; Purcell effect and enhanced anti-Stokes emission.

+ COOLING · DENSITY OF STATES



Denis Seletskiy

University of New Mexico

Ultrafast and quantum optics; laser cooling of solids; vacuum-field fluctuations.

○ WELCOME



Matt Sheldon

II-1

University of California, Irvine

Nanophotonics and plasmonics; hot-carrier photophysics; luminescence thermodynamics.

▲ COOLING · COHERENT



Hiroki Tanaka

I-2

Leibniz Institute for Crystal Growth (IKZ), Berlin

Fluoride crystal growth; Yb-doped cooling materials; radiation-balanced laser design.

▲ COOLING · COHERENT



Eli Yablonovitch

VI-2

University of California, Berkeley

Opto-electronic thermodynamics; photon free energy and entropy in emission and absorption; light extraction in LEDs and solar cells.

● COOLING · INCOHERENT

POSTER SESSION

Posters

The posters come from the speakers' groups and from UNM. Each presenter gets two minutes and one slide on Saturday afternoon, at 16:45, before the bus leaves for the restaurant.

Presenting a poster at a meeting where most of the room has written the papers you cite takes some nerve. We are glad you did it. The boards go up at La Fonda del Bosque, where the session runs from 17:20 until dinner at 18:30. Prizes are awarded at the dinner, and the winners give short talks on Sunday morning — but the useful part is the seventy minutes at the boards, which is where most of this field's collaborations have started.

P1 **Jadin Coddens & MaryElizabeth Cain**
Revealing nonradiative relaxation in $CsPbBr_3$ nanocrystals using photothermal ratiometric quantum yield measurements
Saint Mary's College

P2 **Emma Brass**
Defining the parameter space for perovskite optical cooling with photothermal deflection spectroscopy
University of California, Irvine

P3 **Sankhya Hirani**
Mie resonance-enhanced optical refrigeration
University of Washington

P4 **Andy Feng**
Solid-state laser refrigeration of nanoscale quantum sensors
University of Washington

P5 **Trevor Rubin**
High-power narrow-linewidth semiconductor lasers for igniting artificial guide stars
University of New Mexico / femtoQ

P6 **Brandon Stone**
Managing thermal noise in SiN coupled microring resonators
University of New Mexico, CHTM

P7 **Iotsi Bueno Ries**
Optical cooling of Yb:YLF with incoherent and partially coherent light
University of New Mexico / femtoQ

The abstracts follow, each carrying the number of its talk in the program, session numeral first. Poster abstracts were not collected for this first edition.

I - 1

Can you give me a second?

R. I. Epstein

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Part of the early motivation for developing optical cryocoolers was to have vibrationless devices that can be used for high precision clocks. One aim was to cool the silicon reference cavity developed by Jun Ye down to 124 K, the temperature where silicon has zero thermal expansion. CARNOT2026 seems like a good time to reevaluate the usefulness of vibrationless cooling for ultra-high precision clocks. In the last month or so three papers have been published in Nature describing novel clock approaches based on Lu^+ ions or ^{229}Th nuclei. The Lu^+-based cooler, which is currently the most precise by far, operates at a wide range of room temperatures with no need for cryocooling. One of the ^{229}Th-based clocks used a Si reference cavity which might be cooled by optical refrigeration. My talk will describe these various approaches and their significance.

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2. L. Toscani De Col et al. “A thorium-229 optical nuclear clock with a feedback loop” Nature, 646, 345–351 (2026)
3. B. Huang et al. “A nuclear clock synchronized to ^{229}Th” Nature, October 7, 2026

I - 2

Crystalline materials for optical refrigeration

Z. Liestmann[1], L. Koldeweyh[1], and H. Tanaka[1,*]
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We have been pursuing three approaches to overcoming the current material-related limitations of optical refrigeration: (i) identifying host materials with more favorable properties for Yb^{3+}-based optical refrigeration, (ii) understanding and mitigating background absorption caused by impurities in YLF. (iii) exploring alternative rare-earth ions with low-energy transitions.

For the first approach, we found that Yb:KY_3F_{10} exhibits intrinsically more favorable spectral properties for cryogenic cooling than Yb:YLF [1], and demonstrated cooling to 145 K by pumping at 1020 nm, being not optimized for this material [2].

For the second approach, we investigated the role of Fe ions, which have been considered as the source of background absorption. We experimentally confirmed that Fe:YLF exhibits broad near-infrared absorption spanning 800-1500 nm but only in π-polarization (Fig. 1a). The measured absorption coefficients suggest that trace concentrations of Fe are insufficient to explain the background absorption determined in laser-cooling experiments. These results therefore indicate that Fe is likely not the primary source of the background absorption.

For the third approach, we investigated optical refrigeration using the 1.9-μm transition of Tm^{3+}. Temperature-dependent spectroscopy of Tm^{3+}-doped YLF, BaY_2F_8, KY_3F_{10}, and CaF_2 revealed that Tm:YLF exhibits the most favorable intrinsic spectral properties for optical refrigeration. Although laser cooling was observed in all crystals, the performance was limited by energy-transfer upconversion (ETU), which introduces non-radiative relaxation pathways. Interestingly, the impact of ETU was less pronounced in samples with higher Tm^{3+} concentrations. This is attributed to reverse cross-relaxation, which may partially suppress non-radiative losses from the higher-lying $^3H_4$ manifold (Fig. 1b).

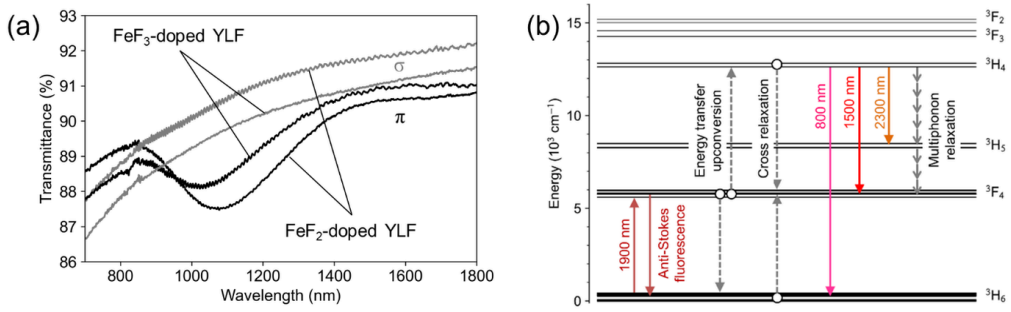


Fig. 1. (a) Polarization-dependent transmission spectra of YLF crystals doped with FeF_2 and FeF_3. (b) Energy diagram of Tm^{3+} in fluoride crystals, showing the possible upconversion pathway after excitation at around 1.9 μm, and subsequent emission channels.

REFERENCES

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2. L. Koldeweyh et al., "Solid-state laser cooling of Yb^{3+}-doped KY_3F_{10} to 145 K," JOSA B 43, 1719–1725 (2026).

I - 3

Anti-Stokes fluorescence cooling in silicate fibers

M. J. F. Digonnet[1,*], C.-W. (Joe) Chen[1,2], P. D. Dragic[3], and J. Ballato[4]
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[2]*Now Department of Physics, University of Bath, Bath BA2 7AY, UK*
[3]*Department of Electrical and Computer Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61801, USA*
[4]*Department of Materials Science and Engineering, Clemson University, Clemson, SC 29634 USA*
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Since the first reports of successful cooling by anti-Stokes fluorescence in a Yb-doped silicate fiber [1] and cane [2] in 2020, several compositions of aluminosilicate glasses have been cooled with increasingly higher temperature changes. The current record is 67 K below room temperature in a Yb-doped aluminosilicate cane with a core diameter of 900 μm [3]. These breakthroughs were made possible thanks to sustained progress in the design and fabrication of silica-based compositions with increasingly high Yb concentrations, now reaching 6 wt.% Yb, while minimizing concentration quenching, which limits the Yb excited-state population that drives spontaneous emission and cooling, and background absorption due to impurities, which injects undesirable heat in the cooled fiber.

In this talk, we will review the progress made in cooling Yb-doped aluminosilicate and aluminophosphosilicate fibers fabricated at Clemson University, which has led to the recent demonstration of cooling in a multimode fiber with a 48-μm core diameter by as much as 1.1 K below room temperature. Cooling required only 2.2 W of pump power at 1040 nm, corresponding to an efficiency of 0.50 K/W, the highest value reported to date. We will show that of seven commercial Yb-doped silicate fibers tested, the five that cooled did not cool nearly as well because of a lower Yb concentration, higher quenching, and/or higher background absorption [4]. A part of this talk will discuss the performance of larger silica fibers and canes that have been cooled in other groups [3, 5], in an attempt to identify the compositions that have the lowest backscattering loss and/or highest critical quenching concentration. We will end with a brief overview of the radiation-balanced fiber lasers (200 mW) and amplifier (600 mW) that have been demonstrated using the best custom fibers.

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II-1

Quantifying optical cooling in perovskite nanocrystal ensembles with photothermal deflection spectroscopy

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Optical refrigeration in all-inorganic lead halide perovskite nanocrystals requires phonon-assisted anti-Stokes emission to extract more heat than competing loss processes generate [1]. We are refining photothermal deflection spectroscopy to quantify this balance in ensemble solutions and identify the material parameters and operating conditions that govern cooling efficiency [2]. By measuring net heat exchange together with absorption and photoluminescence, we connect concentration- and power-dependent luminescence yields with actual heat extraction. For example, for a sample with approximately 98% photoluminescence quantum yield, the quantified cooling power reaches a maximum of approximately 2 μW near 535 nm and decreases with further detuning. Cooling occurs at tested concentrations of suspensions of nanocrystals between approximately 0.23–0.35 μM, with the strongest measured response near 0.35 μM and a reversal to heating near 0.46 μM. Concentration-dependent emission trends are consistent with passivation losses upon dilution and reabsorption at higher particle loading. Photothermal threshold behavior reports quantum-yield increasing from 98.8% to 99.9% as relative excitation power decreases from 100% to 70%, while higher irradiance introduces a delayed heating contribution that can overcome initial cooling. In parallel, structure–function studies systematically vary lead–halide octahedral tilting to relate composition and crystal structure to electron–phonon coupling and the energetics and interconversion of free-exciton and polaronic states involved in anti-Stokes emission [3]. Together, direct thermal measurements and structural control connect microscopic photophysics with ensemble heat balance, defining the factors that limit current cooling performance and guiding improvements in cooling efficiency and heat extraction.

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II-2

Solid state laser cooling

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mkuno@nd.edu

One holy grail of light/matter science is the optical refrigeration of a semiconductor.[1,2] The concept underlying how light can act as a refrigerant to cool matter precedes the Doppler cooling of atomic gases. Today, a race exists to demonstrate semiconductor laser cooling because of the very low cooling floors that can be realized. If successful, semiconductor laser cooling would open the door to a number of applications. Although early reports have suggested cooling successes with various semiconductor nanostructures, none have survived strict scrutiny.[1-3]

This talk focuses on efforts made at Notre Dame to demonstrate optical refrigeration in all-inorganic, $CsPbBr_3$ nanocrystals. The particles are made using colloidal chemistry and exhibit near-unity emission quantum yields. We have further found that the paticles possess unusually large single-photon/multiple-phonon up-conversion efficiencies. Together, both suggest that cooling is possible with these materials. We describe recent efforts to demonstrate verifiable optical cooling with these materials.

REFERENCES

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2. Y. Ding et al. “Solid state laser cooling,” Nature Methods Primer, 6, 46 (2026).
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III-1

Solid state laser refrigeration of nanoscale quantum sensors

Peter Pauzauskie[1,2*], Andy Feng[2], and Sankhya Hirani[1], Alexey Soldatenko[1], Lars Forberger[1]
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Photothermal heating remains a major challenge during the optical excitation of nanoscale quantum sensors. At low laser powers, heating of the sensor leads to the thermal drift of quantum electronic transition energies. At high laser powers, sensors degrade due to thermally-induced phase transitions, including melting. In this talk I will present a general approach for mitigating the photothermal heating of nanoscale quantum sensors through solid state laser refrigeration of the sensors' underlying substrate. Experimentally, both nanodiamonds and gold nanocrystals are attached separately to a ceramic laser-cooling substrate through van der Waals interaction. A combination of Debye-Waller factor thermometry and optically detected magnetic resonance spectroscopy of nitrogen vacancy centers is used to demonstrate that solid state laser refrigeration of the substrate can reduce the temperature of attached nanodiamond payloads by 25 +/- 3 K below steady state operating temperatures. Stokes/anti-Stokes Raman spectroscopy is used to demonstrate reduced photothermal heating of plasmonic gold nanocrystals of 8.8 +/- 2.7 K during surface-enhanced Raman spectroscopy (SERS) sensing of rhodamine-6G molecules. These results suggest that solid state laser cooling could open up new experimental possibilities for rapid feedback-controlled cooling of a wide range of nanoscale quantum resources. Additionally, I will present some experimental advances related to the design and synthesis of calcium-fluoride microspheres that increase the absorption of ytterbium ions used for solid-state laser refrigeration through the use of internal optical Mie-resonances within the microspheres.

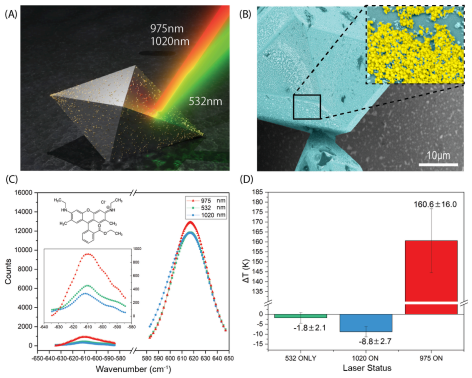


Fig. Schematic of a Yb:YLF microcrystal coated with plasmonic gold nanorods used for surface enhanced Raman spectroscopy (SERS). The YLF microcrystal serves as a substrate that can be optically refrigerated, reducing the heat load on molecular analytes during SERS measurements.

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III-2

Environment engineering and electrodynamic traps for laser cooling

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schmiegelow@df.uba.ar

Anti-Stokes laser cooling of rare-earth-doped crystals has reached cryogenic temperatures in Yb^{3+}:$YLiF_4$ (YLF) [1], down to below 90K, but further progress is limited: as the crystal cools, the population of the pumped upper ground-state Stark level vanishes and parasitic background absorption outweighs the cooling. First, I will show that this limit can be shifted by engineering the electromagnetic environment of the emitters [2]. Placing a Yb^{3+}:YLF nanocrystal inside a short Fabry–Pérot microcavity resonant with the most energetic emission line (1↔5, ~971 nm) enhances this cooling channel through the Purcell effect, while inhibiting the off-resonant, less energetic decays that heat the crystal [3]. This allows pumping from a lower ground-state level, which remains populated down to much lower temperatures. Using a quantum master-equation model fed with measured emission spectra, we find that the cooling efficiency is consistently improved below 100 K, that accounting for Purcell inhibition raises it by 25–65% relative to enhancement alone, and that the minimum achievable temperature is pushed well below that of liquid nitrogen, possibly below 20 K. I will discuss geometries providing the required spectral selectivity, such as fiber-based microcavities with free spectral ranges of ~60 nm, as well as the technical limitations that stand in the way of approaching absolute zero and possible strategies to circumvent them. Finally, I will review our latest progress on electrodynamic (Paul) trapping of micron-sized Yb-doped particles, a natural platform to isolate the crystal from its surroundings and to host such engineered optical environments.

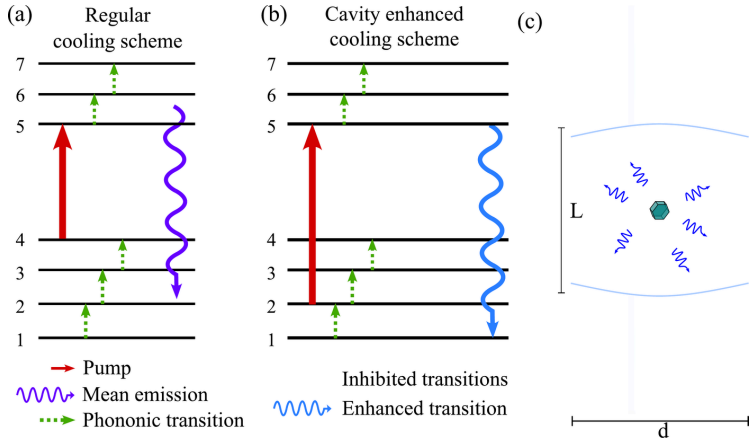


Fig. 1. (a) Standard anti-Stokes cooling scheme of Yb^{3+}:YLF, pumping the 4↔5 transition. (b) Cavity-enhanced scheme: pumping 2↔5 while a Fabry–Pérot microcavity enhances the 1↔5 emission and inhibits the {2,3,4}↔5 lines. (c) Fiber-based microcavity of length L and mirror diameter d, with the nanoparticle levitated at its center. Adapted from Ref. [2].

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III-3

Nanophotonic inverse design for optical refrigeration

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At Maxwell Labs, our mission is to develop high power, high efficiency optical refrigeration for more effective cooling of computational chips. This is an exciting but challenging problem that demands us push the boundaries of material capability and device design. Most existing efforts to push cooling performance have been focused on developing better materials platforms and the demonstration of cooling in bulk. In this talk, we will instead focus on the comparatively under-explored prospects of enhancing anti-Stokes fluorescent cooling through nanostructuring. In recent years, computational inverse design has emerged as a powerful, practical paradigm for discovering non-intuitive, high-performance nanophotonic devices. We will review the theoretical and practical constraints on optical refrigeration, discuss various aspects of nanophotonic inverse design, and explore how it can enable higher power, more efficient optical refrigeration.

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IV-1

Fibers and fiber materials for power scaling of radiation balanced fiber lasers

P. D. Dragic[1,*], M. Gachich[1], J. Hutson[1], S. Messing[1], S. Wang[1], B. Baldus[2], K. Chapman[2], B. Meehan[2], M. Walton[2], M. J. F. Digonnet[3], T. W. Hawkins[2], and J. Ballato[2,*]

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For radiation balanced fiber lasers (RBFLs) to displace the current state-of-the-art Stokes pumped lasers, power scaling to well beyond 1 kW is required. In a conventional RBFL [1], the fiber core contains the rare earth ion (Yb^{3+}) which can either deposit heat through stimulated emission or annihilate a phonon via anti-Stokes fluorescence. In this case, power scaling is severely limited by the low absorption cross-section at the pumping wavelength. This problem is magnified when the fiber is double-clad, leading to the requirement of impractically long lengths of active fiber. The absorption may be increased by increasing both the ratio of core-to-cladding diameters and the Yb^{3+} doping concentration. Alternatively, cooling may be decoupled from gain by doping the cladding. Here, the cladding is doped with the cooling ion and may be pumped independently of the core [2-4]. For low brightness diode pumping, this ultimately requires a more complicated structure, possessing a shaped, additional inner cladding [5]. The core is then pumped more conventionally, while the cooling region is anti-Stokes pumped. Although the temperature may be managed in an RBFL, power scaling may suffer from the same subset of nonlinearities as state-of-the-art fiber lasers, including stimulated Brillouin and Raman scattering, and transverse mode instability, which must be managed. We show that with appropriate host material, Yb^{3+} quenching-free concentrations up to 5×10^{26} m^{-3}, stimulated Brillouin scattering thresholds >> 6 dB below commercial fibers, and near-zero thermo-optic coefficients are available. The RBFL also provides a unique platform for thermo-optically tailored fibers.

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VI-1

Solar-pumped radiation-balanced laser

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Solar-pumped lasers directly convert broadband sunlight into coherent radiation, offering promising applications in sustainable photonics, space-based optical communication, and renewable energy technologies. However, their power scalability remains constrained by thermal loading arising from quantum defects and nonradiative relaxation processes [1]. Radiation-balanced lasing provides a potential solution by compensating laser-induced heat generation through optical cooling.

Here, we investigate the potential of ytterbium (Yb)-based gain media for scalable solar-pumped lasers and assess the feasibility of radiation-balanced operation. We first examine a Yb-based thin-disk laser architecture incorporating a dome concentrator that traps and repeatedly redirects incident sunlight through the gain medium, enhancing pump absorption. Our results demonstrate that Yb offers superior power scalability compared with neodymium (Nd), owing to its smaller quantum defect and higher permissible doping concentrations. Increasing the Yb doping concentration to 10% yields lasing thresholds comparable to those of Nd-based systems while enabling up to threefold higher output power.

Building on these findings, we explore radiation-balanced lasing in Yb under spectrally filtered solar pumping within the 1020–1033 nm wavelength range, with laser emission at 1050 nm. Numerical simulations predict radiation-balanced operation at a pump intensity of approximately 28.5 kW cm^{-2}. However, the limited solar irradiance available within this narrow spectral window, approaching only 300 W cm^{-2}, presents a major challenge to achieving radiation-balanced lasing under solar illumination. To address this limitation, we investigate a dual-wavelength pumping strategy incorporating an additional pump channel centered at 941 nm. This channel introduces controlled heat deposition, providing a means to balance optical cooling and heating through tailored solar excitation [2].

These findings establish Yb as a promising gain medium for high-power solar-pumped lasers and provide insights into the opportunities and practical constraints of radiation-balanced operation under concentrated sunlight.

REFERENCES

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VI-2

Opto-electronic thermodynamics

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Lasers, Solar Cells, or Light Emitting Diodes, convert Light to Electricity, OR vice versa. These all fall into a single family of opto-electronic devices. Electrons, holes, & excited molecules have a Chemical Potential, moreover photons have a Free Energy. The Free Energy, U-TS, contains the entropy S. Therefore heat is exchanged in every act of photon emission or absorption. There is laser cooling, but every LED lamp in our homes can act as a little refrigerator.

VI-3

Thermodynamics of photoluminescence-based cooling with incoherent photon sources

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Optical refrigeration using anti-Stokes photoluminescence is now well established, especially for rare-earth-doped solids where cooling to cryogenic temperatures has recently been achieved. The cooling efficiency of optical refrigeration is constrained by the requirement that the increase in entropy of the photon field must be greater than the decrease in entropy of the sample. Laser radiation has been used in all demonstrated cases of optical refrigeration with the intention of minimizing the entropy of the absorbed photons. In this presentation, I will first show that the laws of thermodynamics permit optical cooling of materials with incoherent sources such as light emitting diodes and filtered sunlight almost as efficiently as with lasers. Furthermore, I will show how the polaron-mediated anti-Stokes photoluminescence in $CsPbBr_3$ nanocrystals also allows for cooling with incoherent pumps. Finally, ongoing work on the effect of pump and sample spatio-temporal modes on cooling efficiency will be presented.

REFERENCES

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WHO MADE THIS

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PRACTICAL

Getting around, and who to call

VENUE	Physics, Astronomy and Interdisciplinary Science (PAIS) Building 210 Yale Boulevard NE, Albuquerque NM 87106 *University of New Mexico main campus, off Central · entered through the courtyard on the west side of the building*
ROOMS	**PAIS 1100 · the Lecture Hall** · a 200-seat auditorium with a large screen: all talks and the panel discussion. **PAIS 1110 · the conference room** · lunch and discussion through the day. **PAIS 1140** and **PAIS 1160 · the classrooms**, for the Sunday working groups.
LODGING	Hotel Parq Central 806 Central Avenue SE, Albuquerque NM 87102
DINNER AND POSTERS	La Fonda del Bosque, at the National Hispanic Cultural Center 1701 4th Street SW, Albuquerque NM 87102 · 505-238-5316 *The bus boards outside PAIS at 17:00 on Saturday, straight after the flash talks, and reaches the restaurant at 17:20. The poster session and reception are held there, and dinner follows at 18:30. The bus returns to the hotel and to PAIS afterwards.*
FROM THE AIRPORT	Albuquerque International Sunport (ABQ) is 10 minutes from the hotel. Hotel Parq Central runs a complimentary airport shuttle, 7:30 am to 10:30 pm.
HOTEL TO PAIS	The free 777 Express bus, or a 25-minute walk.
PARKING	**Cornell Parking Structure**, on Redondo Drive east of Popejoy Hall, is the nearest paid visitor parking and is enforced around the clock. $1.75 per half hour, with a $28 daily maximum, so a full day of the workshop costs $28. Arriving after 3 pm, the flat rate is $10. Pay stations take cards; cash only on the third floor, and they give no change. ParkMobile zone 512. Accessible parking is closer: a marked bay on Redondo immediately east of PAIS. *Both are shown on the map overleaf. The accessible bay needs a state-issued placard or plate, and the posted fee still applies.*
WORKING GROUPS	Sunday's discussion panel splits into two groups. Sign-up sheets are at the registration desk on Sunday morning: join one, both, or neither.
POSTERS	4 × 3 feet, **landscape only** — the boards cannot take portrait. Mounting material is provided; bring the poster, not a stand. Every poster gets a two-minute flash talk, prizes are awarded at the dinner, and the winners give ten-minute talks on Sunday morning.

If something goes wrong

WORKSHOP	carnot.workshop@gmail.com
UNM POLICE	505-277-2241 · emergencies 911

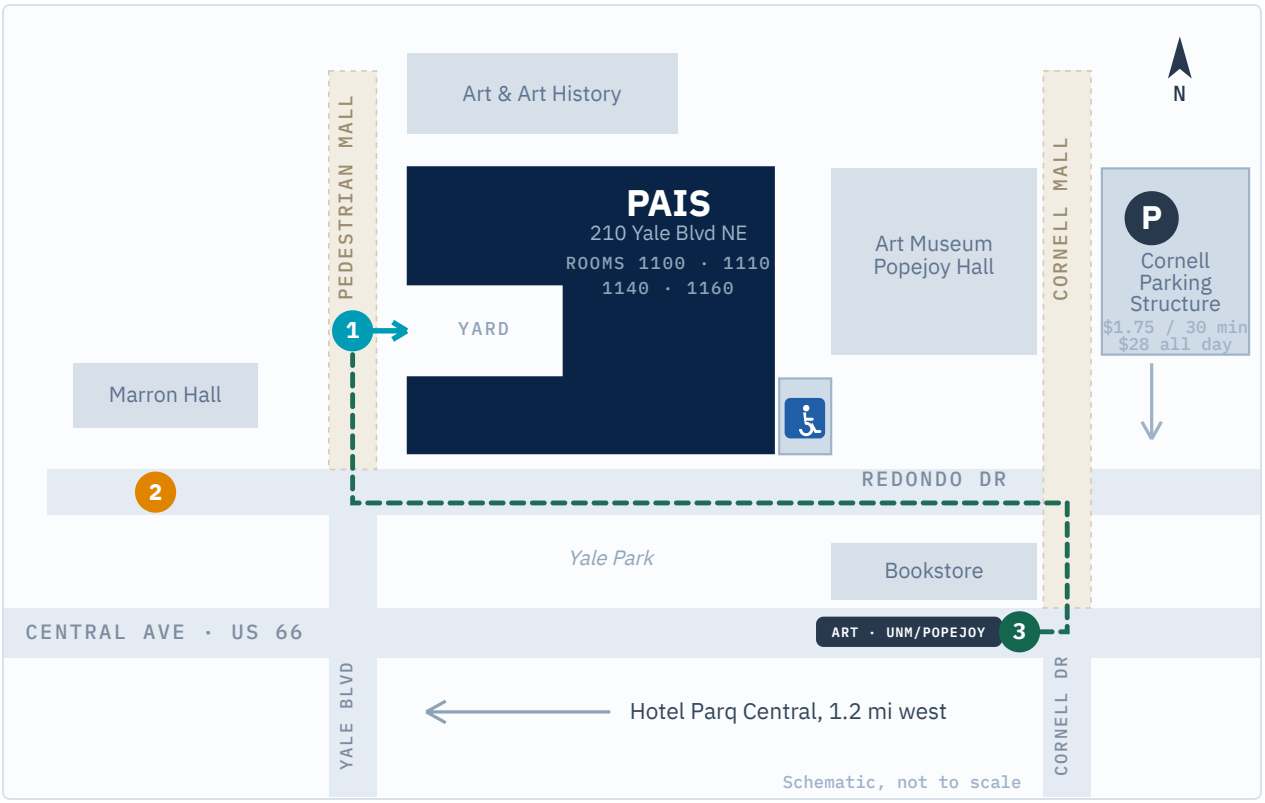
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Notes

FINDING THE ROOM

Getting to PAIS

The talks are in the Lecture Hall, PAIS 1100; lunch and discussion in PAIS 1110; the Sunday working groups in Rm 1140 and Rm 1160.



1 PAIS is entered through the courtyard, which opens west onto the pedestrian mall. 2 The bus leaves at 17:00 on Saturday from the stop on Redondo Drive, west of Yale, for the poster session and dinner. Yale and Cornell are both closed to traffic on campus — Yale north of Redondo, Cornell north of Central, past the Bookstore — so Redondo is the road to use. Accessible parking is the marked bay on Redondo immediately east of PAIS; paid visitor parking is the **Cornell Parking Structure**, further east past Popejoy Hall. Rates and payment are on the previous page. 3 Arriving by ART: the **UNM/Popejoy** station is in the Central median in front of the UNM Bookstore. Leave the platform at its east end and cross Central at the Cornell signal, then north on Cornell to Redondo, west along Redondo, and right into the mall and the courtyard — about seven minutes.

CARNOT

PHOTONIC HEAT ENGINES

DAY ONE · SATURDAY 24 OCTOBER

08:00 *Registration, arrival, and coffee*

0 · Welcome

08:35 Denis Seletskiy

I · Optical refrigeration — rare earths

09:00 Richard Epstein
09:30 Hiroki Tanaka
10:00 Michel Digonnet
10:30 *Coffee break*

II · Optical refrigeration — semiconductors

11:00 Matt Sheldon
11:30 Masaru Kuno
12:00 *Workshop photograph*
12:10 *Lunch*

III · Nanostructures and engineered environments

13:10 Peter Pauzauskie
13:40 Christian Schmiegelow
14:10 Pengning Chao
14:40 *Coffee break*

IV · High-power and radiation-balanced lasers

15:10 Peter Dragic
15:40 Panel discussion

V · Flash talks

16:45 Flash talks
17:00 *Bus to the restaurant*

Evening

17:20 *Poster session and reception*
18:30 *Workshop dinner*

DAY TWO · SUNDAY 25 OCTOBER

08:00 *Registration, arrival, and coffee*

VI · Thermodynamics and broadband sources

08:30 Hanieh Fattahi
09:00 Eli Yablonovitch
09:30 Sushrut Ghonge
10:00 *Coffee break*
10:30 Talks from the poster prize winners

VII · A roadmap for the photonic engine community

11:00 Working groups A and B — first round
11:30 Second round
12:00 Joint discussion with summary from moderators
12:30 *Lunch*
13:30 Lab tours / adjourn

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