Solar Ca appendix

Sun · Ca · downloadable appendix

Document	Solar Ca appendix
Subject	Solar photospheric abundance appendix · Ca
Author	Ryan Schmitt
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Solar calcium: 6.405 ± 0.049

Asplund, Amarsi & Grevesse 2021: 6.30 ± 0.03 · this measurement +0.105 dex

The Ca I value sits about 0.1 dex above Asplund et al. 2021. They fit the light from the centre of the solar disc; we fit the light of the whole disc, as we must for other stars. Fitting the disc centre with the same lines and code gives their value, so the difference comes from the strong lines' edge-of-disc light, not from the line data. The Ca II lines agree with Asplund et al. 2021. The infrared values read about 0.1 dex higher still. On iron lines that also have laboratory values, the Cepheid-calibrated oscillator strengths sit about 0.14 dex low, which would push a calcium abundance up by about that much; the infrared products are shown as measured, with that caveat. In the red-optical only three Ca I lines can be measured (7148, 7202 and 7326 Angstrom), and they read about 0.2 to 0.3 dex below the visible lines; with so few lines those products are shown as measured but carry little weight. With the Civis et al. 2013 oscillator strengths, Ca I in the H band reads 6.18 to 6.28 on five or six lines and in the K band 6.27 to 6.37 on 19 to 22 lines, about 0.1 to 0.2 dex below the visible lines; with a 0.11 dex uncertainty on every line's oscillator strength, they are shown as measured. In the near ultraviolet, where the spectrum is crowded with other lines, only three Ca I lines can be measured, and the fits are poor; they read 6.61 to 6.68, about 0.2 dex above the visible lines. They are shown as measured, as a first look at that part of the spectrum, and carry little weight.

Asplund, Amarsi & Grevesse (2021) give no line recipe we can repeat for this element, so this is our best HARPS product: the Reference Grade analysis with the most complete treatment, then the most lines.

VIS: 6.405 ± 0.049 · HARPS · VIS · Ca I · Asplund et al. 2021 lines · 3D NLTE (Amarsi)

Highlighted Products

near-UV

6.675 ± 0.117

Ca I · reference lines · 1D NLTE (Bergemann) · Kitt Peak (Kurucz 2005) · Reference Grade

VIS

6.413 ± 0.048

Ca I · Asplund et al. 2021 lines · 3D NLTE (Amarsi) · Kitt Peak (1984, molecfit) · Reference Grade

red-optical

6.466 ± 0.059

Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) · Kitt Peak (1984, molecfit) · Reference Grade

NIR

6.500 ± 0.058

Ca I · Codex-graded lines · <3D> LTE (Gerber) · Kitt Peak (1984, molecfit) · Codex Grade

H

6.258 ± 0.057

Ca I · Codex-graded lines · <3D> LTE (Gerber) · CRIRES+ H (full arm, telluric-corrected) · Codex Grade

K

6.365 ± 0.074

Ca I · Codex-graded lines · <3D> LTE (Gerber) · CRIRES+ · Codex Grade

Line grades

Every product is measured on one of three grades of spectral lines and the grades are never mixed in one number.

Grade	What it means	This element
Reference Grade	lines from a published solar line set (Asplund et al. 2021 and similar), measured with the oscillator strengths the authors used	106 products -- Ca I · Asplund et al. 2021 lines; Ca I · reference lines; Ca II · Asplund et al. 2021 lines
Codex Grade	lines chosen by the Codex whose oscillator strength carries a published uncertainty (laboratory measurement, NIST accuracy class A-C, or the paper's own stated error), between 5% and 60% deep	110 products -- Ca I · Codex-graded lines; Ca II · Codex-graded lines
Deep Grade	the same oscillator-strength rule on lines deeper than 60% -- stronger lines, more sensitive to damping and the model atmosphere	none for the Sun: every line in this grade is excluded as saturated or an outlier (see Excluded lines)

Error-bar Forest Plot

near-UV — Kitt Peak (Kurucz 2005)
A(Ca) dex; axis 6.24–6.82



Ca I · reference lines · 1D LTE
Reference Grade · 3 lines — 6.652 ±0.116



Ca I · reference lines · 1D NLTE (Bergemann)
Reference Grade · 3 lines — 6.675 ±0.117

near-UV — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 6.24–6.82



Ca I · reference lines · 1D LTE
Reference Grade · 3 lines — 6.609 ±0.152



Ca I · reference lines · 1D NLTE (Bergemann)
Reference Grade · 3 lines — 6.632 ±0.154

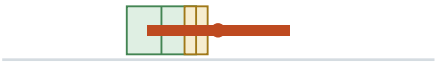
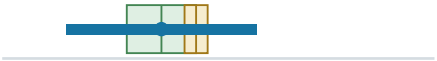
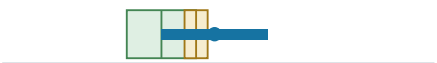
near-UV axis: 6.24 · 6.39 · 6.53 · 6.68 · 6.82 A(Ca) dex

VIS — HARPS
A(Ca) dex; axis 6.16–6.54

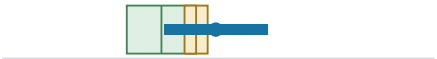
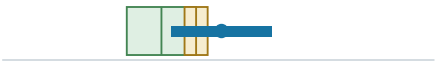
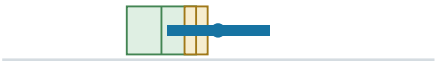
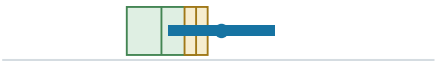


Ca II · Asplund et al. 2021 lines · 1D LTE
Reference Grade · 2 lines — 6.293 ±0.066

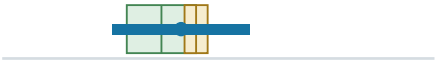
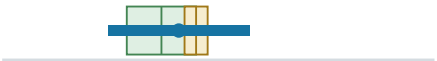
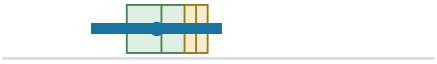
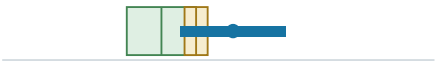
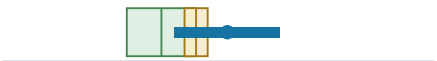
VIS — HARPS
A(Ca) dex; axis 6.16–6.54

Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.300 ±0.083
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.290 ±0.068
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.258 ±0.066
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.271 ±0.063
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.349 ±0.062
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.332 ±0.065
Ca II · Codex-graded lines · 1D LTE Codex Grade · 2 lines		6.293 ±0.066
Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.300 ±0.083
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 2 lines		6.290 ±0.068
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 2 lines		6.258 ±0.066
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 2 lines		6.271 ±0.063
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.349 ±0.062
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.332 ±0.065
Ca I · Asplund et al. 2021 lines · 1D LTE Reference Grade · 10 lines		6.343 ±0.046
Ca I · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.405 ±0.049
Ca I · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 10 lines		6.322 ±0.045
Ca I · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 10 lines		6.346 ±0.046
Ca I · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 10 lines		6.346 ±0.046

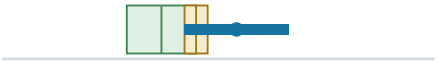
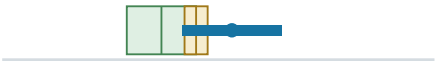
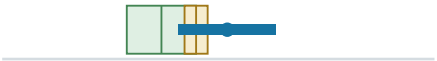
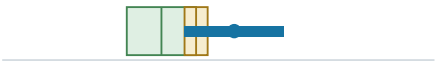
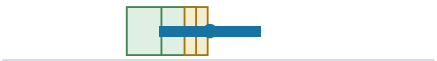
VIS — HARPS
A(Ca) dex; axis 6.16–6.54

Ca I · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 10 lines · EXPERIMENTAL-NOT-ADOPTED		6.438 ±0.049
Ca I · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 10 lines · EXPERIMENTAL-NOT-ADOPTED		6.434 ±0.048
Ca I · Codex-graded lines · 1D LTE Codex Grade · 17 lines		6.347 ±0.045
Ca I · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 10 lines		6.405 ±0.049
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 17 lines		6.352 ±0.043
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 17 lines		6.336 ±0.044
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 17 lines		6.349 ±0.044
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.438 ±0.046
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.409 ±0.044
Ca I · reference lines · 1D LTE Reference Grade · 45 lines		6.339 ±0.046
Ca I · reference lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.405 ±0.049
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 45 lines		6.352 ±0.046
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 45 lines		6.310 ±0.046
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 45 lines		6.343 ±0.046
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.448 ±0.046
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.411 ±0.046

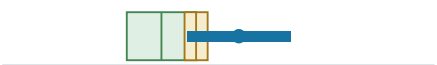
VIS — Kitt Peak (Kurucz 2005)
A(Ca) dex; axis 6.16–6.54

Ca II · Asplund et al. 2021 lines · 1D LTE Reference Grade · 2 lines		6.317 ±0.059
Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.325 ±0.075
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.315 ±0.061
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.263 ±0.047
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.296 ±0.056
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.373 ±0.056
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.351 ±0.058
Ca II · Codex-graded lines · 1D LTE Codex Grade · 2 lines		6.317 ±0.059
Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.325 ±0.075
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 2 lines		6.315 ±0.061
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 2 lines		6.263 ±0.047
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 2 lines		6.296 ±0.056
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.373 ±0.056
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.351 ±0.058
Ca I · Asplund et al. 2021 lines · 1D LTE Reference Grade · 10 lines		6.362 ±0.046
Ca I · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.412 ±0.048
Ca I · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 10 lines		6.341 ±0.044
Ca I · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 10 lines		6.357 ±0.046

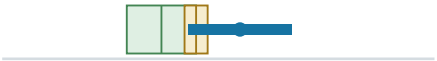
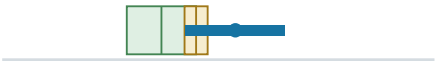
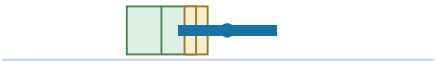
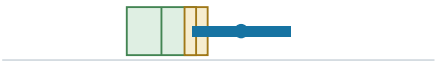
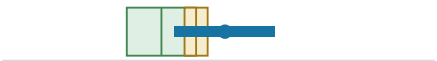
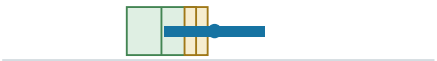
VIS — Kitt Peak (Kurucz 2005)
A(Ca) dex; axis 6.16–6.54

Ca I · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 10 lines		6.365 ±0.045
Ca I · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 10 lines · EXPERIMENTAL-NOT-ADOPTED		6.455 ±0.048
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Ca I · Codex-graded lines · 1D LTE Codex Grade · 17 lines		6.361 ±0.043
Ca I · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 10 lines		6.412 ±0.048
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 17 lines		6.357 ±0.042
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 17 lines		6.341 ±0.043
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 17 lines		6.363 ±0.043
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.449 ±0.044
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.436 ±0.044
Ca I · reference lines · 1D LTE Reference Grade · 45 lines		6.337 ±0.044
Ca I · reference lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.412 ±0.048
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 45 lines		6.348 ±0.044
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 45 lines		6.298 ±0.044
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 45 lines		6.342 ±0.044
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.449 ±0.045
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.402 ±0.044

VIS — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 6.16–6.54

Ca II · Asplund et al. 2021 lines · 1D LTE Reference Grade · 2 lines		6.319 ±0.054
Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.327 ±0.069
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.317 ±0.056
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.287 ±0.056
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.298 ±0.052
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.374 ±0.052
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.354 ±0.053
Ca II · Codex-graded lines · 1D LTE Codex Grade · 2 lines		6.319 ±0.054
Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.327 ±0.069
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 2 lines		6.317 ±0.056
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 2 lines		6.287 ±0.056
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 2 lines		6.298 ±0.052
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.374 ±0.052
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.354 ±0.053
Ca I · Asplund et al. 2021 lines · 1D LTE Reference Grade · 10 lines		6.364 ±0.045
Ca I · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.413 ±0.048
Ca I · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 10 lines		6.345 ±0.043
Ca I · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 10 lines		6.367 ±0.045

VIS — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 6.16–6.54

Ca I · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 10 lines		6.368 ±0.045
Ca I · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 10 lines · EXPERIMENTAL-NOT-ADOPTED		6.459 ±0.047
Ca I · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 10 lines · EXPERIMENTAL-NOT-ADOPTED		6.450 ±0.047
Ca I · Codex-graded lines · 1D LTE Codex Grade · 17 lines		6.364 ±0.043
Ca I · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 10 lines		6.413 ±0.048
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 17 lines		6.359 ±0.042
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 17 lines		6.357 ±0.042
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 17 lines		6.369 ±0.043
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.460 ±0.044
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 17 lines · EXPERIMENTAL-NOT-ADOPTED		6.444 ±0.044
Ca I · reference lines · 1D LTE Reference Grade · 45 lines		6.341 ±0.044
Ca I · reference lines · 3D NLTE (Amarsi) Reference Grade · 10 lines		6.413 ±0.048
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 45 lines		6.355 ±0.043
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 45 lines		6.310 ±0.043
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 45 lines		6.346 ±0.044
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.462 ±0.044
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 45 lines · EXPERIMENTAL-NOT-ADOPTED		6.420 ±0.044

VIS axis: 6.16 · 6.26 · 6.35 · 6.44 · 6.54 A(Ca) dex

red-optical — IAG FTS
A(Ca) dex; axis 5.85–6.62

Ca II · Asplund et al. 2021 lines · 1D LTE Reference Grade · 2 lines		6.458 ±0.067
Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.472 ±0.075
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.422 ±0.054
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.320 ±0.034
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.430 ±0.063
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.485 ±0.066
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.362 ±0.034
Ca II · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.494 ±0.049
Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.472 ±0.075
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.379 ±0.046
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.327 ±0.034
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.464 ±0.047
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.523 ±0.048
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.368 ±0.034
Ca I · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.170 ±0.088
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.047 ±0.120
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.153 ±0.085
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.173 ±0.087

red-optical — IAG FTS
A(Ca) dex; axis 5.85–6.62

Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.258 ±0.090
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.229 ±0.084
Ca I · reference lines · 1D LTE Reference Grade · 3 lines		6.170 ±0.088
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 3 lines		6.047 ±0.120
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 3 lines		6.153 ±0.085
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 3 lines		6.173 ±0.087
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.258 ±0.090
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.229 ±0.084

red-optical — Kitt Peak (Kurucz 2005)
A(Ca) dex; axis 5.85–6.62

Ca II · Asplund et al. 2021 lines · 1D LTE Reference Grade · 2 lines		6.477 ±0.060
Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.491 ±0.068
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.441 ±0.048
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.335 ±0.037
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.448 ±0.056
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.502 ±0.059
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.377 ±0.037
Ca II · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.514 ±0.046

red-optical — Kitt Peak (Kurucz 2005)
A(Ca) dex; axis 5.85–6.62

Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.491 ±0.068
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.406 ±0.043
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.350 ±0.036
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.485 ±0.044
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.544 ±0.046
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.393 ±0.035
Ca I · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.231 ±0.080
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.108 ±0.112
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.228 ±0.073
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.235 ±0.079
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.322 ±0.082
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.295 ±0.074
Ca I · reference lines · 1D LTE Reference Grade · 3 lines		6.231 ±0.080
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 3 lines		6.108 ±0.112
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 3 lines		6.228 ±0.073
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 3 lines		6.235 ±0.079
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.322 ±0.082
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.295 ±0.074

red-optical — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 5.85–6.62

Ca II · Asplund et al. 2021 lines · 1D LTE Reference Grade · 2 lines		6.453 ±0.052
Ca II · Asplund et al. 2021 lines · 3D NLTE (Amarsi) Reference Grade · 2 lines		6.466 ±0.059
Ca II · Asplund et al. 2021 lines · 1D NLTE (Bergemann) Reference Grade · 2 lines		6.417 ±0.041
Ca II · Asplund et al. 2021 lines · 1D NLTE (Gerber) Reference Grade · 2 lines		6.318 ±0.041
Ca II · Asplund et al. 2021 lines · 1D LTE (Gerber) Reference Grade · 2 lines		6.425 ±0.049
Ca II · Asplund et al. 2021 lines · <3D> LTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.479 ±0.051
Ca II · Asplund et al. 2021 lines · <3D> NLTE (Gerber) Reference Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.351 ±0.048
Ca II · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.485 ±0.042
Ca II · Codex-graded lines · 3D NLTE (Amarsi) Codex Grade · 2 lines		6.466 ±0.059
Ca II · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.392 ±0.041
Ca II · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.321 ±0.036
Ca II · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.455 ±0.041
Ca II · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.514 ±0.042
Ca II · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.383 ±0.040
Ca I · Codex-graded lines · 1D LTE Codex Grade · 3 lines		6.123 ±0.091
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 3 lines		6.000 ±0.123
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.121 ±0.088
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 3 lines		6.127 ±0.090

red-optical — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 5.85–6.62

Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.209 ±0.093
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.176 ±0.085
Ca I · reference lines · 1D LTE Reference Grade · 3 lines		6.123 ±0.091
Ca I · reference lines · 1D NLTE (Bergemann) Reference Grade · 3 lines		6.000 ±0.123
Ca I · reference lines · 1D NLTE (Gerber) Reference Grade · 3 lines		6.121 ±0.088
Ca I · reference lines · 1D LTE (Gerber) Reference Grade · 3 lines		6.127 ±0.090
Ca I · reference lines · <3D> LTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.209 ±0.093
Ca I · reference lines · <3D> NLTE (Gerber) Reference Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.176 ±0.085

red-optical axis: 5.85 · 6.04 · 6.23 · 6.43 · 6.62 A(Ca) dex

NIR — CRIRES+ J
A(Ca) dex; axis 6.24–6.63

Ca I · Codex-graded lines · 1D LTE Codex Grade · 2 lines		6.508 ±0.040
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 2 lines		6.502 ±0.041
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 2 lines		6.473 ±0.042
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 2 lines		6.511 ±0.040
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 2 lines · EXPERIMENTAL-NOT-ADOPTED		6.562 ±0.040

NIR — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 6.24–6.63

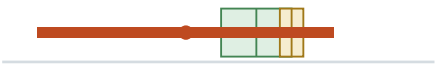
Ca I · Codex-graded lines · 1D LTE Codex Grade · 4 lines		6.439 ±0.060
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 4 lines		6.411 ±0.070

NIR — Kitt Peak (1984, molecfit)
A(Ca) dex; axis 6.24–6.63

Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 3 lines		6.396 ±0.072
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 4 lines		6.441 ±0.059
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 4 lines · EXPERIMENTAL-NOT-ADOPTED		6.500 ±0.058
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 3 lines · EXPERIMENTAL-NOT-ADOPTED		6.486 ±0.070

NIR axis: 6.24 · 6.34 · 6.44 · 6.53 · 6.63 A(Ca) dex

H — CRIRES+ H
A(Ca) dex; axis 6.08–6.45

Ca I · Codex-graded lines · 1D LTE Codex Grade · 5 lines		6.236 ±0.051
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 5 lines		6.230 ±0.050
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 5 lines		6.208 ±0.051
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 5 lines		6.250 ±0.050
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 6 lines · EXPERIMENTAL-NOT-ADOPTED		6.283 ±0.139
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 6 lines · EXPERIMENTAL-NOT-ADOPTED		6.240 ±0.126

H — CRIRES+ H (full arm, telluric-corrected)
A(Ca) dex; axis 6.08–6.45

Ca I · Codex-graded lines · 1D LTE Codex Grade · 6 lines		6.198 ±0.069
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 6 lines		6.185 ±0.067
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 6 lines		6.179 ±0.063
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 6 lines		6.204 ±0.067
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 6 lines · EXPERIMENTAL-NOT-ADOPTED		6.258 ±0.057

H — CRIRES+ H (full arm, telluric-corrected)
A(Ca) dex; axis 6.08–6.45

Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 6 lines · EXPERIMENTAL-NOT-ADOPTED		6.209 ±0.062

H axis: 6.08 · 6.18 · 6.27 · 6.36 · 6.45 A(Ca) dex

K — CRIRES+
A(Ca) dex; axis 6.17–6.47

Ca I · Codex-graded lines · 1D LTE Codex Grade · 22 lines		6.293 ±0.072
Ca I · Codex-graded lines · 1D NLTE (Bergemann) Codex Grade · 19 lines		6.286 ±0.076
Ca I · Codex-graded lines · 1D NLTE (Gerber) Codex Grade · 19 lines		6.270 ±0.068
Ca I · Codex-graded lines · 1D LTE (Gerber) Codex Grade · 22 lines		6.300 ±0.072
Ca I · Codex-graded lines · <3D> LTE (Gerber) Codex Grade · 22 lines · EXPERIMENTAL-NOT-ADOPTED		6.365 ±0.074
Ca I · Codex-graded lines · <3D> NLTE (Gerber) Codex Grade · 19 lines · EXPERIMENTAL-NOT-ADOPTED		6.297 ±0.072

K axis: 6.17 · 6.25 · 6.32 · 6.39 · 6.47 A(Ca) dex

How to read this forest. Each row is one independent product, preserving its band, holding, engine, indicator and line set. Engines and indicator families are never averaged. Each bar is the uncertainty as Asplund et al. 2021 quote it: line-to-line scatter, the 3D-model term and the NLTE term (at least 0.03 dex). For a molecule the NLTE term is replaced by its dependence on the other element, and the 3D term comes from the 3D-to-1D difference Amarsi et al. 2021 publish for the same band. Atomic-data and observational terms are not in the bar, as in Asplund; they stay in the full error budget attached to the row. Grades describe the supplied line-pool provenance, not engine quality; evaluated theoretical CNO oscillator strengths are not relabelled as laboratory evidence. Quarantined, failed and unconstrained fits have no abundance mark. Experimental products remain explicitly not adopted. Literature references provide context, never tuning targets.

How this was measured

Every calcium value on this page comes from fitting synthetic spectra to the observed solar spectrum, line by line or band by band, with the calcium abundance as the free parameter. The synthesis includes the atomic lines and the molecular opacity in every window, so blended absorption is modelled rather than attributed to the line being measured. The continuum is placed locally around every line by comparing the observation with the synthesis on its own highest pixels, and ground-based spectra are telluric-corrected across their full range.

Each indicator is measured independently on each solar spectrum and reported separately; nothing is averaged across indicators or instruments. Where a 3D or NLTE correction is published for the lines, it is applied as its own product (1D-LTE, 1D-NLTE and 3D-NLTE are separate rows). Every value carries a full uncertainty budget: fit, line strengths, microturbulence, continuum, fit window, model atmosphere, telluric residual, and the spread between spectra, each measured by refitting with that one input changed. The headline at the top is the Asplund-grade product: a published line set, the most complete treatment, then the most lines.

Band	near-UV
What was measured	Ca I · reference lines
Solar spectra	Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE
Lines	3
Result A(Ca)	6.632–6.675 (1D-NLTE)
Largest uncertainty terms (dex)	fit / line-to-line scatter 0.11, line strengths (gf) 0.05

Band	VIS
What was measured	Ca I · Codex-graded lines; Ca II · Codex-graded lines
Solar spectra	HARPS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, 3D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	2–17
Result A(Ca)	6.300–6.413 (3D-NLTE)
Largest uncertainty terms (dex)	NLTE / 3D correction 0.03, model atmosphere 0.03

Band	VIS
What was measured	Ca I · reference lines
Solar spectra	HARPS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, 3D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	10–45
Result A(Ca)	6.405–6.413 (3D-NLTE)
Largest uncertainty terms (dex)	NLTE / 3D correction 0.03, model atmosphere 0.03

Band	VIS
What was measured	Ca I · Asplund et al. 2021 lines; Ca II · Asplund et al. 2021 lines
Solar spectra	HARPS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, 3D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	2–10
Result A(Ca)	6.300–6.413 (3D-NLTE)
Largest uncertainty terms (dex)	NLTE / 3D correction 0.03, model atmosphere 0.03

Band	red-optical
What was measured	Ca I · Codex-graded lines; Ca II · Codex-graded lines
Solar spectra	IAG FTS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, 3D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	2–3
Result A(Ca)	6.466–6.491 (3D-NLTE)
Largest uncertainty terms (dex)	line strengths (gf) 0.07, fit / line-to-line scatter 0.05

Band	red-optical
What was measured	Ca I · reference lines
Solar spectra	IAG FTS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	3
Result A(Ca)	6.176–6.295 (synth-mean3D-NLTE-gerber-stagger)
Largest uncertainty terms (dex)	fit / line-to-line scatter 0.06, model atmosphere 0.03

Band	red-optical
What was measured	Ca II · Asplund et al. 2021 lines
Solar spectra	IAG FTS, Kitt Peak (1984, molecfit), Kitt Peak (Kurucz 2005)
Treatments	1D-LTE, 1D-NLTE, 3D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	2
Result A(Ca)	6.466–6.491 (3D-NLTE)
Largest uncertainty terms (dex)	line strengths (gf) 0.07, fit / line-to-line scatter 0.05

Band	NIR
What was measured	Ca I · Codex-graded lines
Solar spectra	CRIRES+ J, Kitt Peak (1984, molecfit)
Treatments	1D-LTE, 1D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	2–4
Result A(Ca)	6.500–6.562 (synth-mean3D-LTE-gerber-stagger)
Largest uncertainty terms (dex)	line strengths (gf) 0.13, fit / line-to-line scatter 0.04

Band	H
What was measured	Ca I · Codex-graded lines
Solar spectra	CRIRES+ H, CRIRES+ H (full arm, telluric-corrected)
Treatments	1D-LTE, 1D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	5–6
Result A(Ca)	6.258–6.283 (synth-mean3D-LTE-gerber-stagger)
Largest uncertainty terms (dex)	line strengths (gf) 0.11, fit / line-to-line scatter 0.04

Band	K
What was measured	Ca I · Codex-graded lines
Solar spectra	CRIRES+
Treatments	1D-LTE, 1D-NLTE, synth-mean3D-LTE-gerber-stagger, synth-mean3D-NLTE-gerber-stagger
Lines	19–22
Result A(Ca)	6.365 (synth-mean3D-LTE-gerber-stagger)
Largest uncertainty terms (dex)	line strengths (gf) 0.11, fit / line-to-line scatter 0.06

Excluded lines

These lines are left out of the Sun's measurement. They stay in the line lists: a cooler or more evolved star may measure them well. Blended lines are not excluded -- the spectrum synthesis models the blend. 5 lines.

Species	Wavelength (Å, air)	Why it is excluded
Ca I	4307.744	molecular_blend
Ca I	4434.957	atomic_blend
Ca I	4526.928	atomic_blend
Ca I	5041.618	atomic_blend
Ca I	5270.270	atomic_blend

Solar calcium context

Calcium is measured from neutral Ca I and ionized Ca II lines in the visible and red-optical. The reference lines are the ten Ca I and five Ca II lines Asplund et al. 2021 used, with the oscillator strengths they adopted; a wider set of lines with laboratory oscillator strengths and the Codex's own line selection are shown as separate products. In the infrared (Y and J bands, Kitt Peak and CRIRES+) no laboratory oscillator strength exists, so the lines use values Elgueta et al. 2024 calibrated on Cepheid stars, each with its own published uncertainty. In the H and K bands (CRIRES+) the only values not tuned to the Sun are ones Civis et al. 2013 calculated from atomic theory. We tested them: their magnesium values match our laboratory-graded magnesium lines to about 0.04 dex, and on the two calcium lines they share with the Cepheid calibration they differ by 0.11 dex, which we carry as each line's uncertainty. The values Kurucz computed, which we used before, are about 0.16 dex too strong for the main H-band lines and read calcium low by that much. No ionized calcium line in H or K is deep enough to measure, and no usable calcium line was found in the near-ultraviolet.

Published line sets · gf uncertainty model · Methodology

Download the evidence

Download PDF — Solar Ca appendix

Source feed — includes quarantined fit outputs, not adopted abundances

Complete product visibility audit

Shared website/PDF report

Reproducibility manifest

Complete references and product-to-source bindings

Reproducibility

Generated from the pinned science snapshot. Source commit 15e0bc6d372c8ad95d687fd381827c52d64747af
Feed Ca.json v1.379 · updated 2026-11-08T12:32:33Z
Generated 2026-11-08T05:33:14-07:00 (source commit timestamp)
Feed SHA-256 cd9f87d9995d48ee53cab75b5f42698df072b6e5f50b65f6394a2bf82dc16605
Generator scripts/generate_cno_publication.py v1.0.0

Pinned scientific source

References / Data & Model Sources

Sources are separated by their role. Registered grid lineage and quarantined diagnostics do not imply an adopted abundance or an applied correction.

See the source notes for the distinction between reference lineage and the treatment actually recorded in each feed entry.

Science and provenance source notes

Solar abundance and indicator analyses. Solar Ca comparison literature; not an adopted Codex abundance. Sources: [1], [2].

Solar abundance and indicator analyses. Published line set CA_AGSS21 (the line selection). Sources: [1].

Atomic data and gf authorities. Ca II oscillator strengths of this pool, as the product's own uncertainty budget records them (with their lineage). Sources: [1].

Model and grid sources. Feed treatment: 1D-LTE synthesis (Turbospectrum); no NLTE/3D correction claimed. Sources: [3].

Model and grid sources. Cited solar abundance differences from the published model columns, applied additively to our LTE fits; not a new in-transfer 3D calculation. Baseline atmosphere: A_marcs_lte Sources: [1].

Model and grid sources. Feed treatment: ENGINE-B-NLTE; Turbospectrum on the registered Gerber deck. The product retains its own atmosphere and ion identity. Sources: [3].

Model and grid sources. Feed treatment: synth-1D-LTE-gerber; Turbospectrum on the registered Gerber deck. The product retains its own atmosphere and ion identity. Sources: [3].

Model and grid sources. Feed treatment: synth-mean3D-LTE-gerber-stagger; Turbospectrum on the registered Gerber deck with the horizontally averaged 3D (<3D>) Stagger solar model; not a full 3D calculation. Sources: [3], [4].

Model and grid sources. Feed treatment: synth-mean3D-NLTE-gerber-stagger; Turbospectrum on the registered Gerber deck with the horizontally averaged 3D (<3D>) Stagger solar model; not a full 3D calculation. Sources: [3], [4].

Atomic data and gf authorities. Ca I oscillator strengths of this pool, as the product's own uncertainty budget records them (with their lineage). Sources: [6].

Model and grid sources. Feed treatment: 1D NLTE, per-line correction from the Amarsi 2020 GALAH departure grid via PySME (data/nlte_grids/Ca_Amarsi2020_PySME.csv). Sources: [7].

Product-to-source index

VIS · HARPS · Ca II · Asplund et al. 2021 lines · 1D LTE · [1], [2], [3] Ca-products-dd4060b496e3

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