Visible solid-state lasers in rare earth doped fluoride crystals

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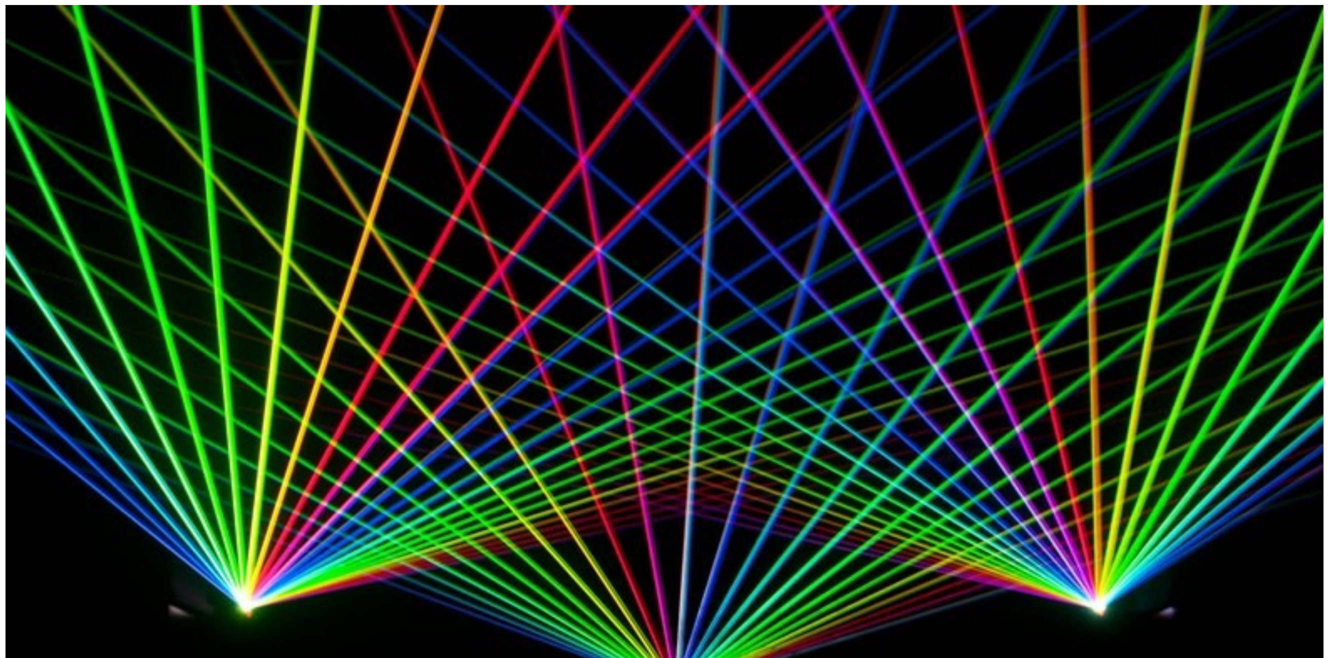
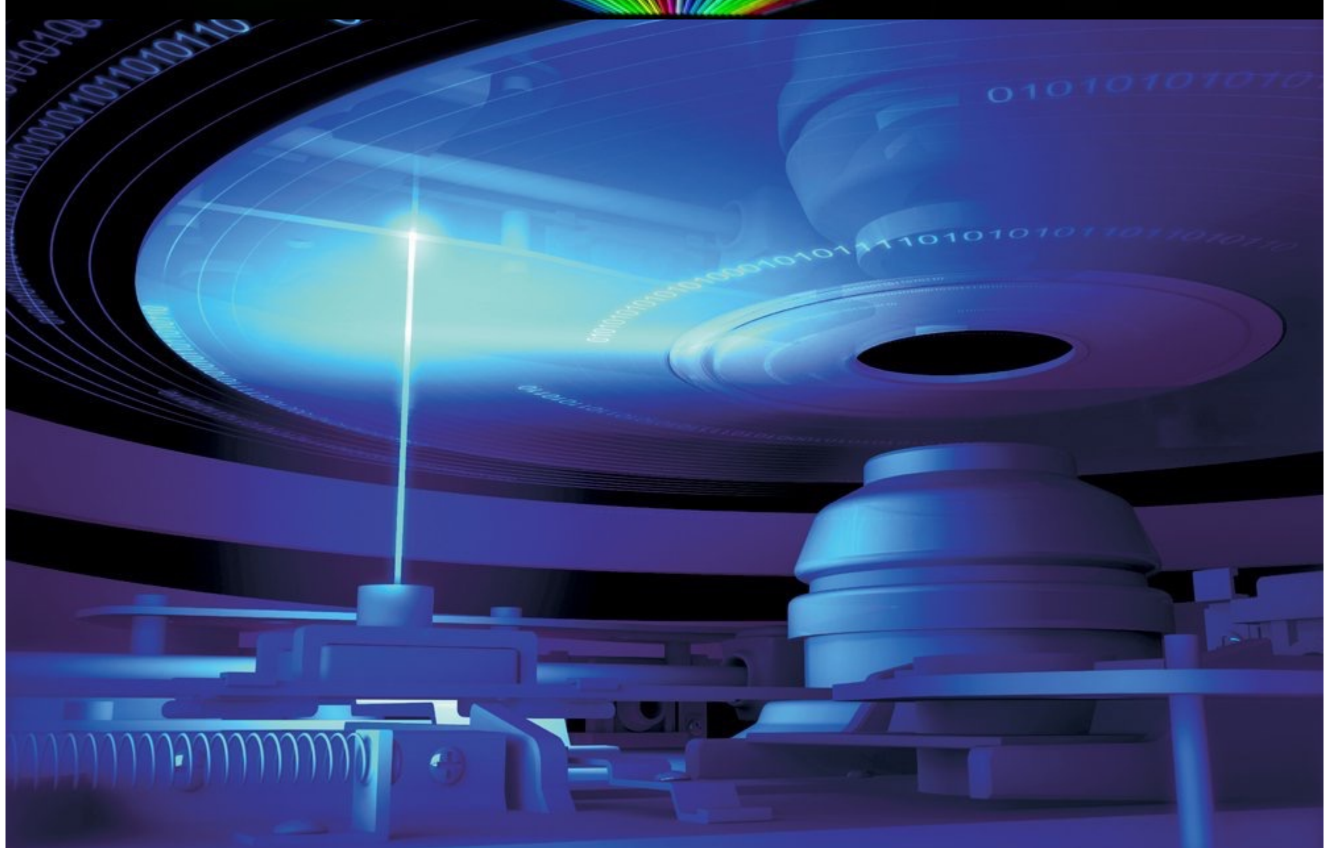
Controrelatore - Prof. D. Ciampini

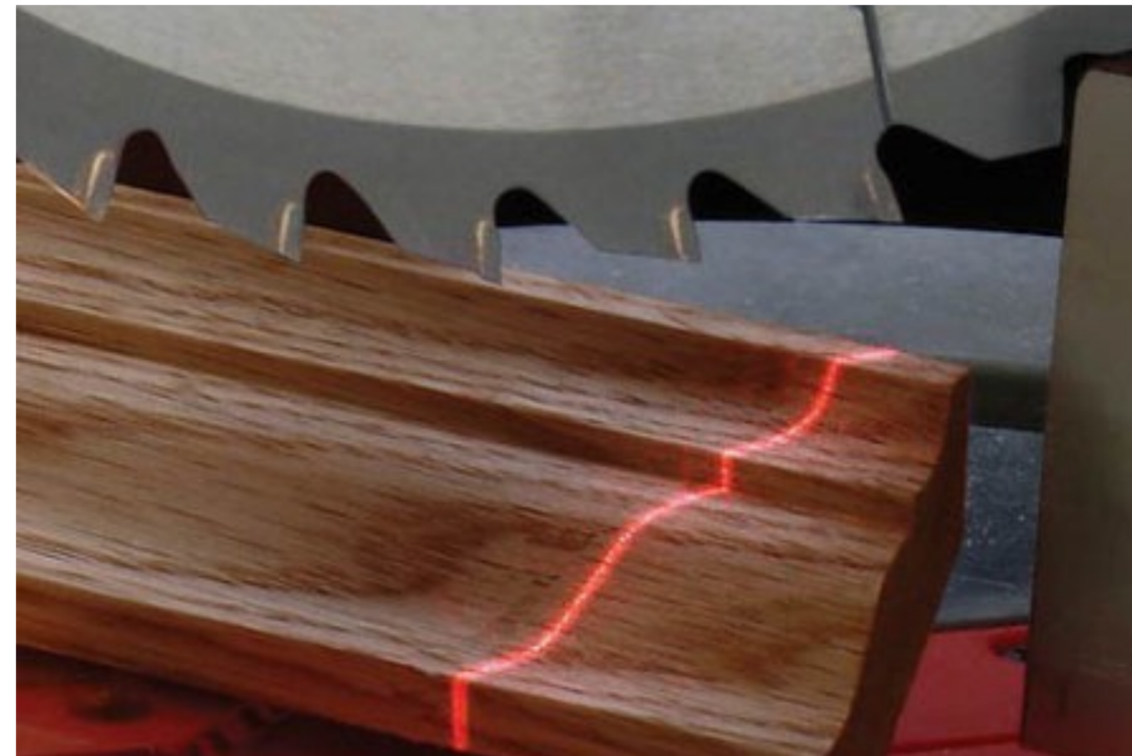
Pisa, 

Visible lasers

Countless applications in science and society

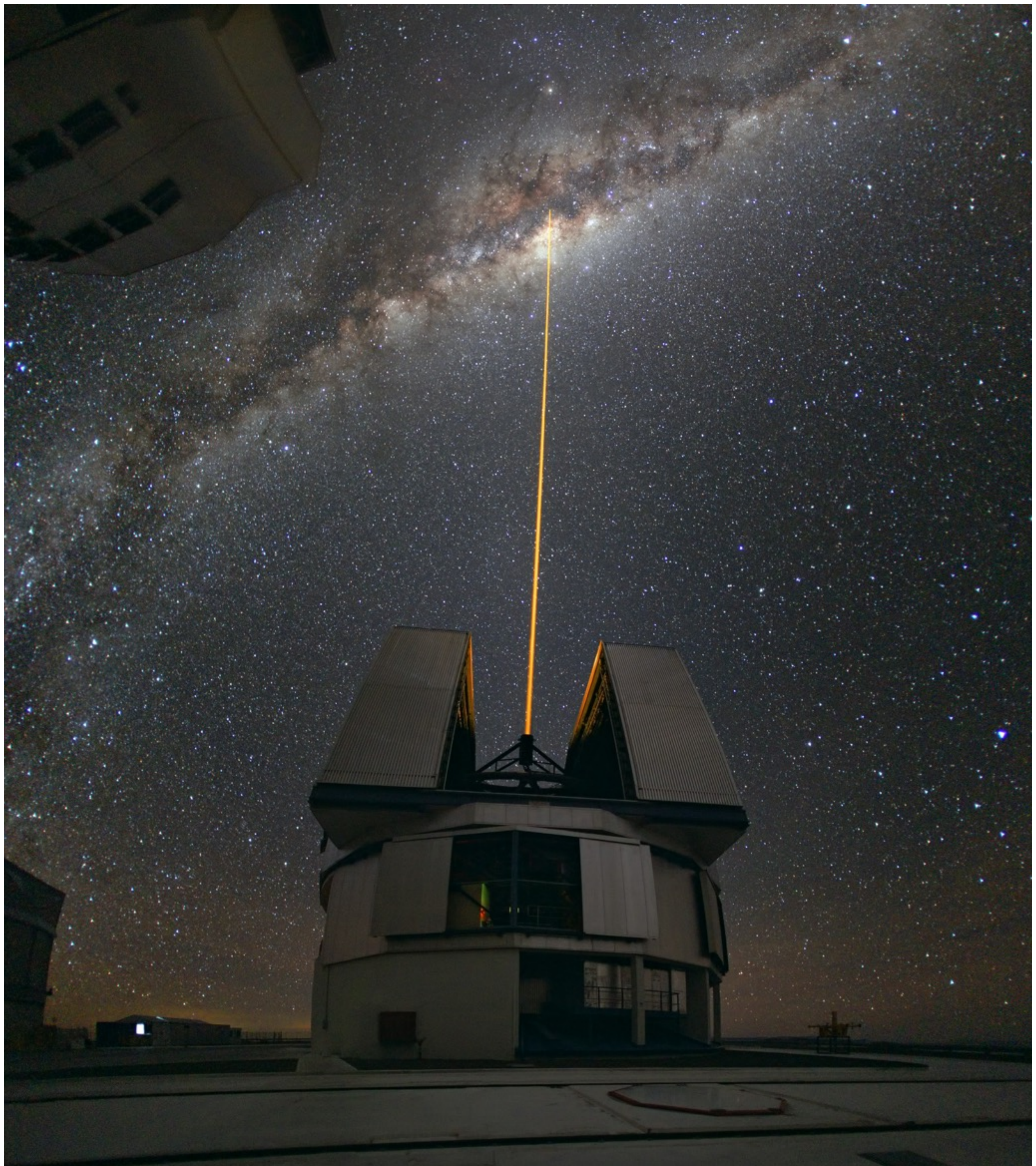


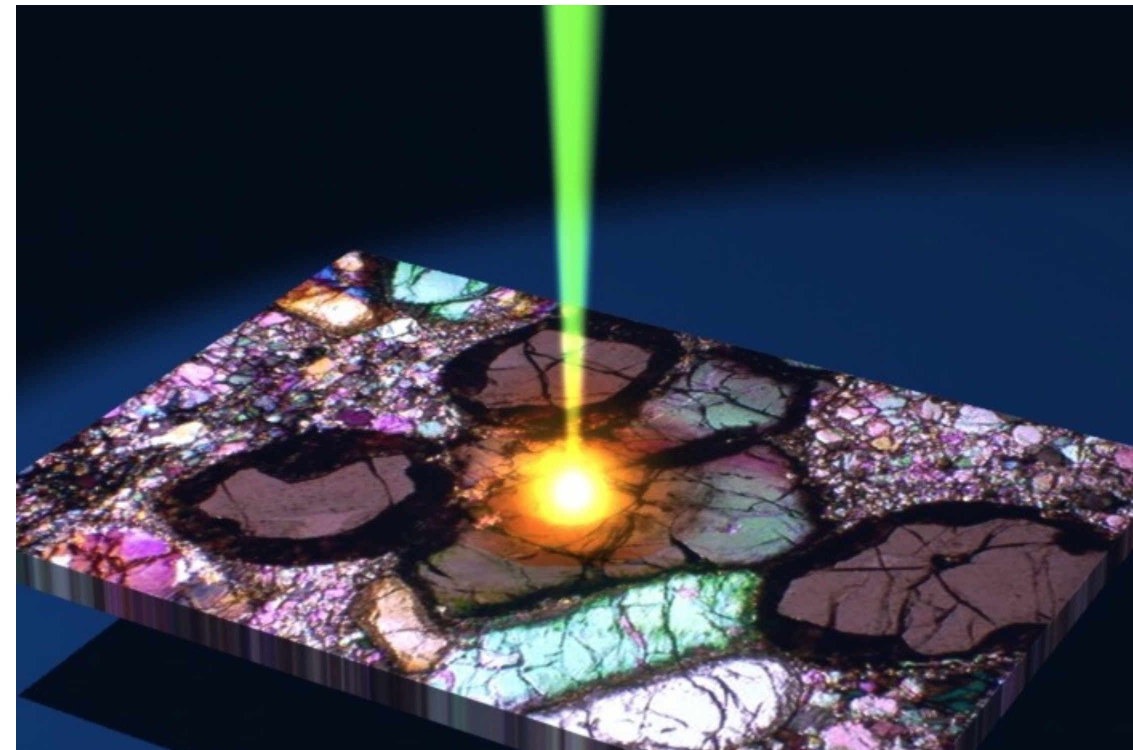


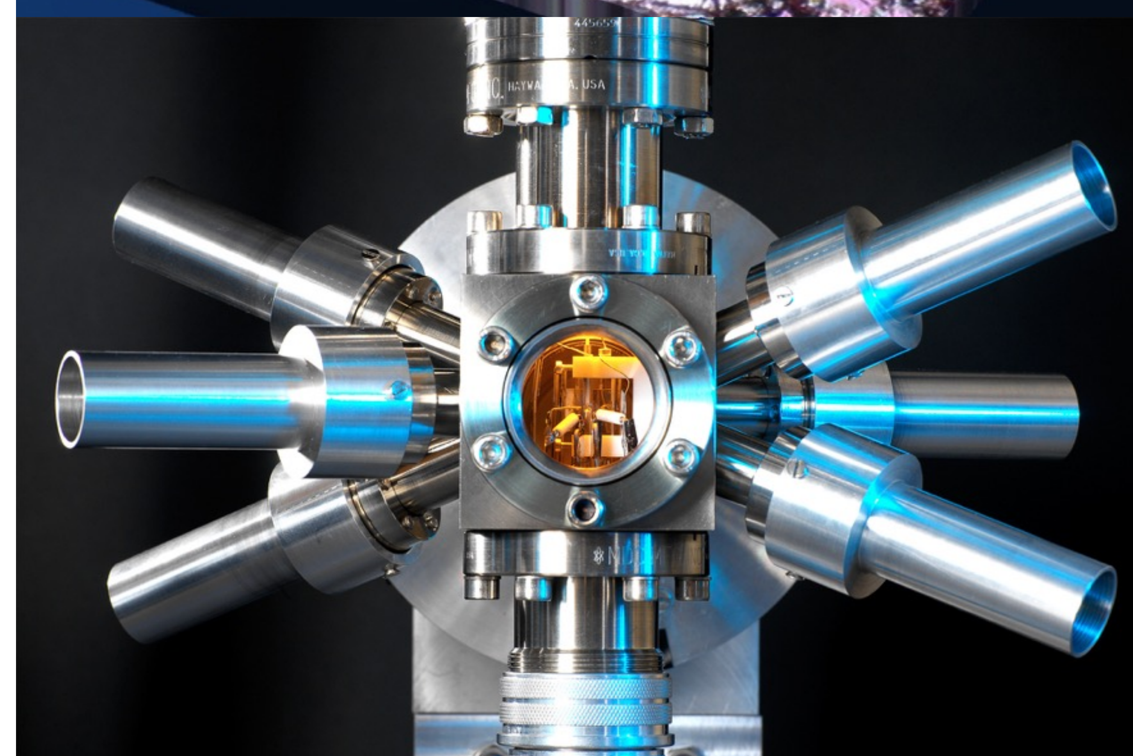


Visible lasers

Countless applications in science and society

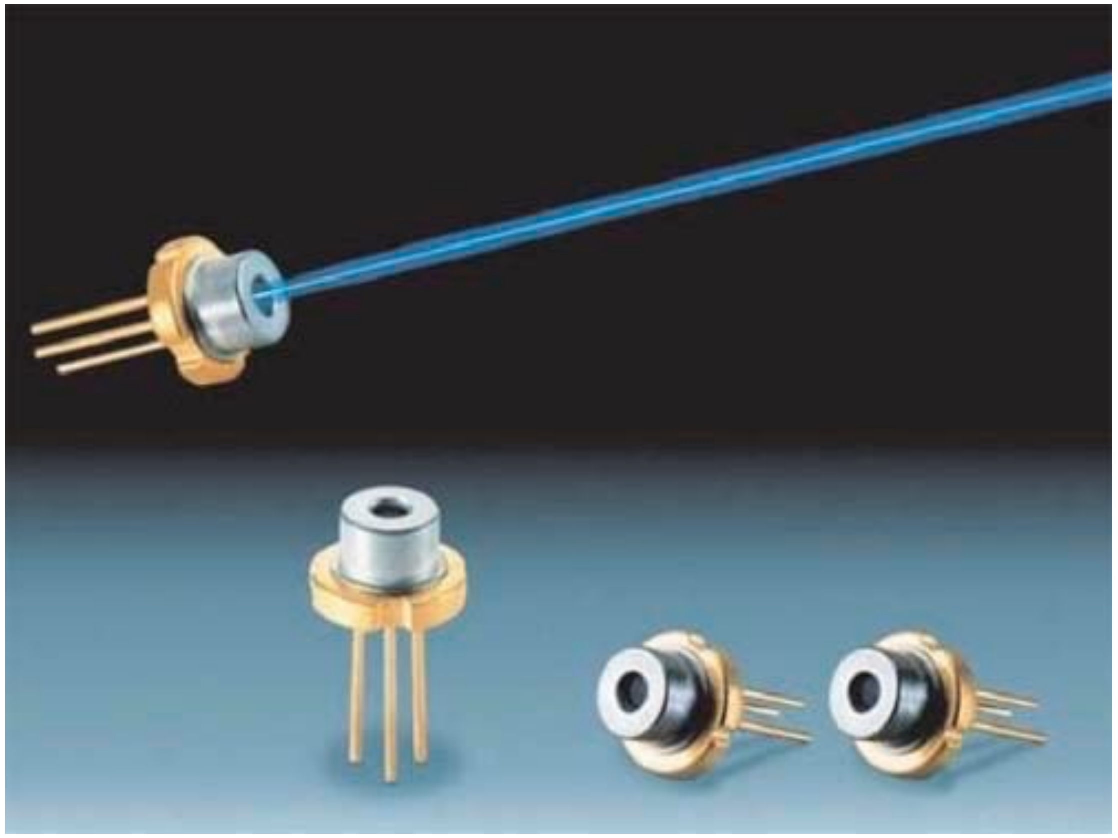


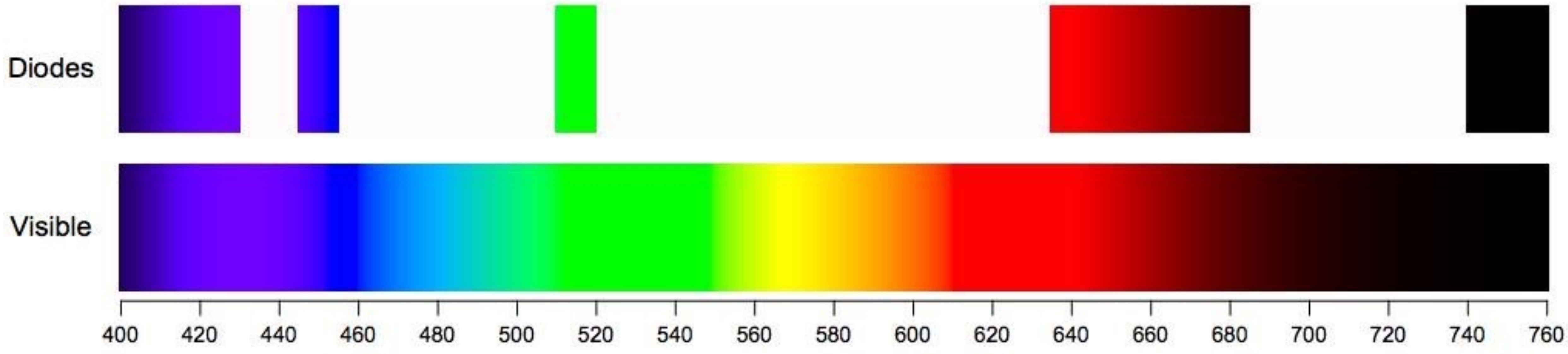




Visible lasers

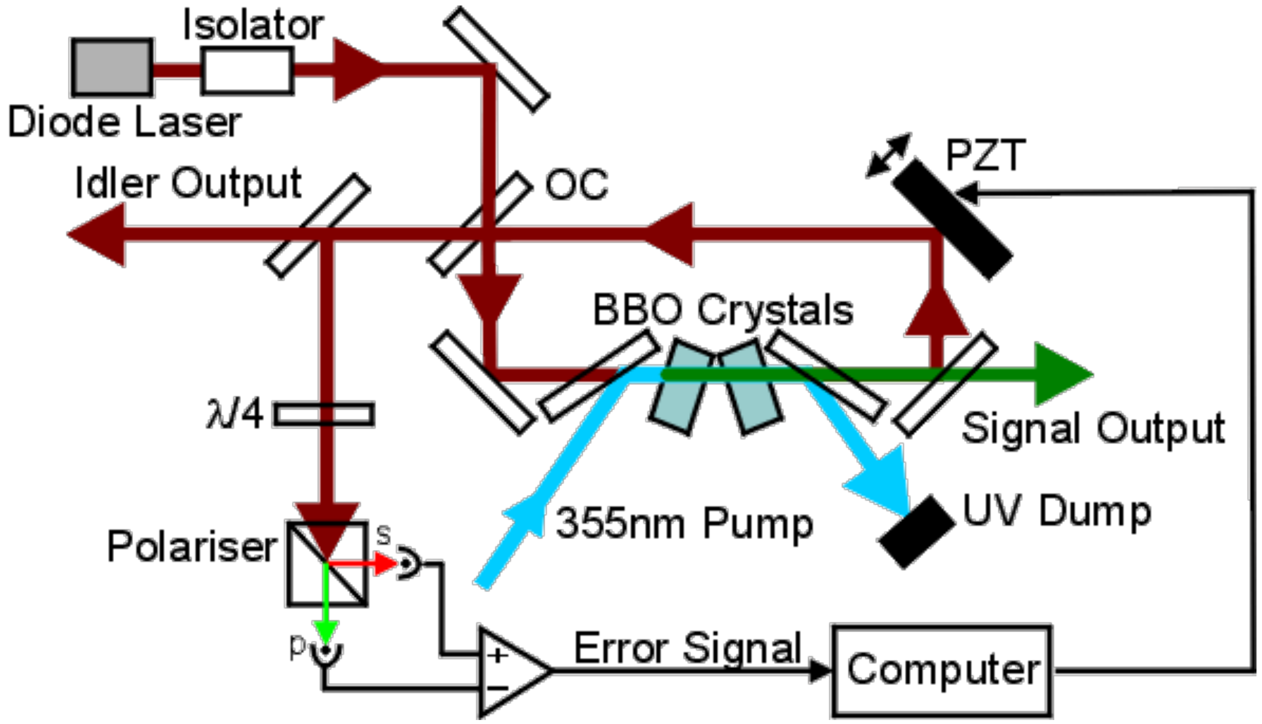
Only a narrow subset of wavelength is easily available

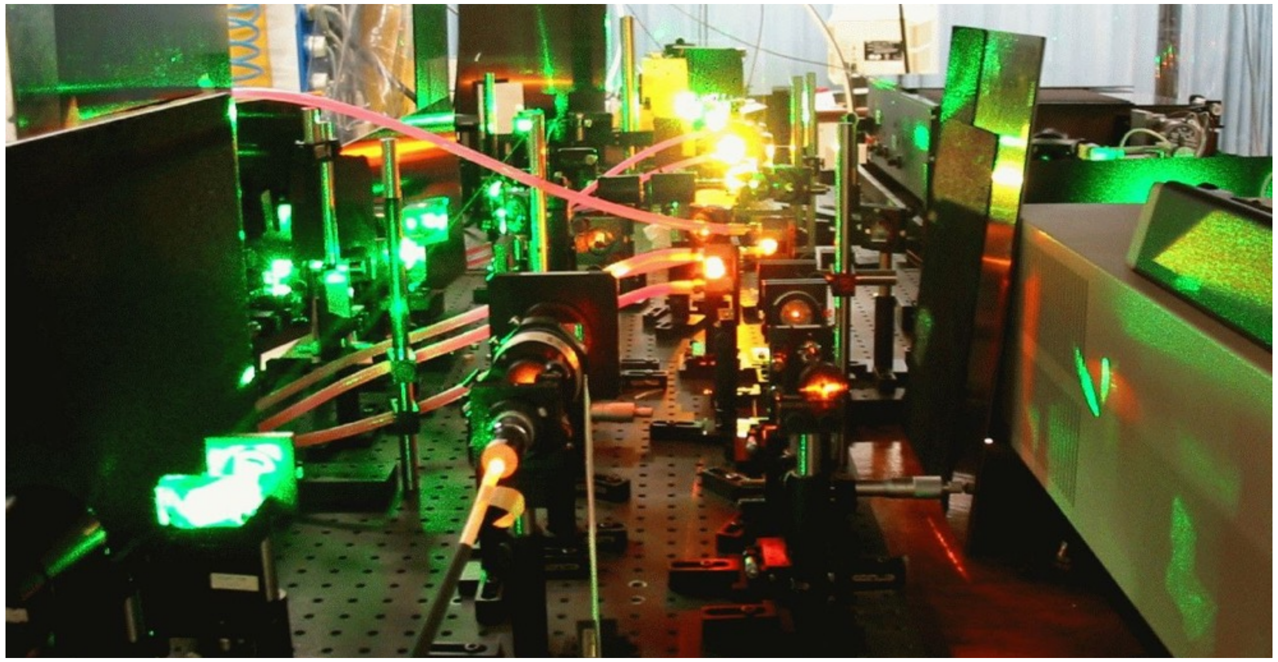


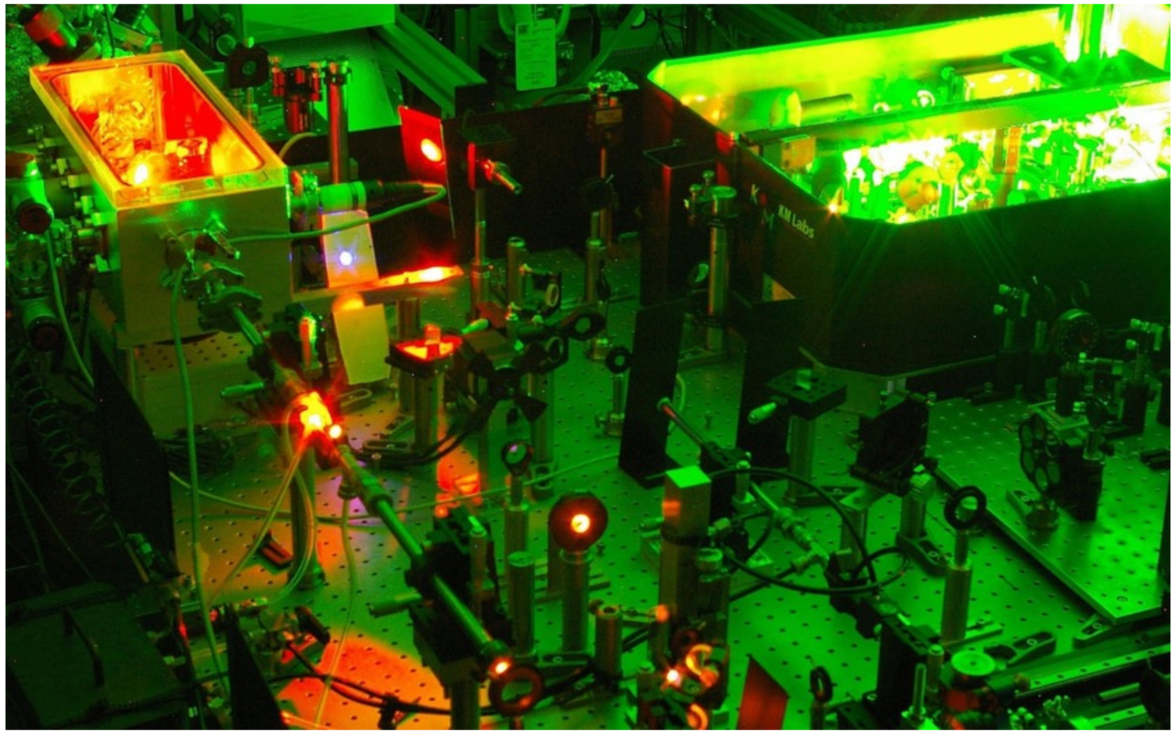


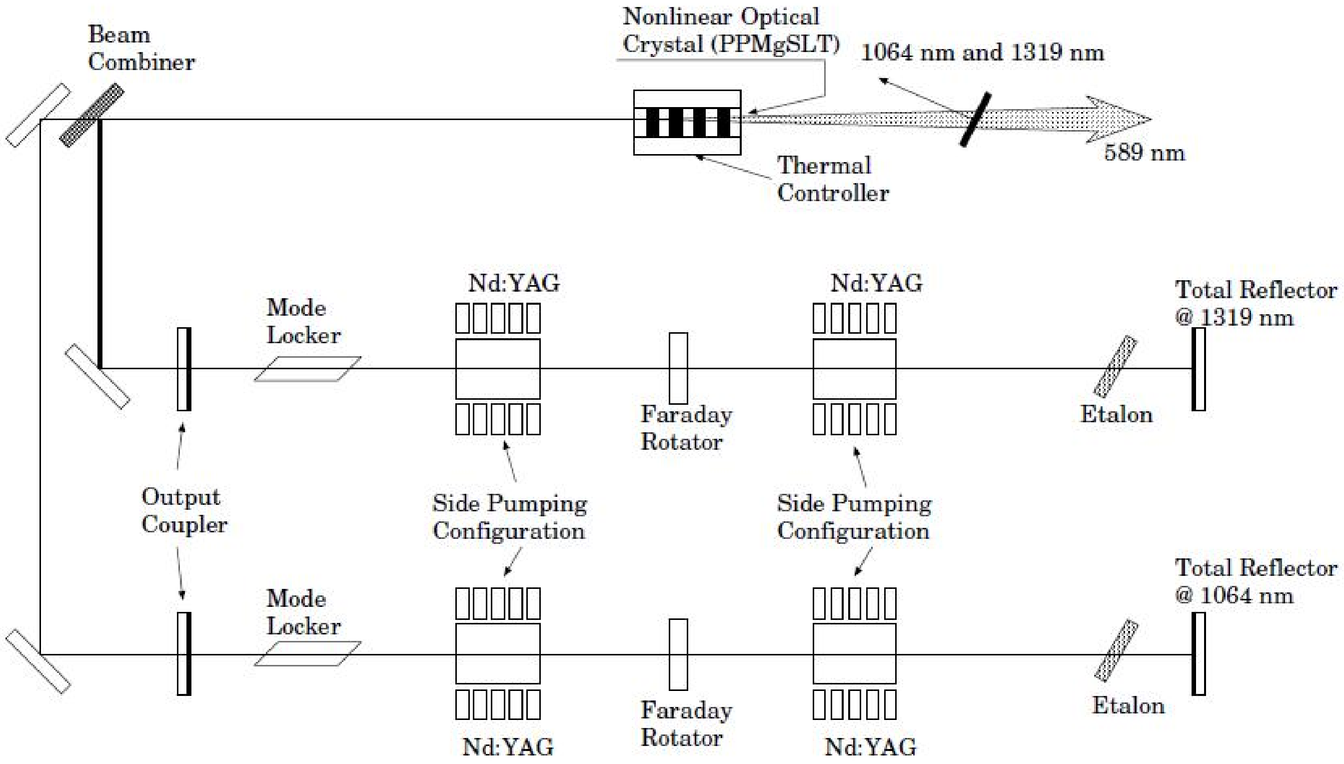
Visible lasers

Often produced with complex and expensive sources



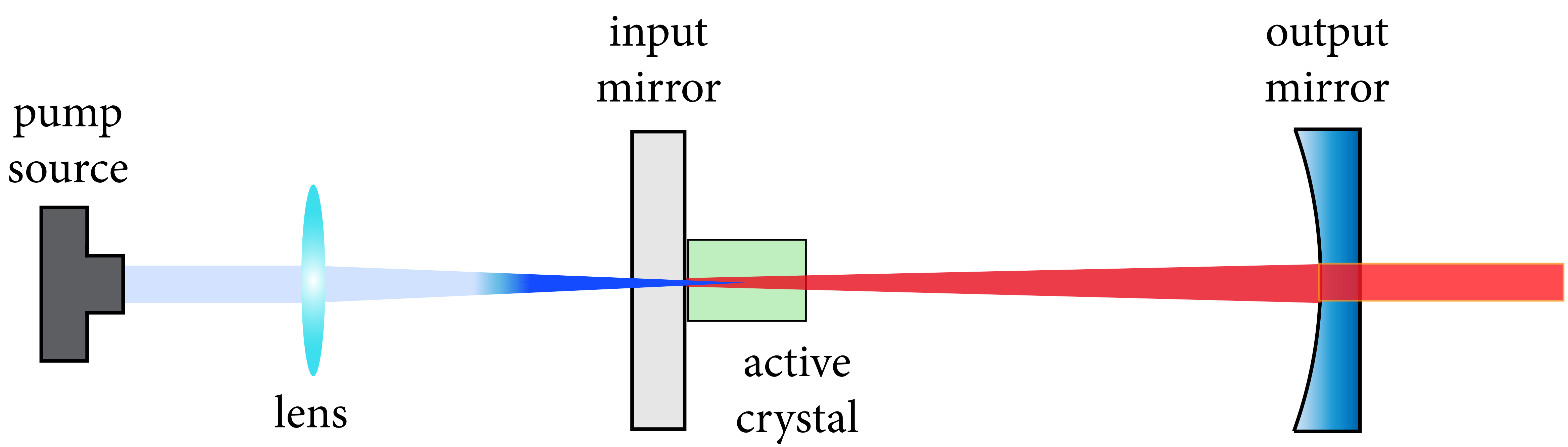




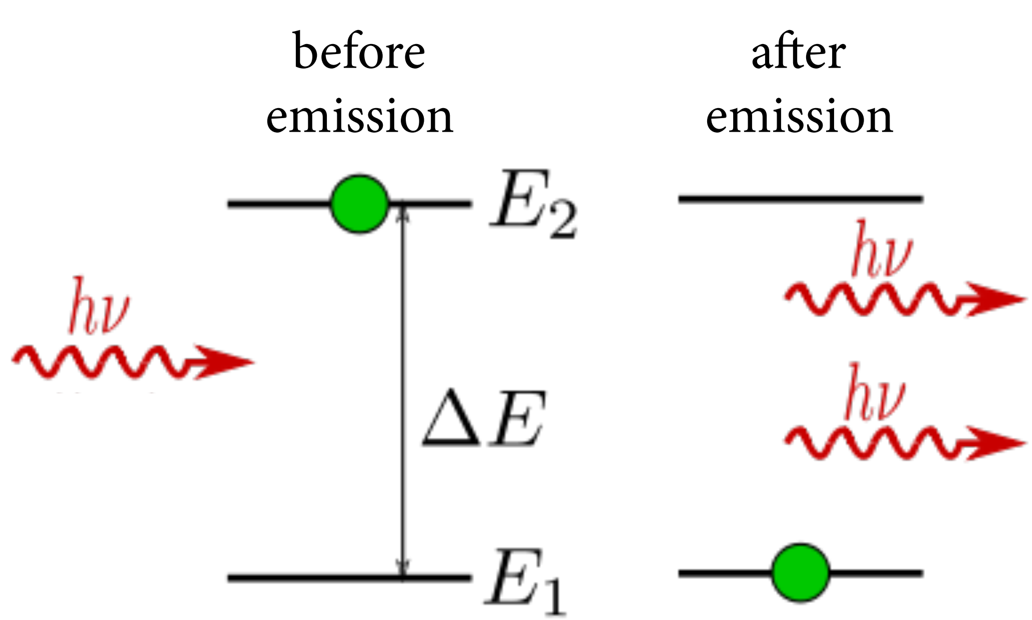


Solid-state visible lasers

Based on transparent solids doped with active elements



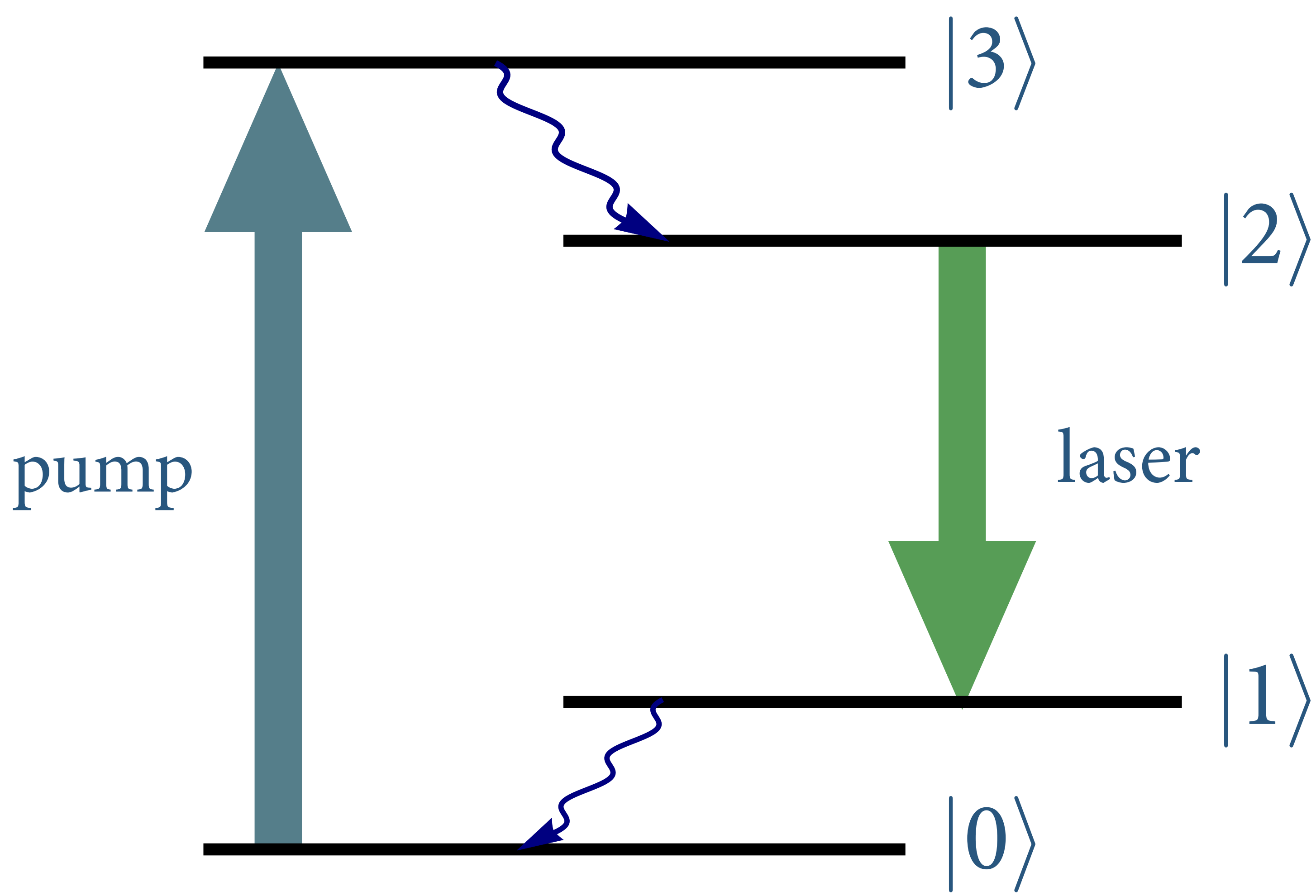
transmittance $T = \frac{P_{out}}{P_{in}}$



- Less complex setups
- High quality output beams
- Optically pumped

4-level laser scheme

Efficiency, threshold, and influence of passive losses



Stationary conditions

$$P_{out} = \eta(P_{abs} - P_{thr})$$

Slope efficiency

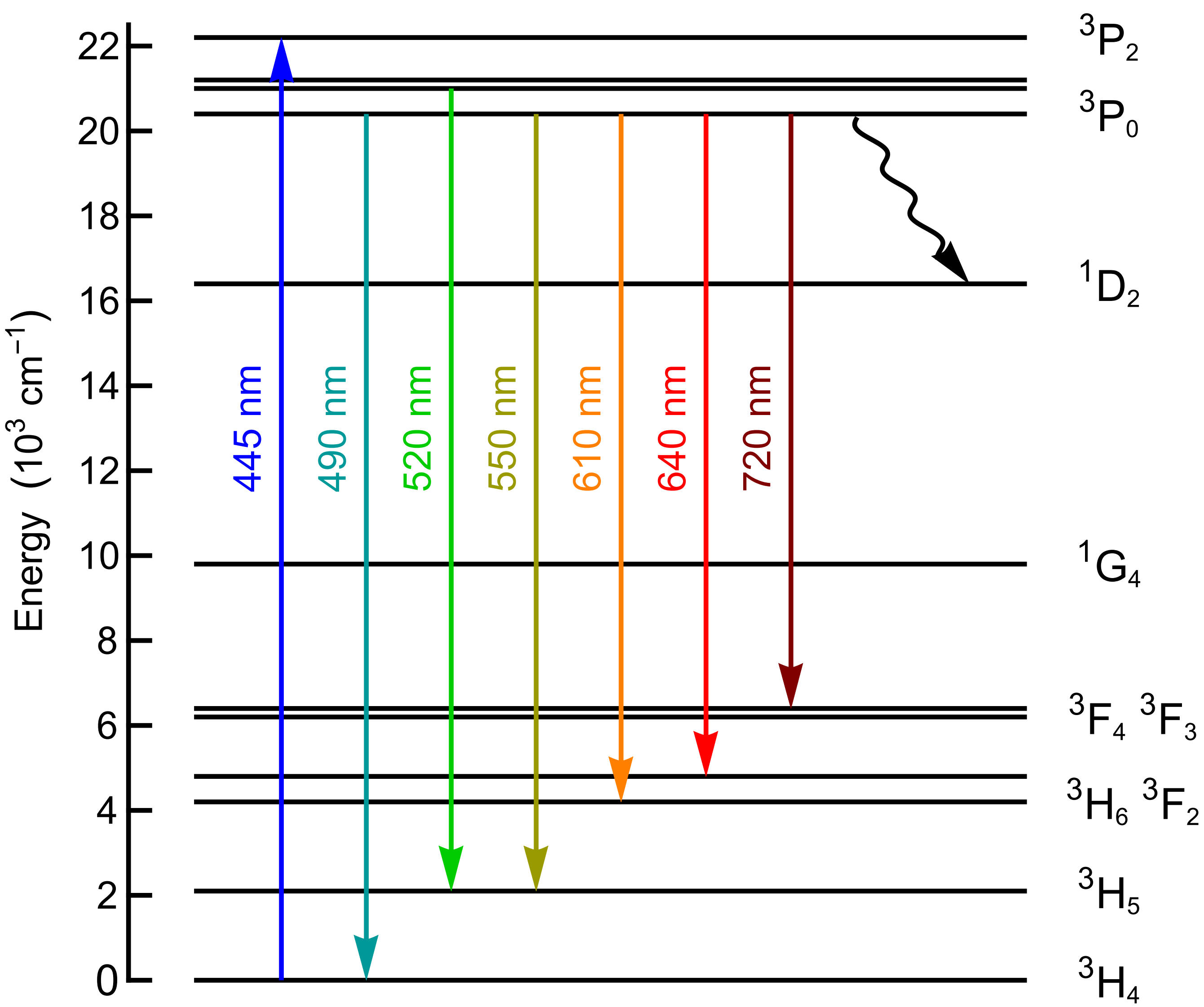
$$\eta = \eta_{sys} \frac{T}{T + L}$$

Threshold power

$$P_{thr} = P_{sys}(T + L)$$

Praseodymium trivalent ion

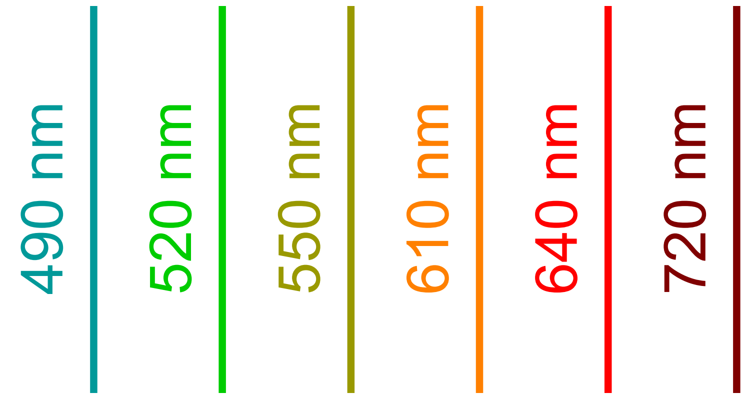
Suitable for laser emission along the whole visible region



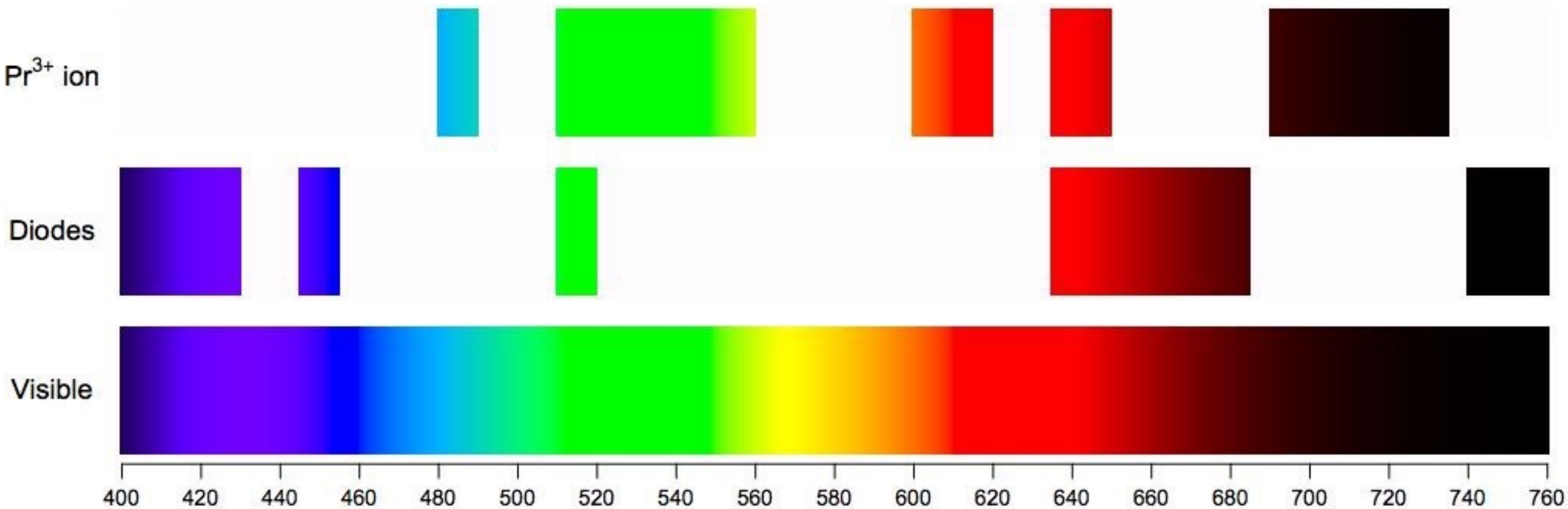
- Absorbs in the blue region from compact laser diodes
- Multiple emission lines with 3- and 4-level schemes
- Wavelengths and intensities sensitive to host material
- Non-radiative decays can deplete population inversion

Praseodymium trivalent ion

Suitable for laser emission along the whole visible region



Emission spectrum complementary to laser diodes



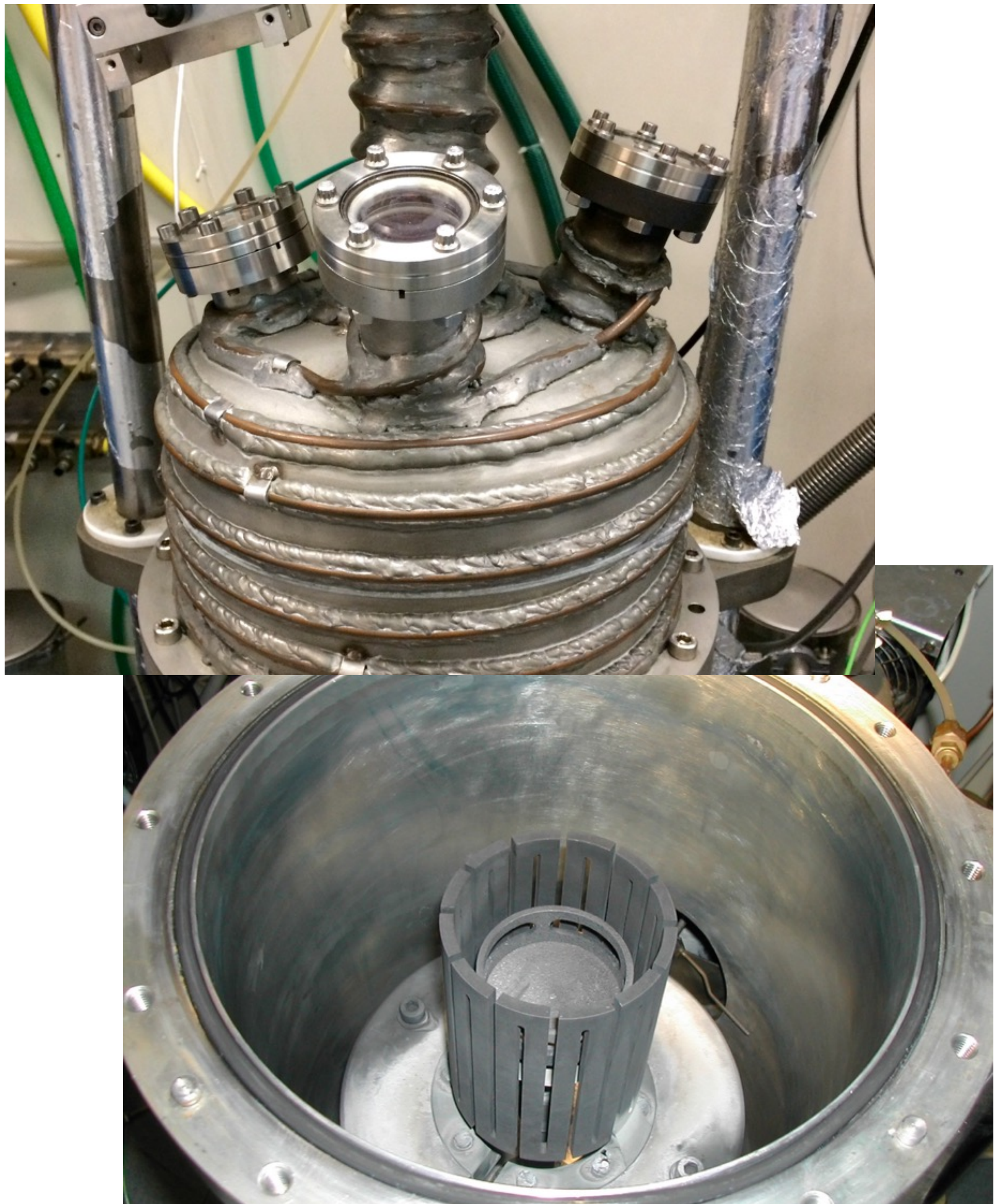
Fluoride crystals

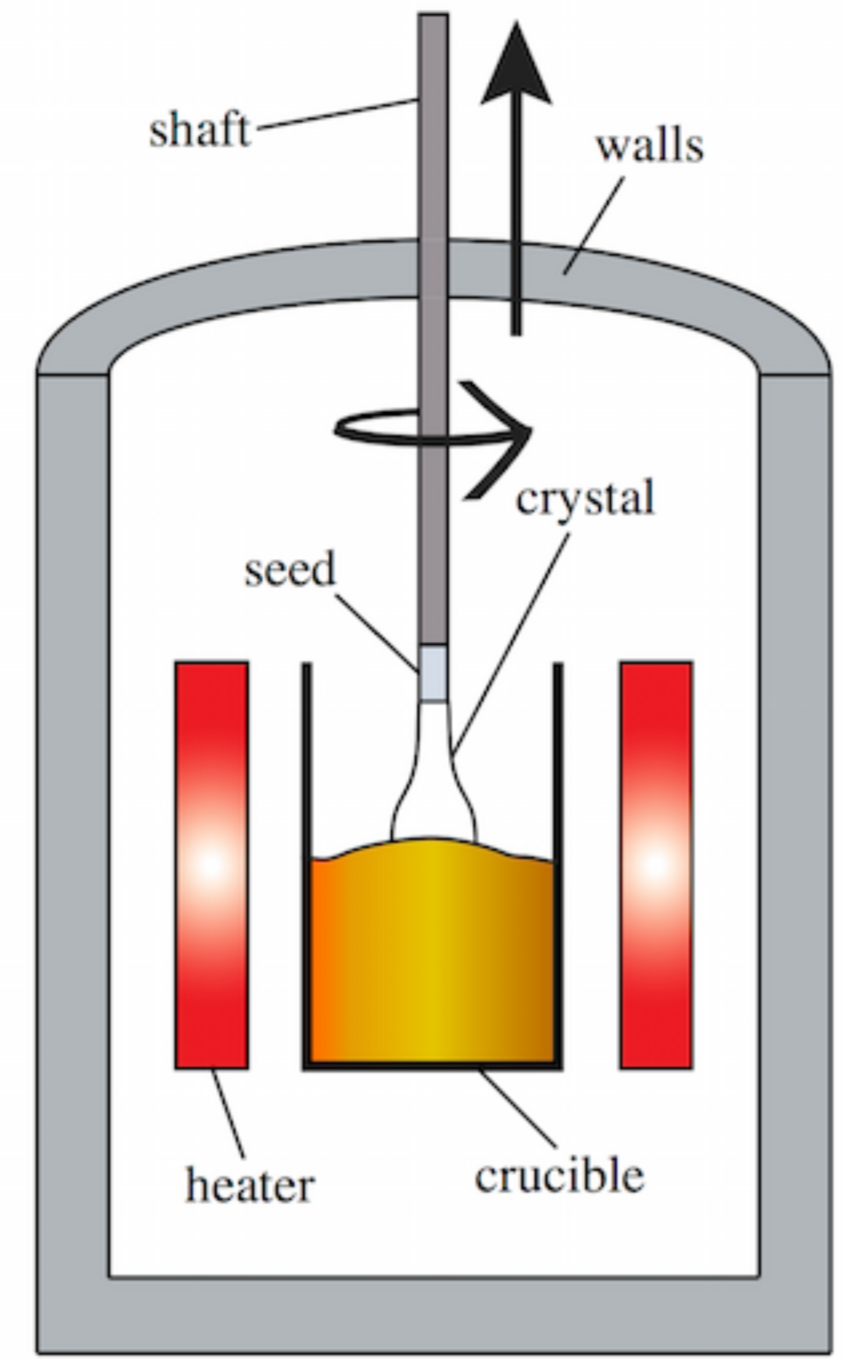
Preferred choice for visible solid-state lasers

- ✓ Non-hygroscopic and stable
- ✓ Wide transparency windows
- ✓ Reduce non-radiative decays
- ✓ Suitable for Pr-doping
- ✗ More complex to grow
- ✗ More expensive

Czochralski method

Custom-made furnace designed to achieve high quality





Czochralski method

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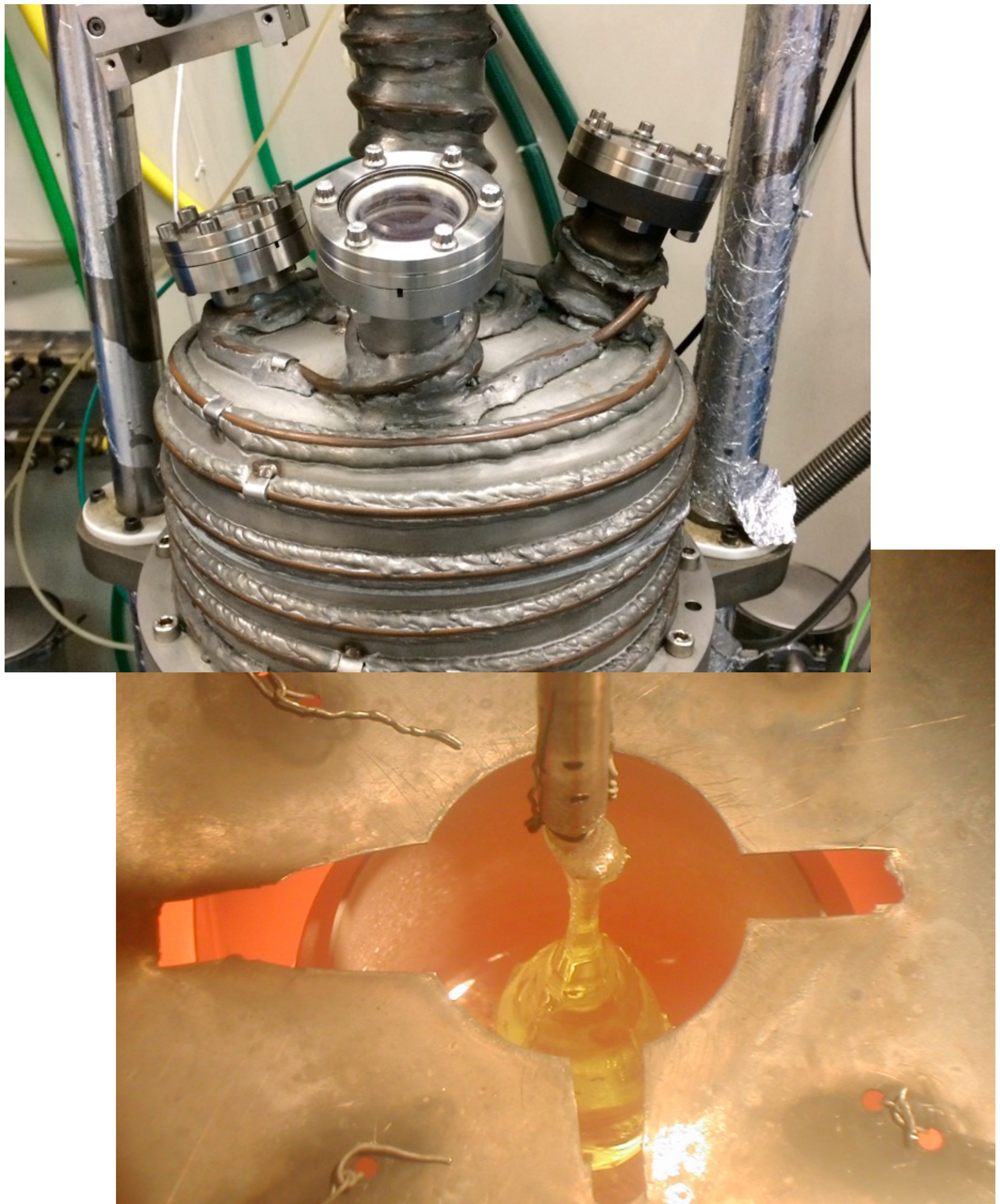
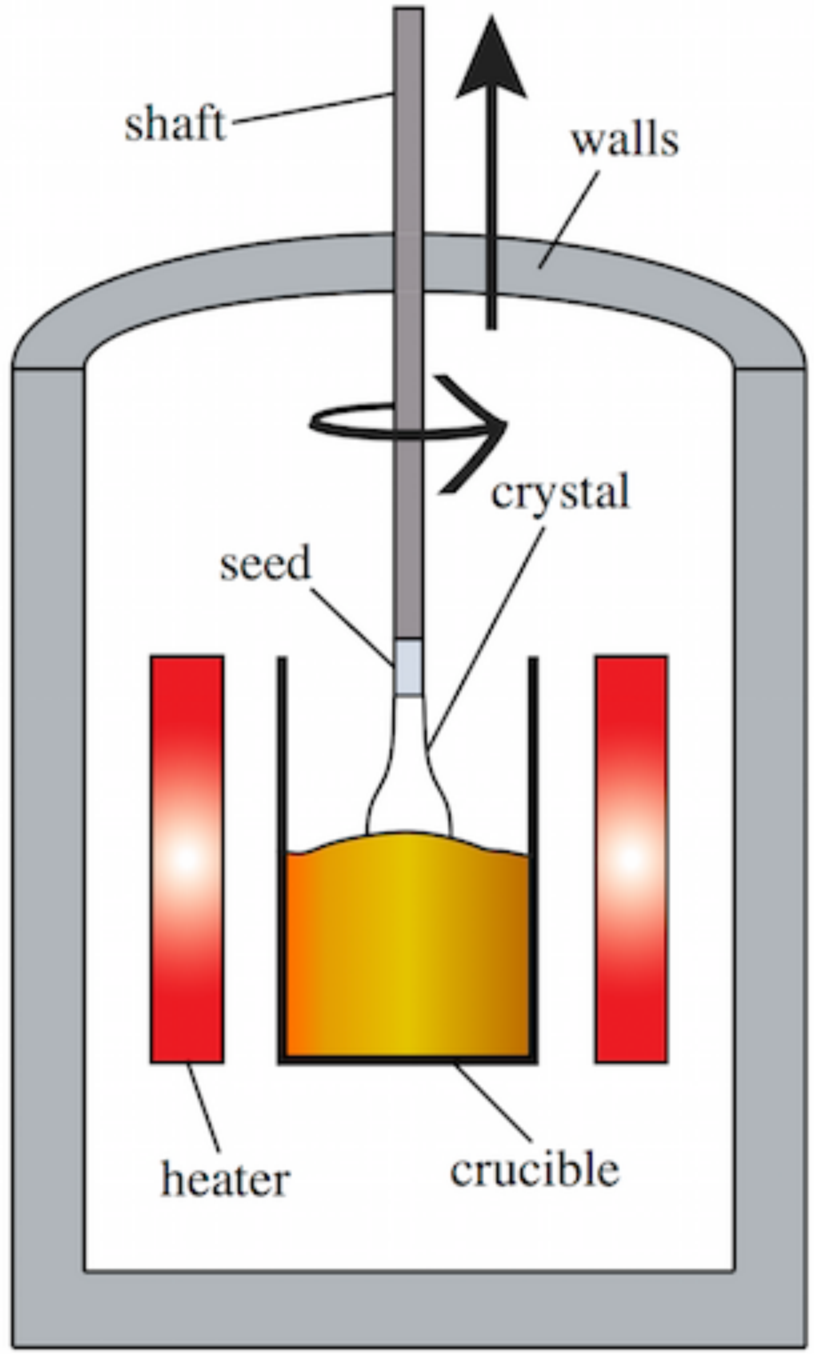


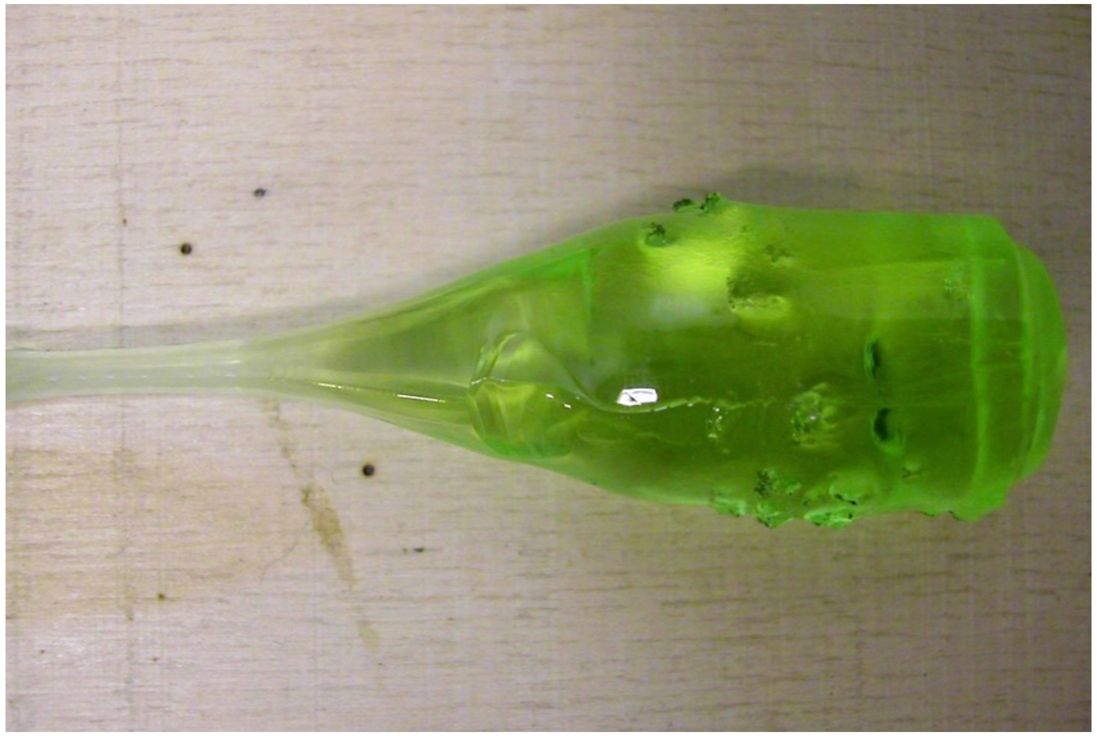


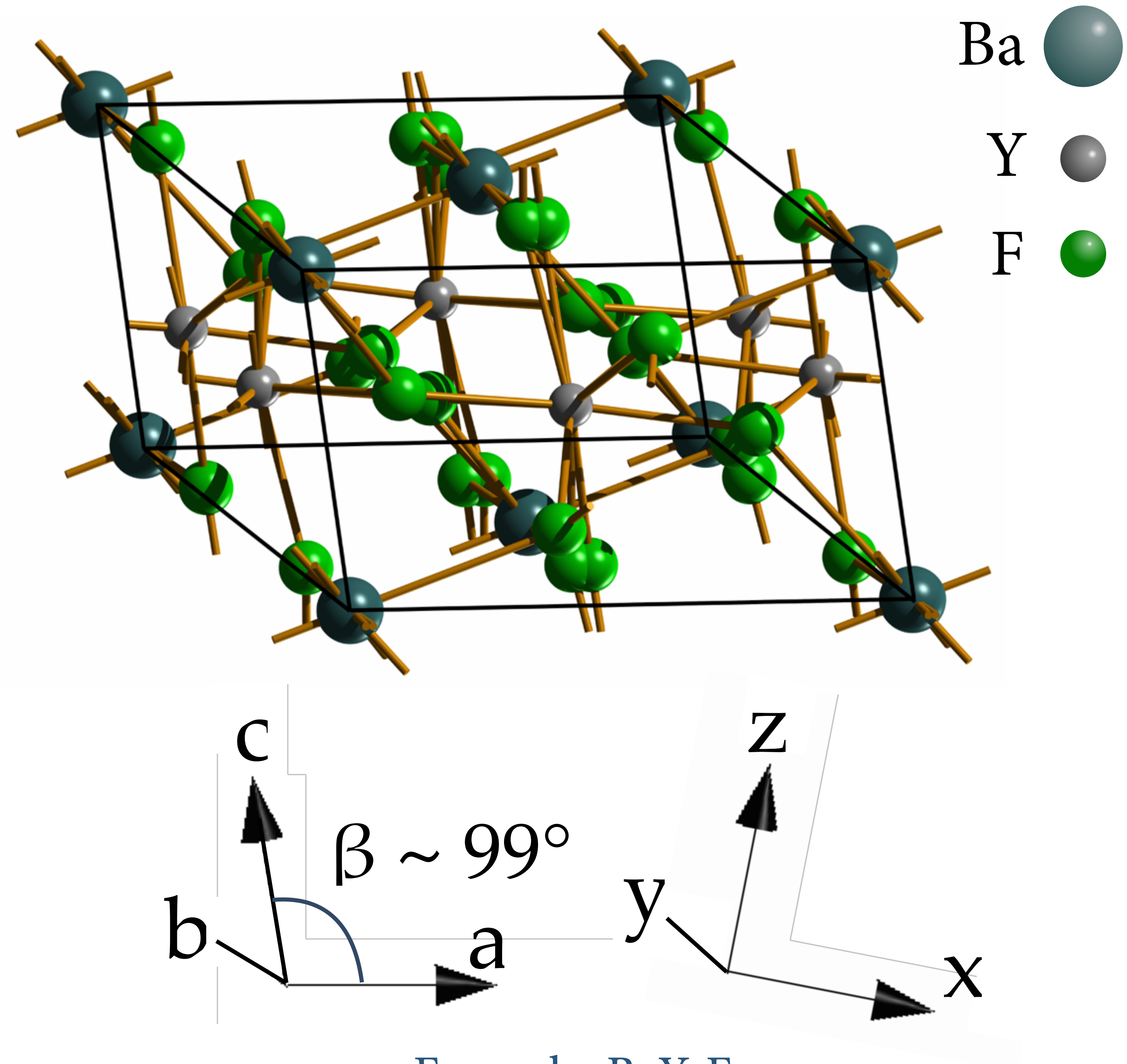
Multiple polarization orange and red lasers in Pr-doped Barium Yttrium Fluoride (BYF)

Pr:BYF orange and red lasers

Barium Yttrium Fluoride (BYF) structure and properties

- Monoclinic structure
- Three different optic axes
- Multiple emission spectra



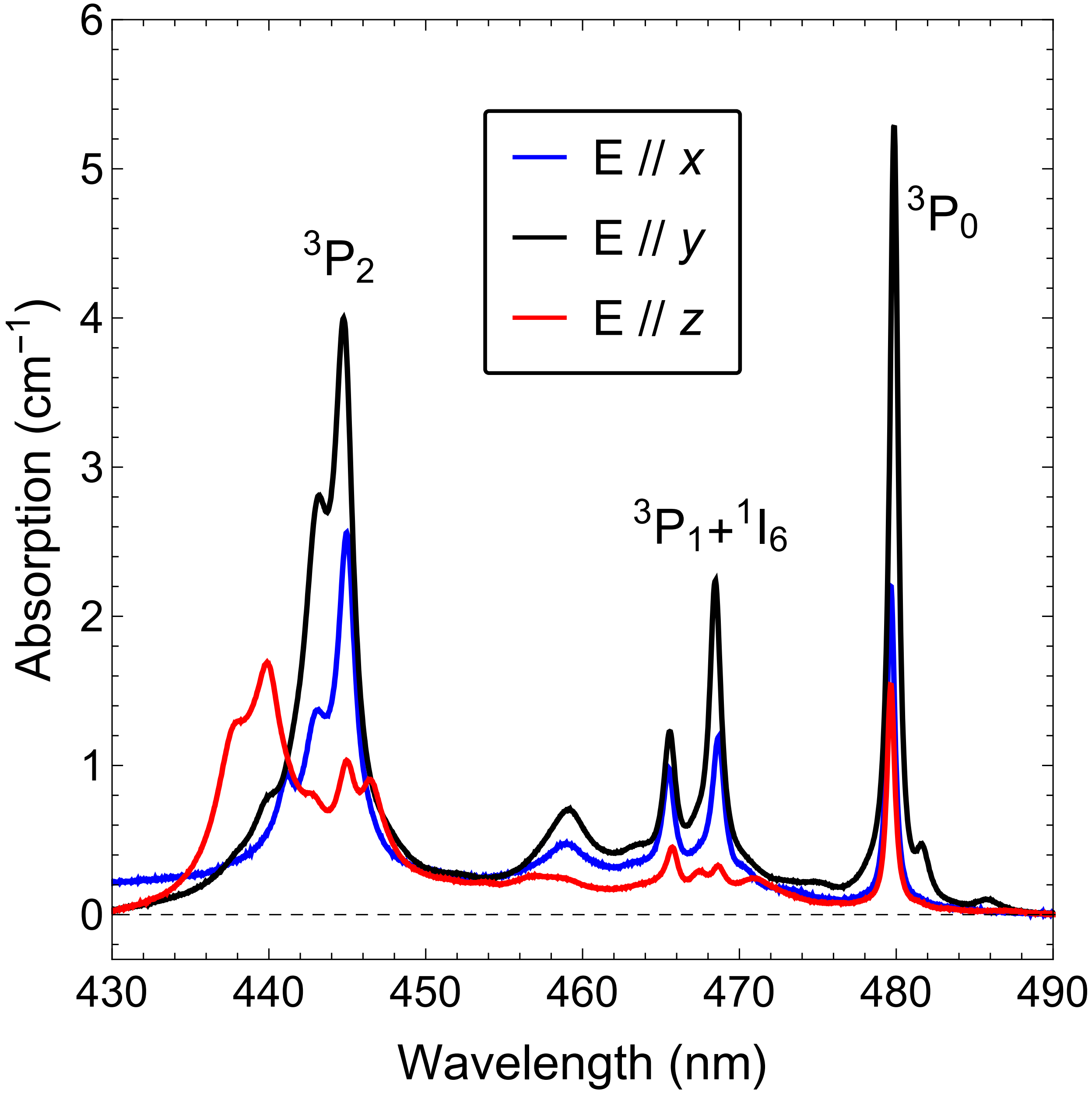


Formula: BaY_2F_8

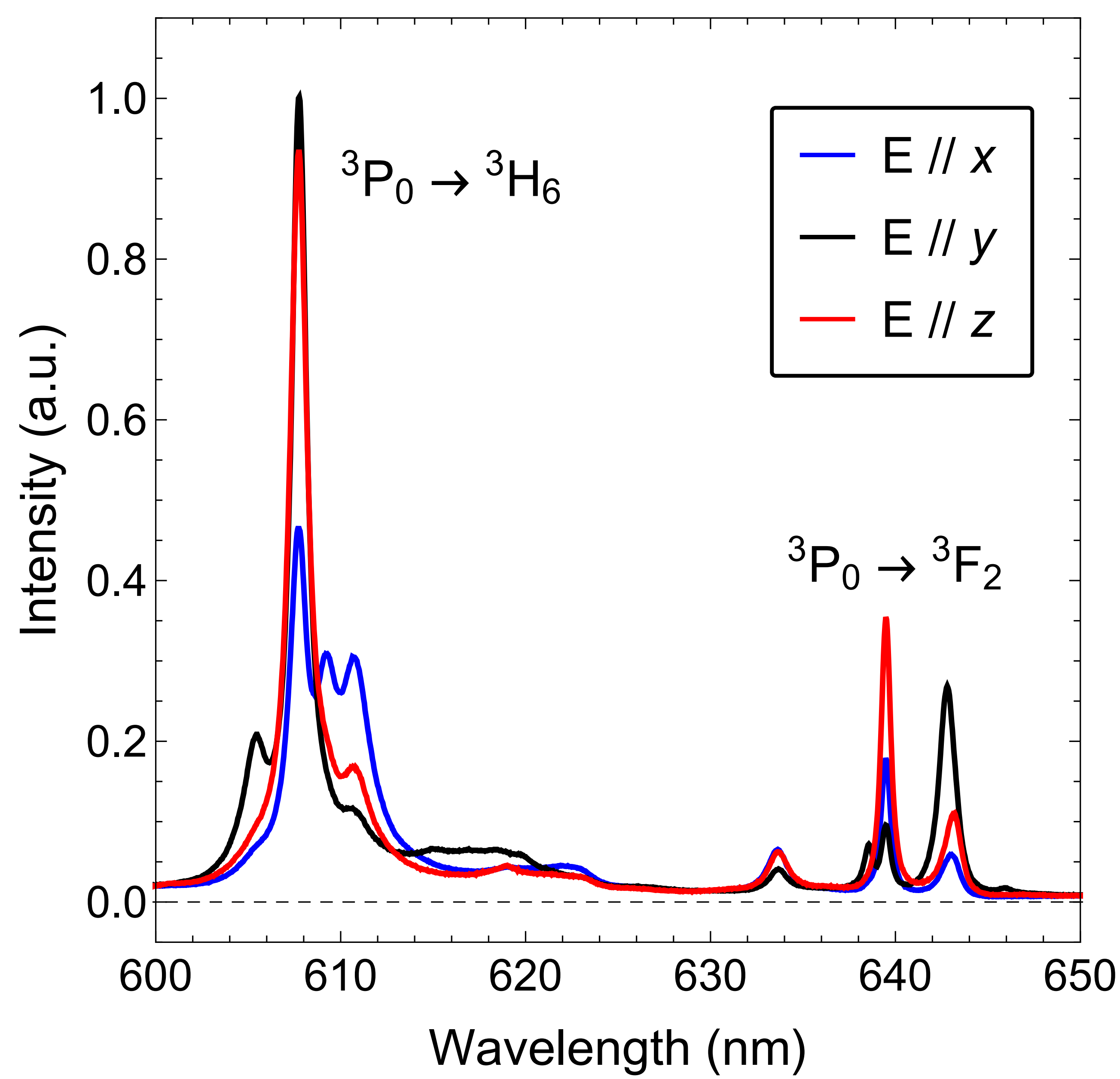
Pr:BYF orange and red lasers

Suitable for GaN diode pumping and visible emissions

Absorption spectra

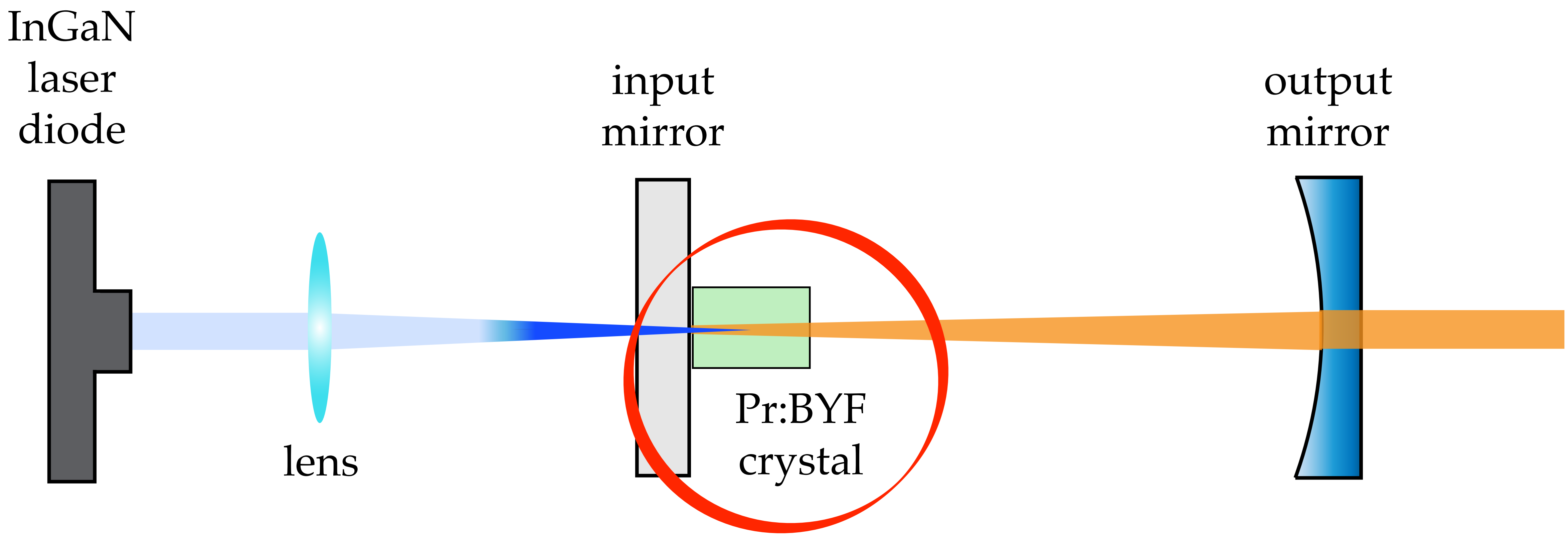


Emission spectra

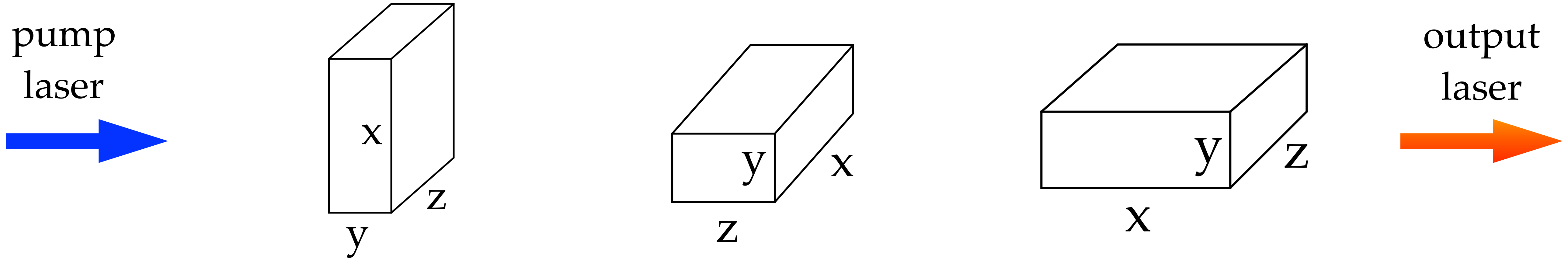


Pr:BYF orange and red lasers

Diode-pumped hemispherical resonant cavity

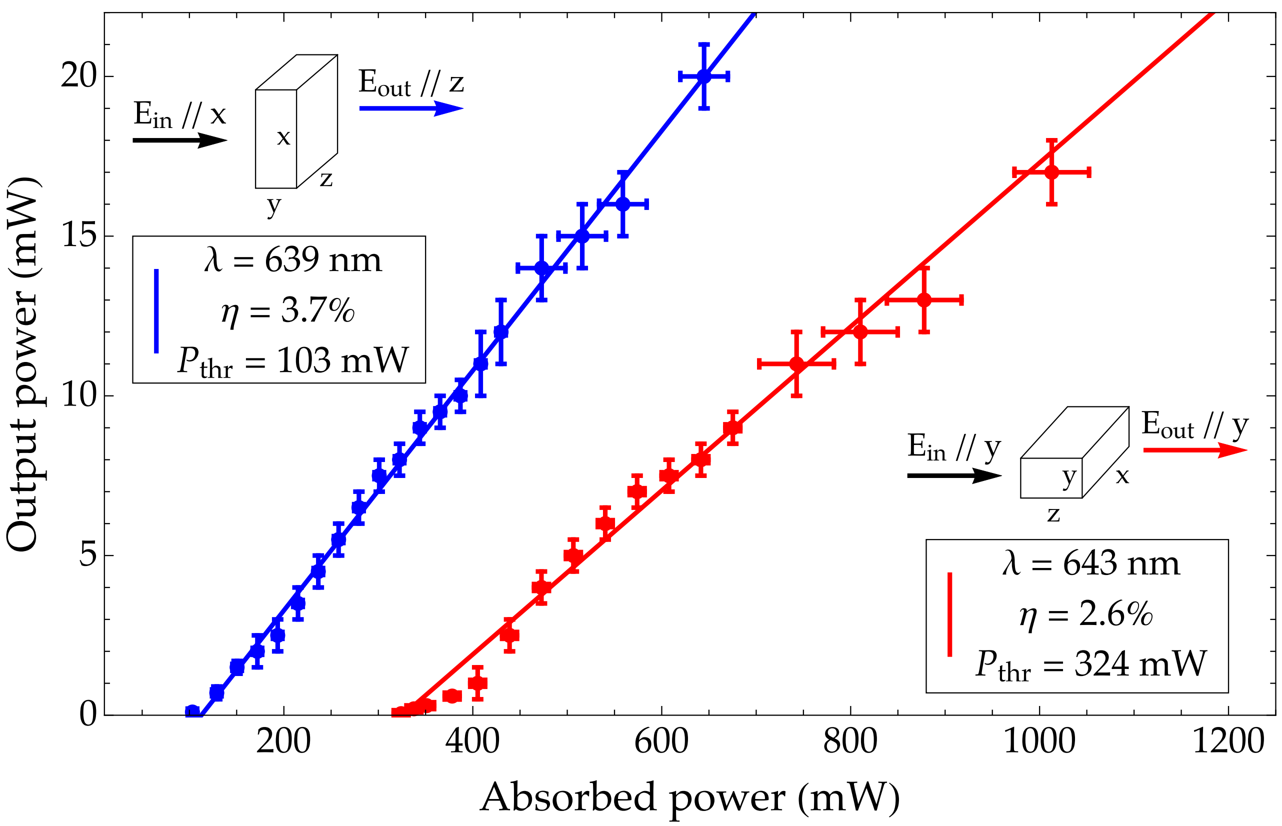


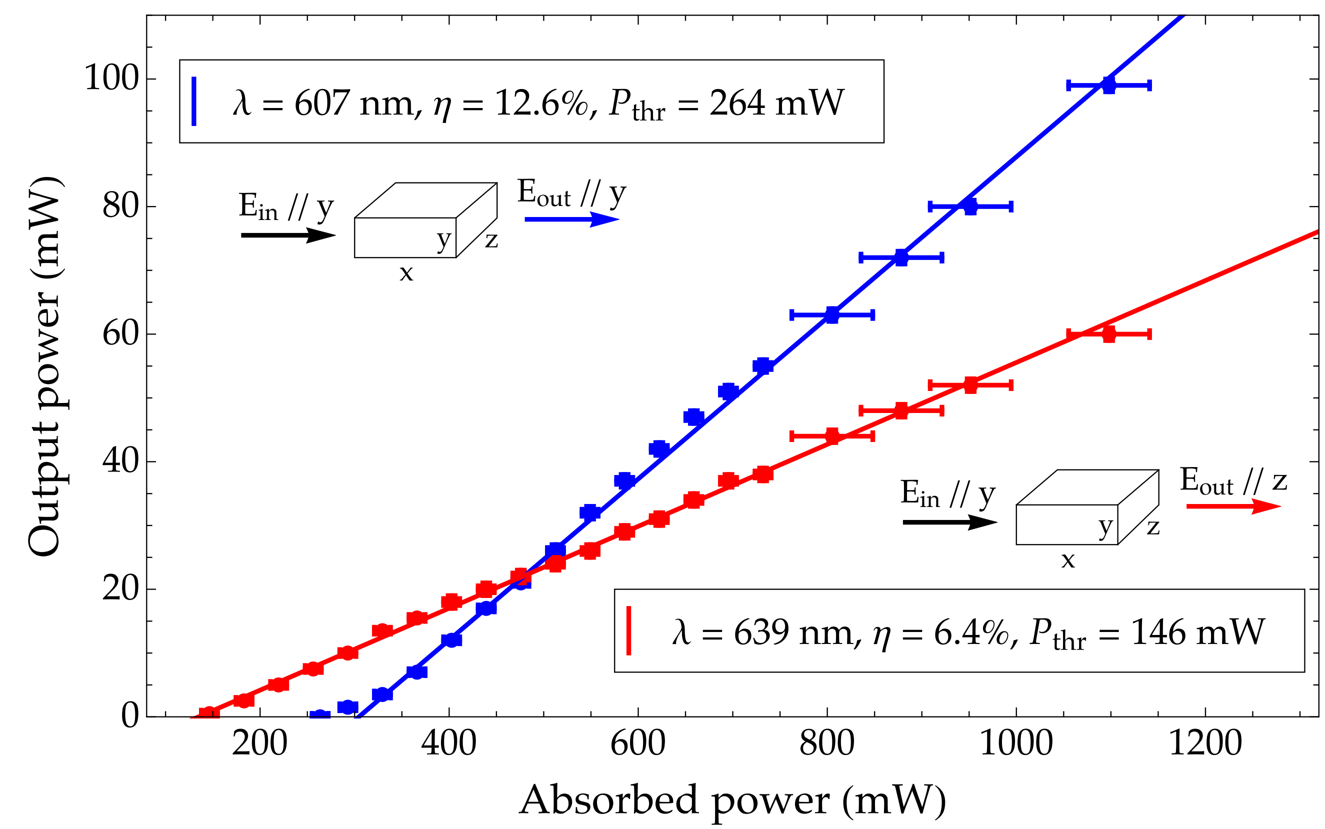
Multiple crystal orientations to select emission polarization



Pr:BYF orange and red lasers

Laser results for all the transitions in the region



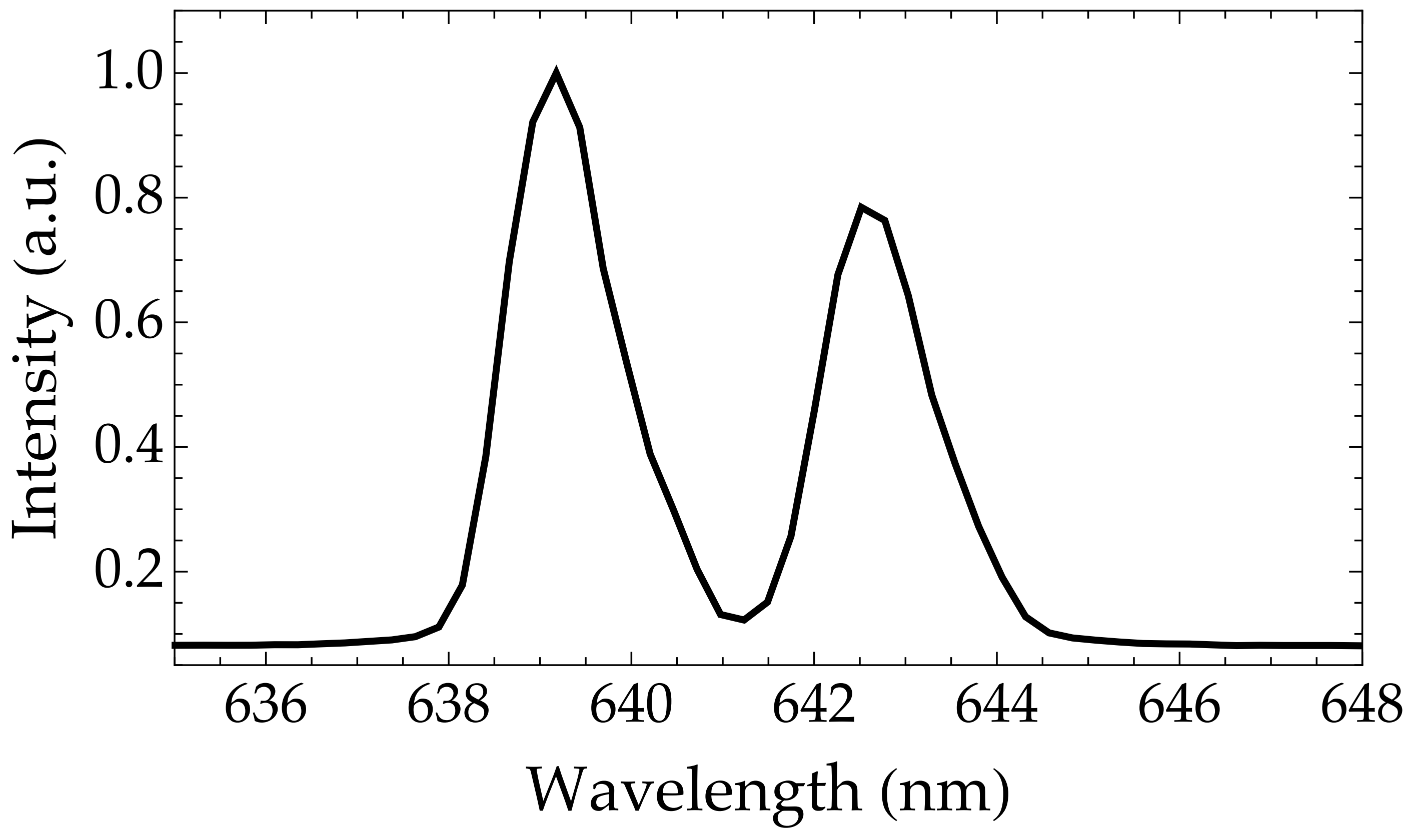


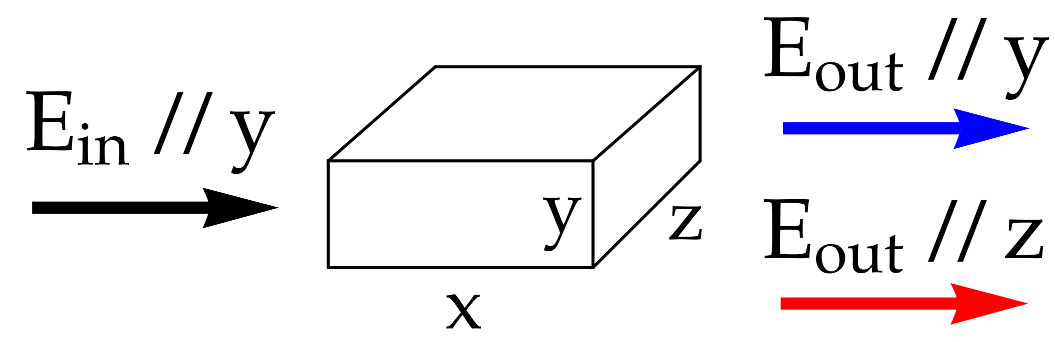
	Abs. power	T	λ	E_{out}	W_{max}
x-y orientation $E_{in} \parallel y$	79%	5%	607 nm	y-axis	64 mW
		0.5%	643 nm	y-axis	17 mW
x-z orientation $E_{in} \parallel x$	50%	5%	607 nm	z-axis	30 mW
		0.5%	639 nm	z-axis	20 mW
y-z orientation $E_{in} \parallel y$	86%	5%	607 nm	y-axis	99 mW
				z-axis	80 mW
		0.5%	639 nm	z-axis	60 mW
			643 nm	y-axis	45 mW

- Test of all available input and output polarizations
- 643 nm laser emission observed for the first time

Pr:BYF orange and red lasers

Simultaneous laser emissions of two lines





- Orthogonally polarized
- **Orange**: same wavelength
- **Red**: difference is in the Terahertz region

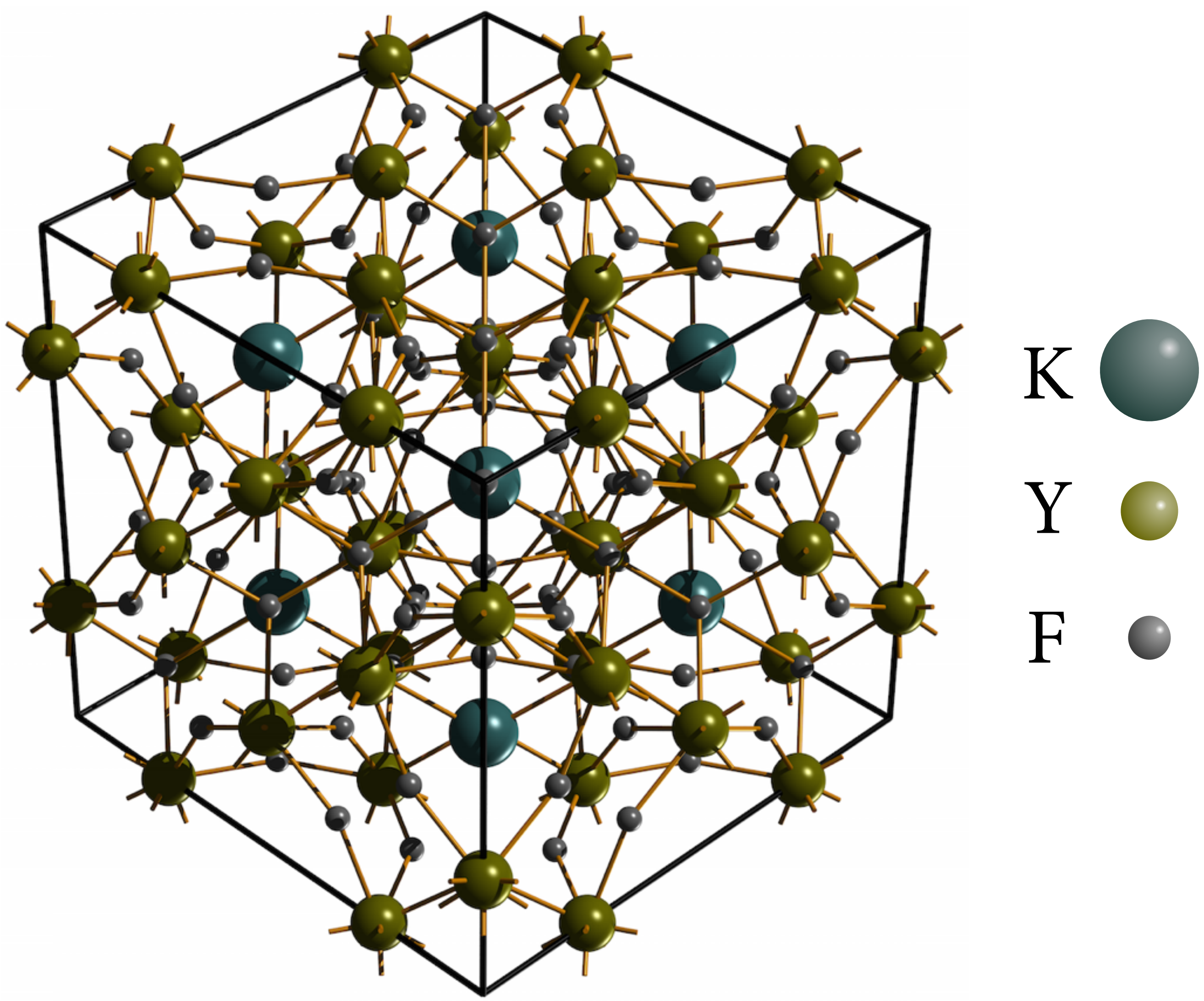
	Abs. power	T	λ	E_{out}	W_{max}
y-z orientation $E_{in} \parallel y$	86%	5%	607 nm	y-axis	45 mW
				z-axis	40 mW
		0.5%	639 nm	z-axis	26 mW
			643 nm	y-axis	22 mW

A. Sottile et *al.*, Opt. Express **22**, 13784 (2014)

Deep red laser emission in Pr-doped Potassium Yttrium Fluoride (KYF)

Pr:KYF deep red laser

KYF is the only fluoride laser crystal with cubic symmetry



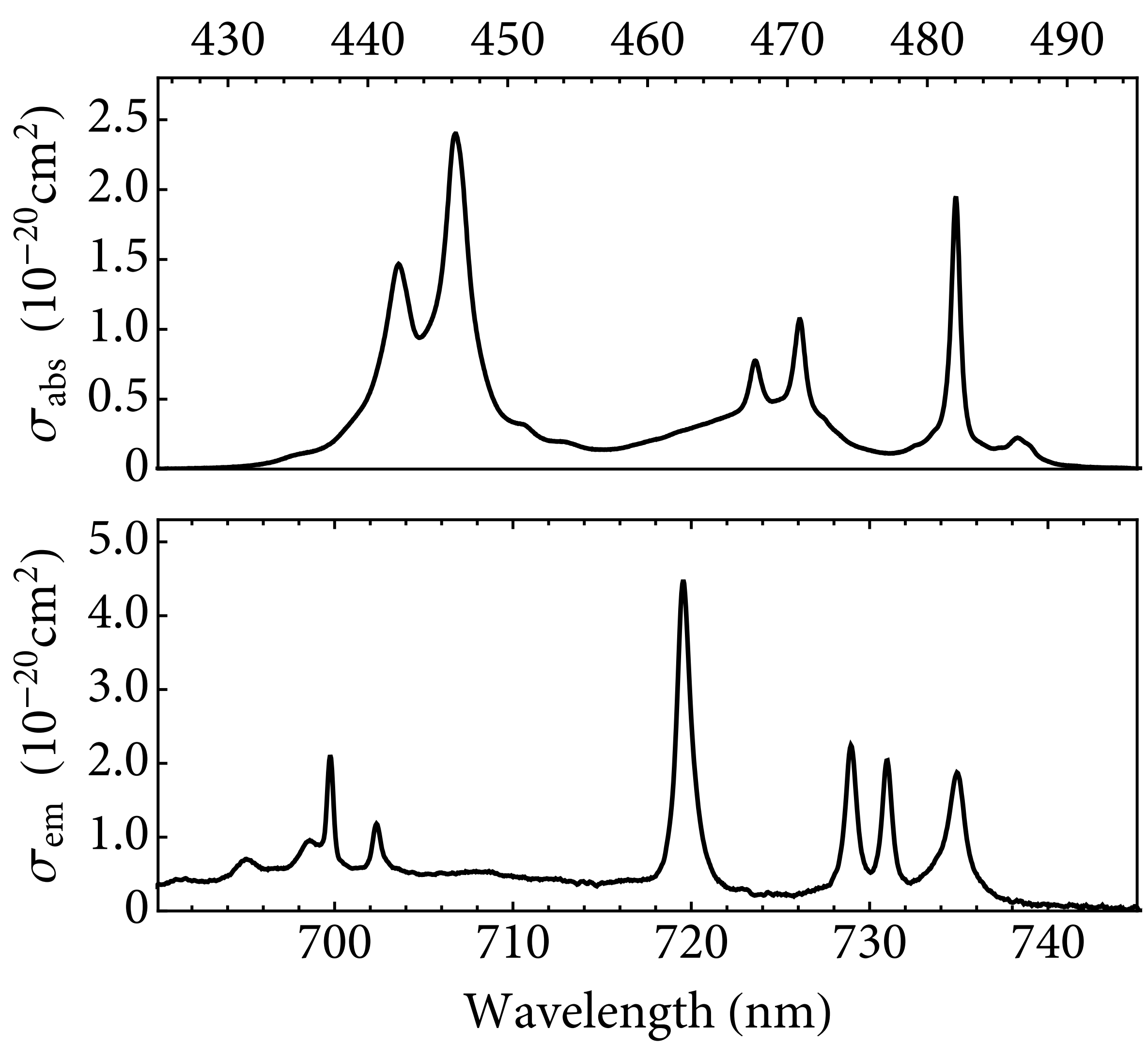
Formula: KY_3F_{10}

- ✓ Unpolarized emissions
- ✓ Symmetric output beams
- ✓ Easier to handle and store
- ✓ Tested in the visible region
- ✗ Growth is not yet optimized
- ✗ Lower performances so far

Pr:KYF deep red laser

Spectroscopic characterization data

Absorption spectrum



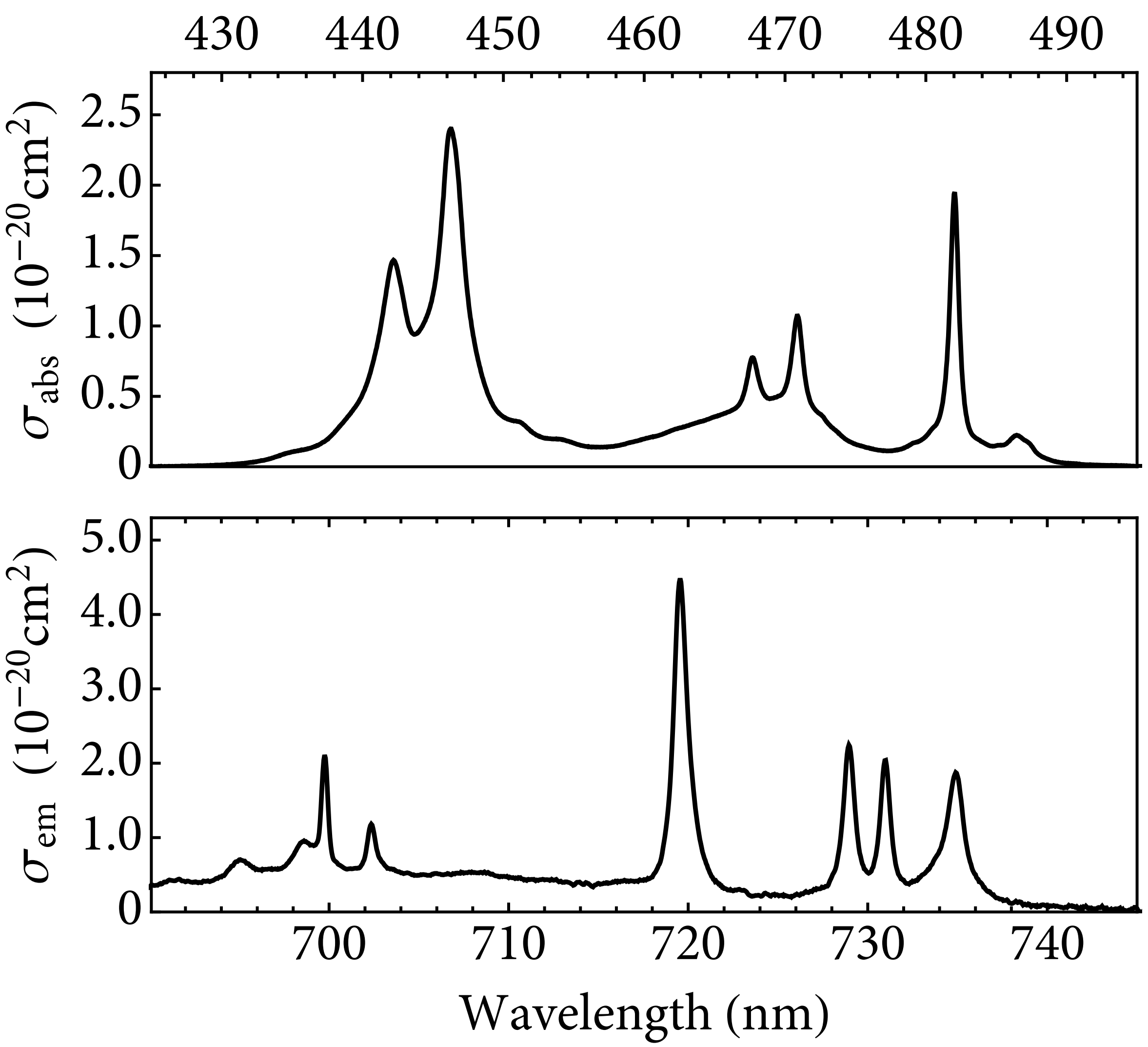
Emission spectrum

- Absorption in blue region
- Multiple deep red emissions
- 720 nm is employed in spectroscopy, cooling and entrapment of atomic gases
- Lack of diodes in this area

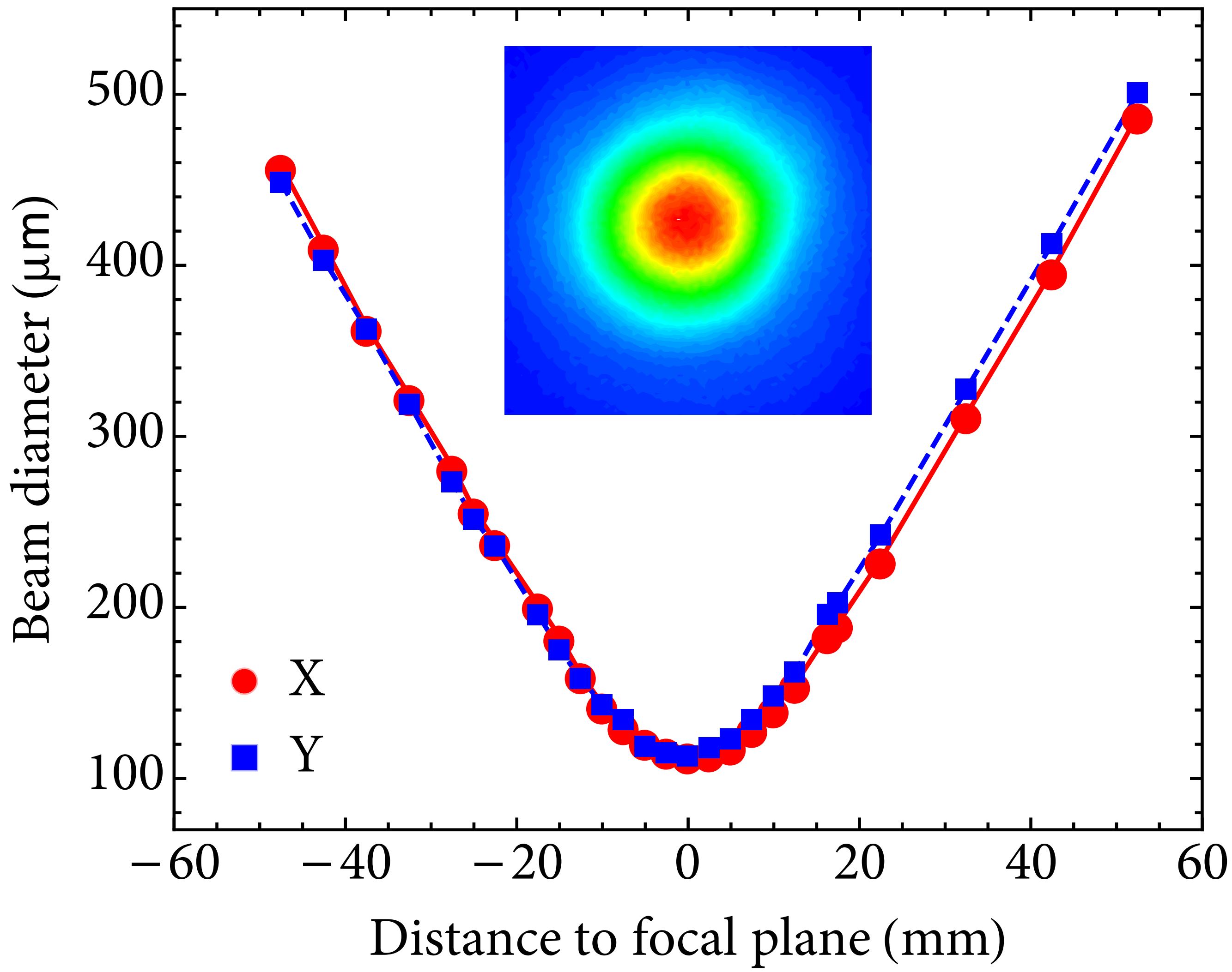
Pr:KYF deep red laser

First laser experiments in this wavelength region with KYF

Absorption spectrum



Emission spectrum



Output beam profile

Pr:KYF deep red laser

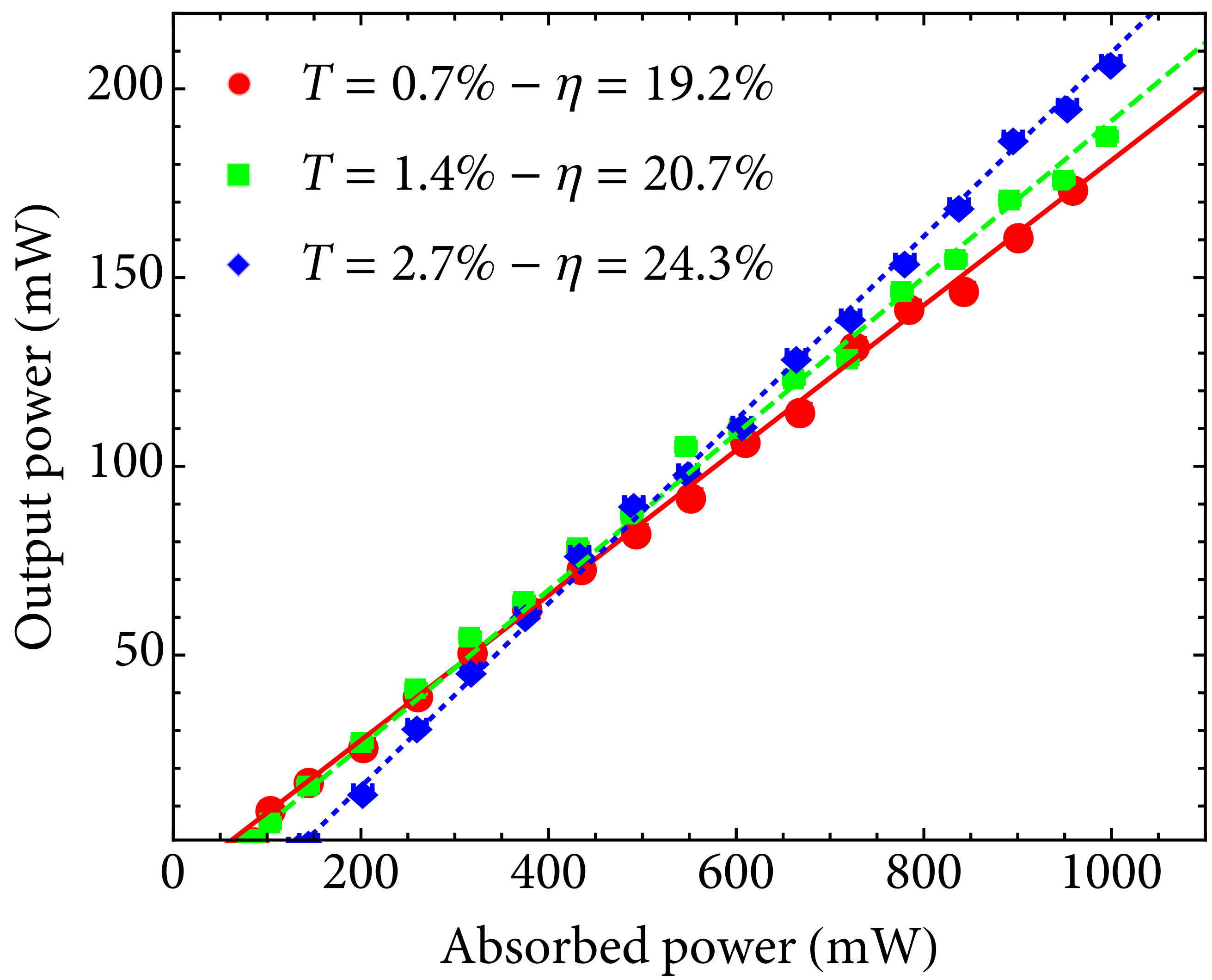
Results comparable for the first time with standard fluorides

Results at 720 nm

	η	L
KY_3F_{10} (this work)	24.3%	0.3% (Caird) 0.6% (Findlay)
$LiLuF_4$	24.0%	0.3%
$LiYF_4$	30.0%	0.6%

Results in Pr:KYF

	green	orange	red	this work
L (%)	2	0.9	5	0.3–0.6

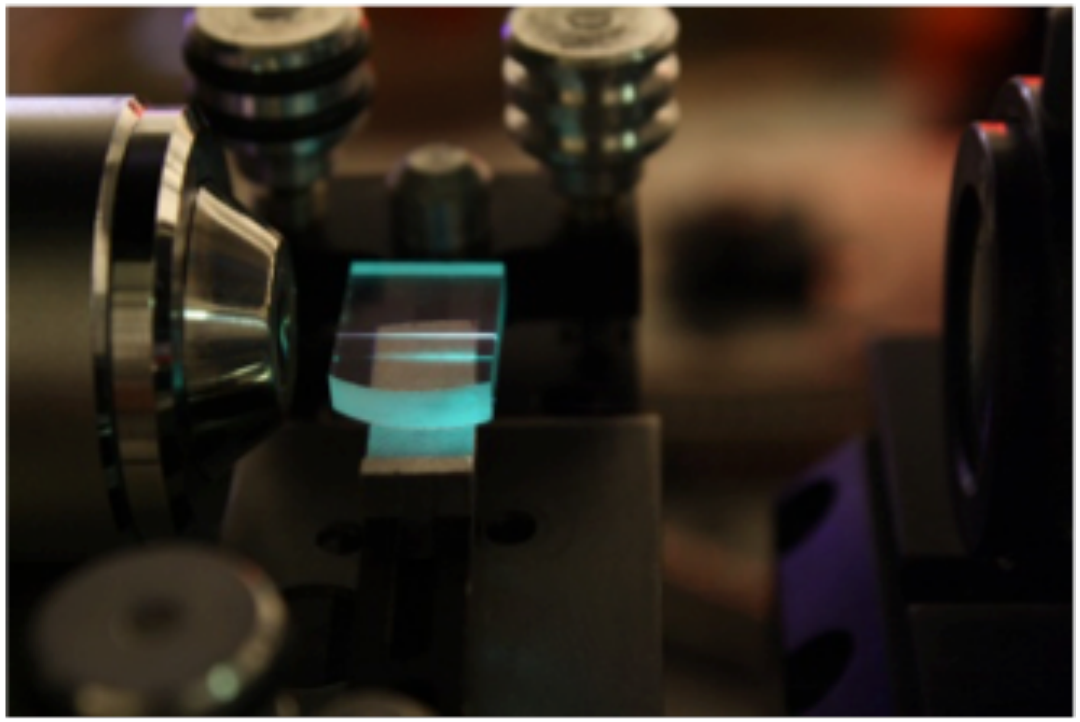


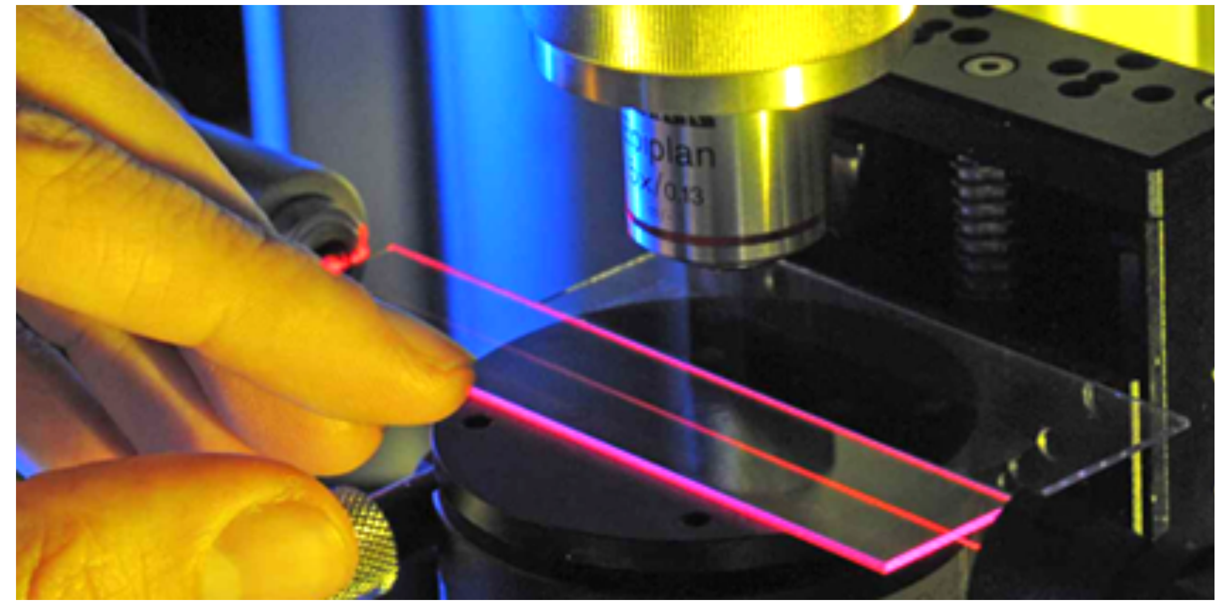
A. Sottile et *al.*, Opt. Lett. **40**, 1992 (2015)

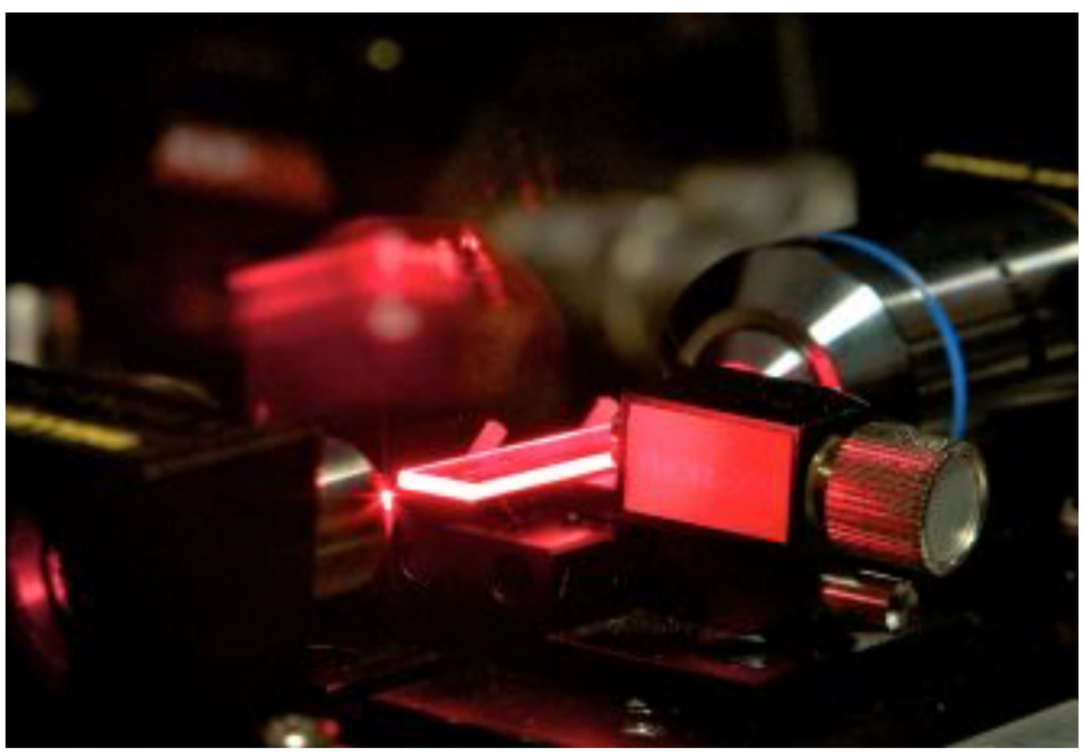
Waveguide inscription and laser in Pr-doped Potassium Yttrium Fluoride (KYF)

Pr:KYF waveguide laser

Benefits of guided channels with respect to bulk crystals





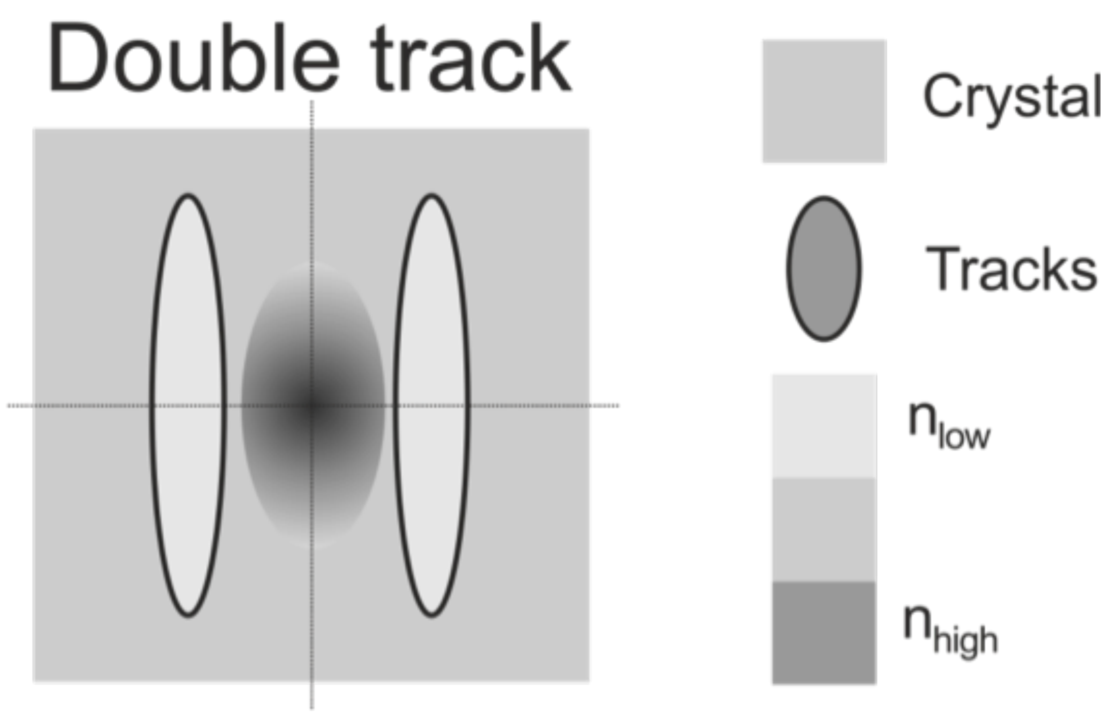


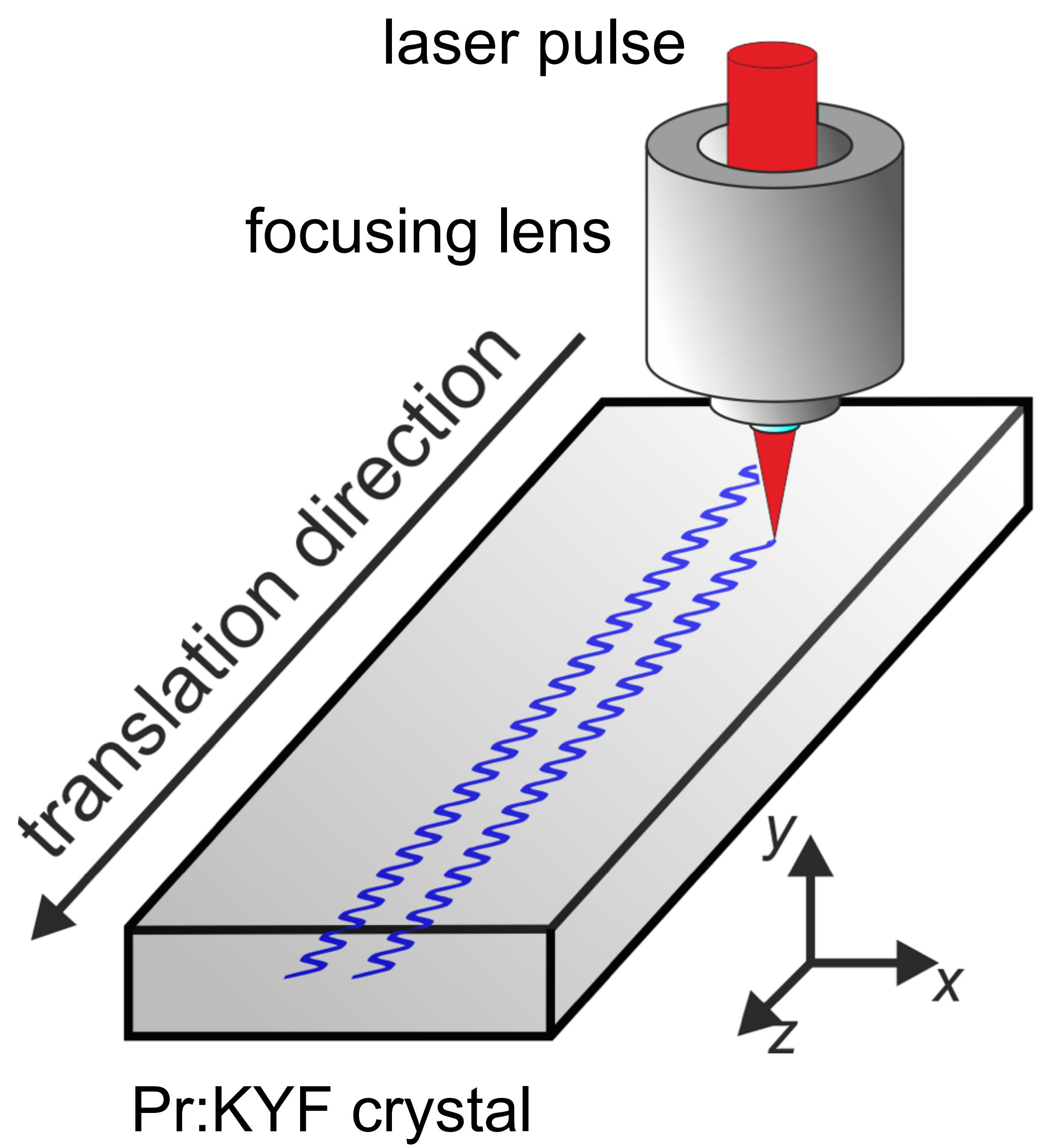
- Confined interaction between pump and output laser beam
- Higher slope efficiencies, lower threshold powers, suitable for weaker laser transitions
- Reduced sizes and influence of thermal and external effects

Pr:KYF waveguide laser

Direct inscription with fs-laser tightly focused pulses

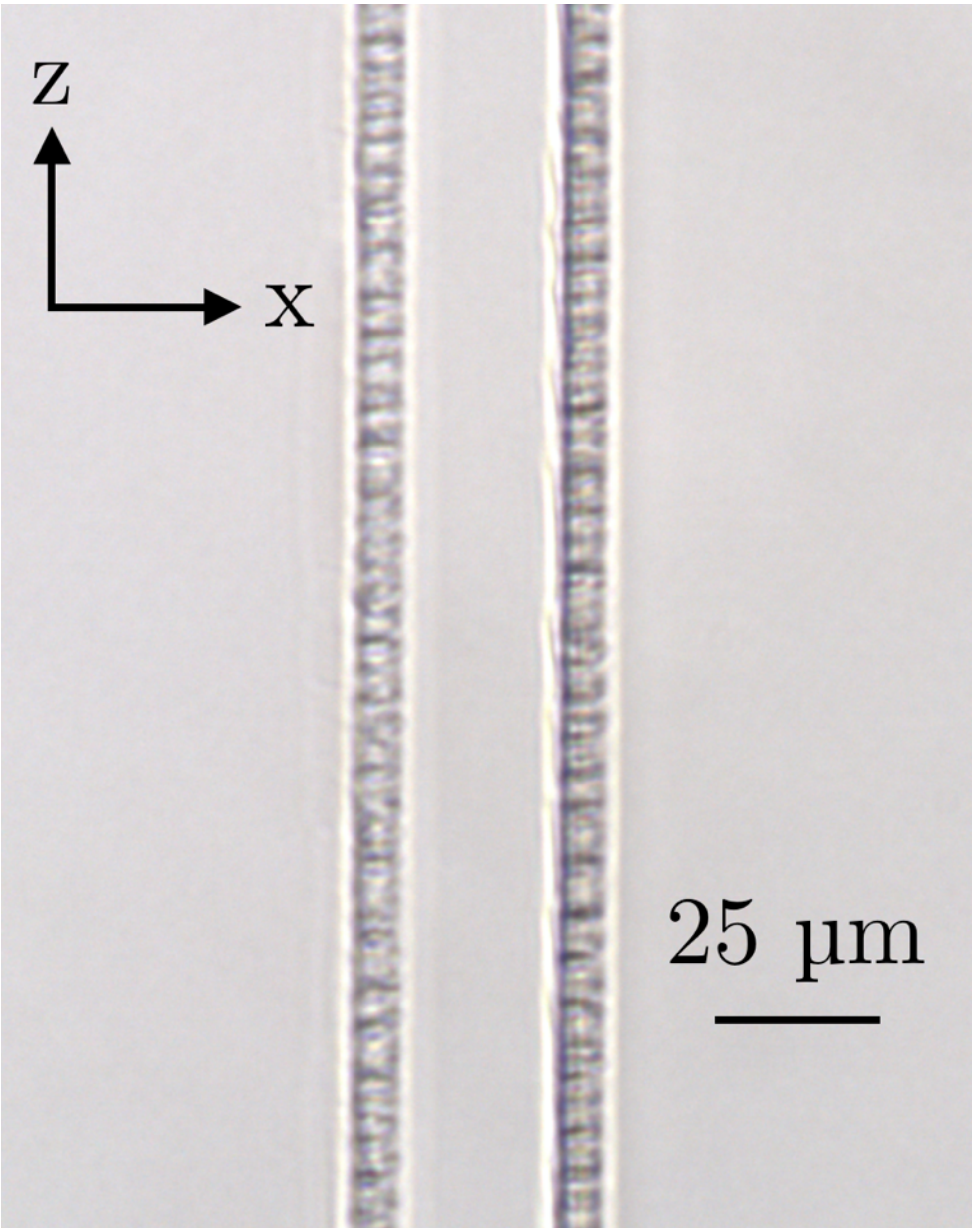
- IR laser pulse releases energy via multiphoton absorption
- Stress-induced birefringence caused by pressure of tracks
- Undamaged guided channel



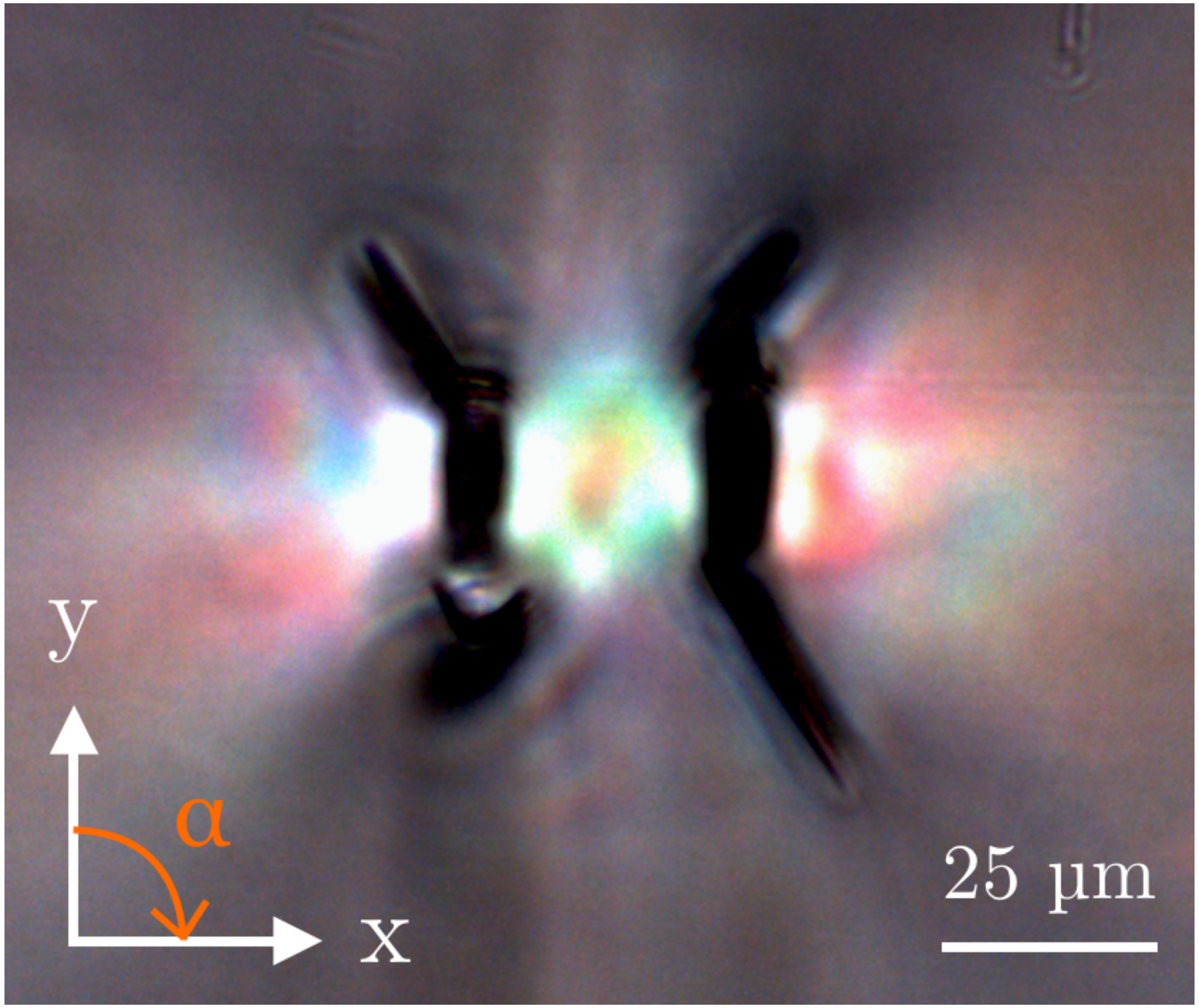


Pr:KYF waveguide laser

Results of waveguide fabrication



Microscope image

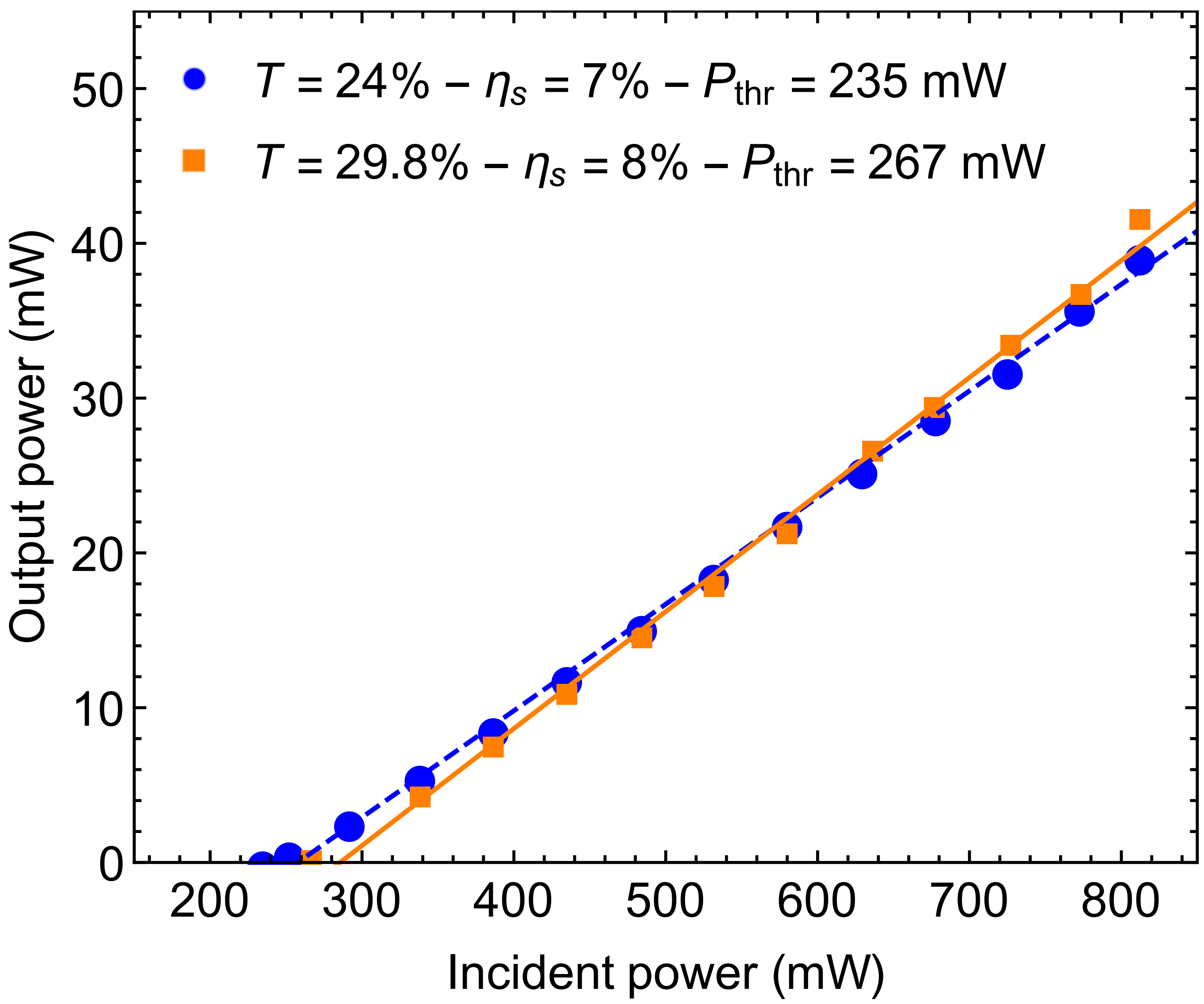


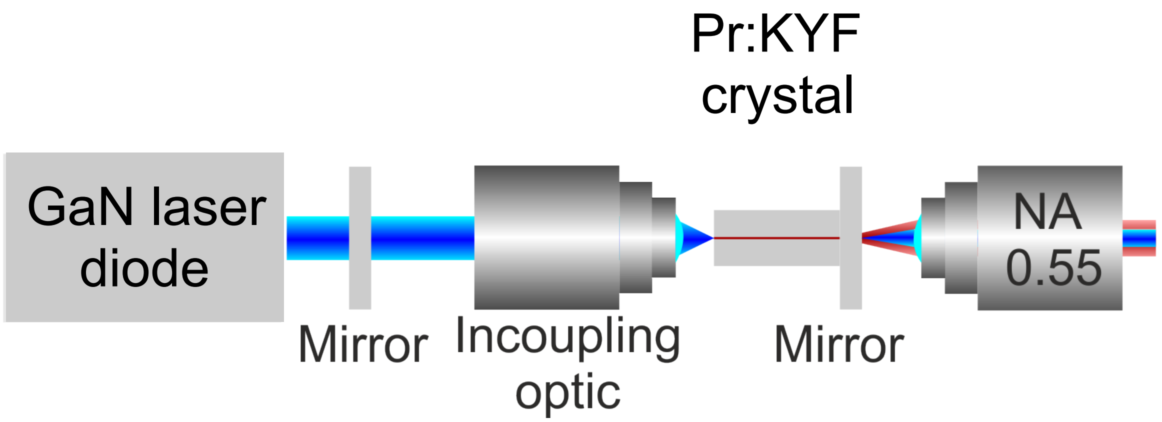
Uniaxial birefringence in the channel

Pr:KYF waveguide laser

First waveguide laser in Pr:KYF

Emission at 607 nm





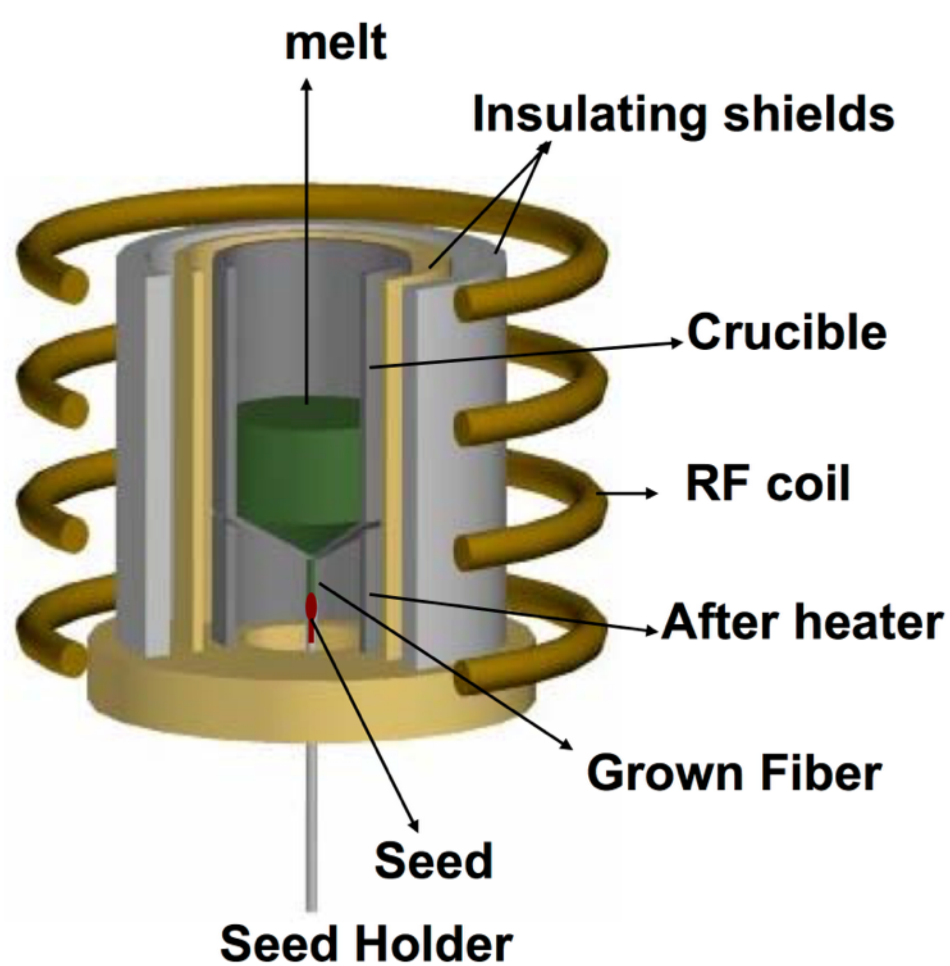
- Laser along both polarizations
- Multimode pump beam caused low absorbed fractions
- Higher performances than in other Pr-doped materials

T. Calmano, A. Sottile et *al.*, in ASSL 2015, AW1A.5

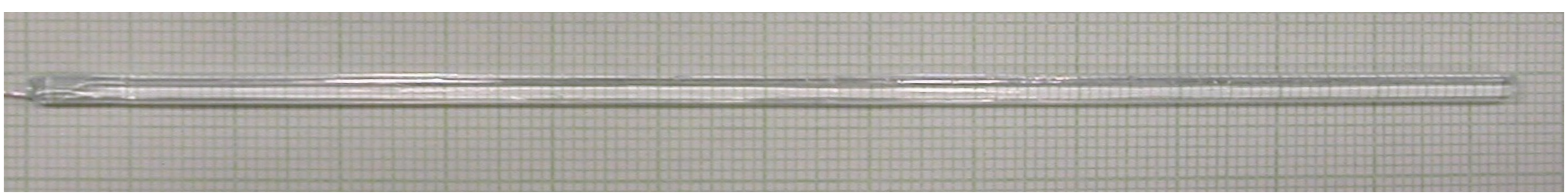
Future activities

Future activities

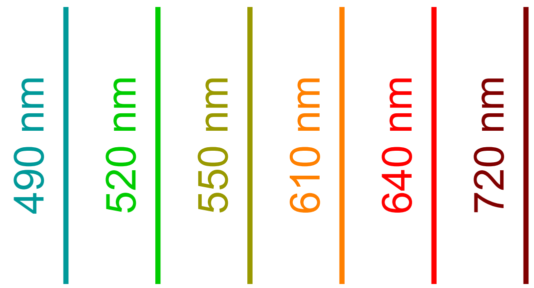
Pr-doped μ-PD grown crystal fiber for compact visible lasers

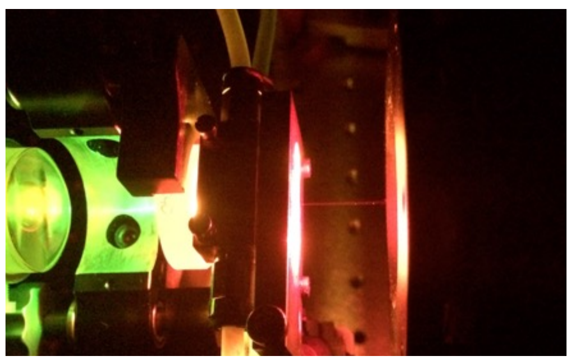


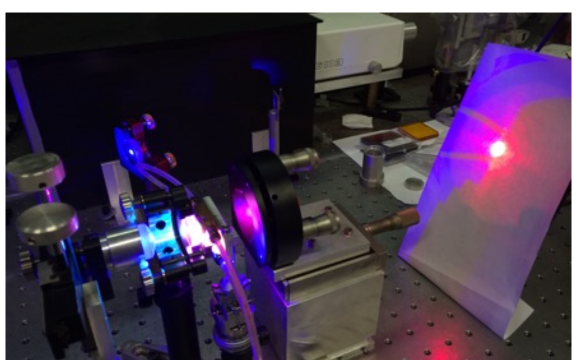
- Only way to shrink size of fluorides without damages
- Tested in the IR region
- No visible laser emissions reported for fiber crystals

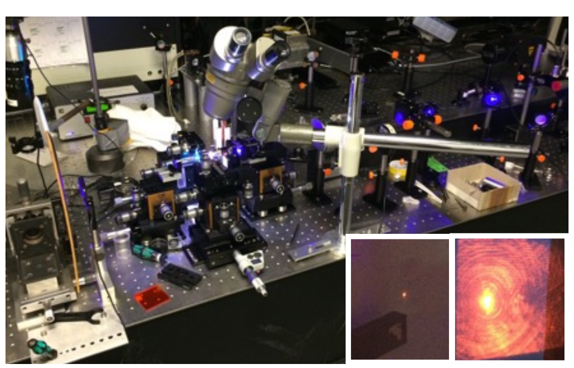


Summary









- Research on innovative visible lasers in Pr^{3+}-doped fluoride single crystals
- Multiple polarization laser study in Pr:BYF at 607 nm, 639 nm, and 643 nm
- First deep red laser characterization in Pr:KYF with improved optical quality
- First waveguide laser in Pr:KYF with uniaxial channels and higher performances

Thank you for your attention

Prof. Mauro Tonelli
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Stefano Veronesi
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Elena Favilla

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Ilaria Grassini
Alessandro Masetti
Fabio Torri