Laser Cooling Wavelengths for Neutral Atoms

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October 31, 2026

Most atoms are cooled on their strongest closed transition, the one an excited atom can only decay back from. Cooling is done in stages: a broad line first, to capture and slow fast atoms, then a narrower line or a sub-Doppler technique to reach microkelvin temperatures.

Rubidium-87 (Harvard/MIT, QuEra, most alkali machines)

Stage	Wavelength	Transition	Typical temperature
2D⁺ MOT source, 3D MOT	780.24 nm (D2 line), 2–3 natural linewidths red of resonance	$5S_{1/2}$ F=2 → $5P_{3/2}$ F′=3	Doppler limit 146 μK
Repumper	780 nm, 6.8 GHz from the cooler	F=1 → F′=2	—
Polarization-gradient cooling	780 nm, detuned further to the red	same as MOT	about 10 μK
Gray molasses (Λ-enhanced)	795 nm (D1 line), blue of resonance	F=2 → F′=2, with D1 repump	a few μK; also used for enhanced loading
Raman sideband cooling in the tweezer	Raman beams near 780 or 795 nm; optical pumping on 795 nm	ground-state hyperfine levels	about the motional ground state

Atoms are imaged on the same 780 nm cooling line, so the imaging light also keeps them cold while they scatter photons.

Cesium-133

- **MOT:** 852.35 nm (D2 line), F=4 → F′=5, with a repumper on F=3 → F′=4. The Doppler limit is 125 μK.
- **Gray molasses:** 894.6 nm (D1 line).

The Harvard trap light is also at 852 nm, but that is a coincidence: it is chosen to sit far from rubidium's lines.

Strontium-88 / 87

Stage	Wavelength	Transition	Linewidth	Limit

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Zeeman slower, “blue” MOT	461 nm	$^1S_0 \rightarrow {}^1P_1$	30.5 MHz	about 0.7 mK
Repumpers	679 nm and 707 nm	$^3P_0$, $^3P_2 \rightarrow {}^3S_1$	—	—
Narrow-line “red” MOT, cooling in the tweezer	689 nm	$^1S_0 \rightarrow {}^3P_1$	7.4 kHz	below 1 μK (recoil-limited)

Ytterbium-171 / 174

Stage	Wavelength	Transition	Linewidth	Limit
Zeeman slower or 2D MOT	399 nm	$^1S_0 \rightarrow {}^1P_1$	29 MHz	about 0.7 mK
Narrow-line “green” MOT, cooling and imaging in the tweezer	556 nm	$^1S_0 \rightarrow {}^3P_1$	182 kHz	4.4 μK

Other alkalis

Sodium uses 589 nm, potassium 767 nm and lithium 671 nm, all on their D2 lines.

Relevance to neutral-atom arrays

- **Separating colors.** The 780 nm MOT and imaging light has to be split from the 852 nm trap light by dichroics. Rb machines also add 795 nm for gray molasses or Raman cooling. Coatings for the SLM, its relay and the objective need to handle 780, 795 and 852 nm together.
- **Stray light at the SLM.** Some 780 nm MOT light scatters back up the objective toward the SLM path. A narrow 852 nm line filter or dichroic in the SLM arm keeps it out.
- **Strontium or ytterbium.** With these atoms the cooling light moves to the blue (461 nm or 399 nm), which is harder on LCoS damage thresholds. These machines usually keep the SLM on the trap wavelength only (for example 813 nm for Sr, or 483–532 nm for Yb).

Wavelengths and linewidths are standard values; D. A. Steck, “Rubidium 87 D Line Data” and “Cesium D Line Data”, are the usual references for the alkali numbers.