

# THE EXOPLANET CODEX

## Glossary of Terms

[Stellar Spectroscopy](#) · [Elemental Abundances](#) · [Exoplanetary Chemistry](#)

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This glossary defines every technical term used in The Exoplanet Codex — from basic spectroscopy concepts to advanced notation. Each entry includes a formal definition, a plain-English explanation, units, and an example. Use the colour-coded figures to build intuition for concepts that are hard to describe in words alone.

### **How to use this glossary**

Terms are organised alphabetically within thematic sections. If you encounter an unfamiliar term anywhere in the Codex — in the methodology document, on a star page, or in a results table — look it up here first. If something is still unclear, that is a gap we want to fill. Email us at [exoplanetcodex.org](mailto:exoplanetcodex.org).

## 1. The Spectrum

A spectrum is light spread out by wavelength — like a rainbow, but for a star. The diagram below shows the key features you will encounter throughout the Codex.

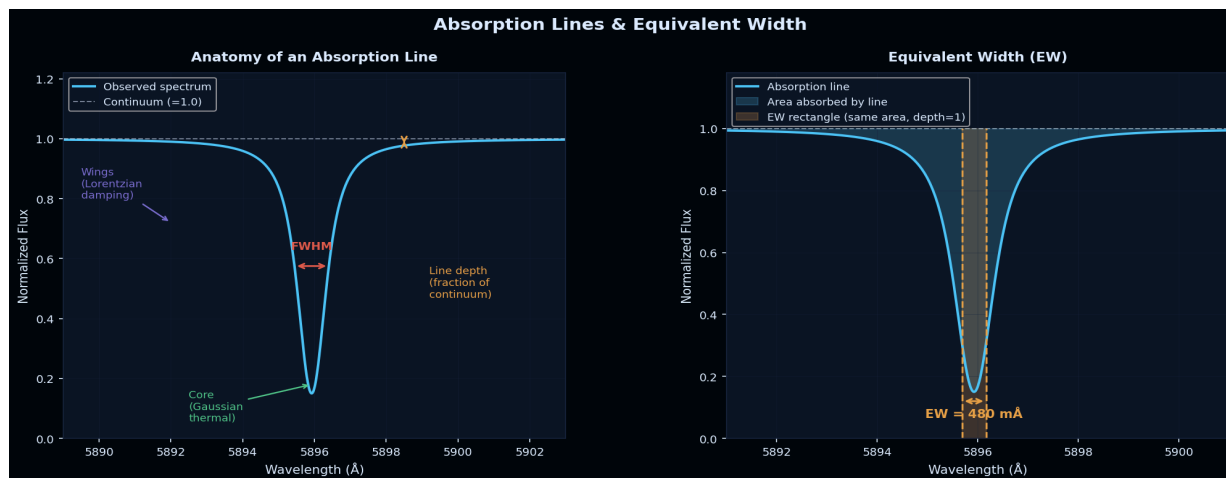


Figure 1. Left: anatomy of a single absorption line, showing the core, wings, depth, and FWHM. Right: the equivalent width (EW) concept — the width of a rectangle that has the same area as the absorption line.

### Spectrum (*SPEK-trum*)

<b>Definition</b>	The distribution of electromagnetic radiation from an object, spread out by wavelength or frequency. A stellar spectrum shows how much light the star emits at each wavelength.
<b>Plain English</b>	Think of it as a detailed "chemical fingerprint" of a star. Just as a supermarket barcode contains information encoded in bars of different widths, a stellar spectrum contains information about the star's composition encoded in the depths and positions of absorption lines.
<b>Units</b>	Wavelength in Angstroms (Å) on x-axis; normalized flux (0 to 1) on y-axis
<b>Example</b>	The HARPS spectrum of 55 Cancri A covers 3780–6910 Å at a resolution of $R \sim 115,000$ .
<b>See also</b>	Absorption line, Continuum, Spectral resolution (R)

### Absorption Line

<b>Definition</b>	A dark feature in a stellar spectrum where atoms in the stellar photosphere have absorbed photons of a specific wavelength, removing that light from the outgoing beam.
<b>Plain English</b>	Imagine a star's light as a full rainbow. Atoms in the outer layers of the star act like tiny "notch filters" — each element absorbs only its specific colours (wavelengths). The result is a rainbow with dark gaps at precise positions.

	Each gap is an absorption line, and each element has a unique set of gap positions — its spectral fingerprint.
<b>Units</b>	Wavelength in Angstroms (Å)
<b>Example</b>	The sodium D1 line at 5895.92 Å is one of the most prominent absorption features in the optical spectrum of a K-type star like 55 Cancri A.
<b>See also</b>	Equivalent Width (EW), Continuum, FWHM

## Continuum

<b>Definition</b>	The smooth underlying flux level of a stellar spectrum, representing light from the photosphere unaffected by discrete atomic transitions. In a normalized spectrum, the continuum equals 1.0.
<b>Plain English</b>	The "baseline" of the spectrum — the bright background against which dark absorption lines appear. Measuring a line's depth requires knowing the continuum level precisely. For metal-rich stars like 55 Cnc ([Fe/H]=+0.32), so many lines overlap that finding the true continuum is challenging.
<b>Units</b>	Normalized flux (dimensionless, set to 1.0)
<b>Example</b>	In the 5000–5400 Å region of 55 Cnc's spectrum, iron lines are so dense that the continuum must be estimated using model atmosphere predictions.
<b>See also</b>	Normalization, Equivalent Width

## Equivalent Width (EW) *(abbrev. EW)*

<b>Definition</b>	A measure of the total absorption by a spectral line, defined as the width (in Angstroms) of a rectangular notch with depth equal to 1 (complete absorption) that has the same area as the actual line profile.
<b>Plain English</b>	The EW is a single number that captures "how much light does this line remove?" regardless of the line's shape. A line that removes a lot of light has a large EW. A faint line has a small EW. The EW is what we measure from the spectrum to eventually calculate how much of each element is present.
<b>Units</b>	Angstroms (Å) or milliAngstroms (mÅ). 1 Å = 1000 mÅ. Most lines: 5–300 mÅ.
<b>Example</b>	The Na I D1 line in 55 Cnc has EW ≈ 480 mÅ (strong). A typical Fe I line has EW ≈ 50–80 mÅ (moderate). A P I line has EW ≈ 12 mÅ (weak — needs high S/N to detect).
<b>See also</b>	Absorption line, Gaussian profile, Voigt profile, Curve of growth

## FWHM — Full Width at Half Maximum

<b>Definition</b>	The width of a spectral line measured at half the maximum line depth. A standard measure of line sharpness.
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<b>Plain English</b>	If a line's deepest point is 0.3 (flux = 0.3 below continuum = 1.0), the FWHM is the wavelength width measured where the line depth equals $0.3/2 = 0.15$ . Narrower lines (small FWHM) are easier to measure and less likely to blend with neighbouring lines. Used in the formula for EW uncertainty: $\sigma_{EW} \approx 1.5 \times \text{FWHM} / \text{S/N}$ .
<b>Units</b>	Angstroms (Å)
<b>Example</b>	A typical HARPS Fe I line has FWHM $\approx 0.08$ – $0.12$ Å. The Na D lines have FWHM $\approx 0.5$ – $1.0$ Å due to their strong pressure-broadened wings.
<b>See also</b>	Broadening, Spectral resolution

## Spectral Resolution (R)

<b>Definition</b>	A dimensionless number defined as $R = \lambda / \Delta\lambda$ , where $\lambda$ is the wavelength and $\Delta\lambda$ is the smallest wavelength difference the instrument can separate. Higher R = sharper, more detailed spectra.
<b>Plain English</b>	Resolution tells you how close together two spectral features can be while still appearing as two separate lines. At $R = 115,000$ (HARPS), two lines just 0.05 Å apart can be distinguished. At $R = 42,000$ (ELODIE, used in 2010), lines must be 0.14 Å apart to be separated. This is why HARPS gives us 3× better detail.
<b>Units</b>	Dimensionless ratio
<b>Example</b>	HARPS: $R \sim 115,000$ . ELODIE (2010 thesis): $R \sim 42,000$ . Typical human eye: $R \sim 100$ (can barely distinguish colours). The [O I] 6300.304 Å line and its Ni I 6300.336 Å blend are only 0.032 Å apart — only resolved at $R > 100,000$ .
<b>See also</b>	HARPS, ELODIE

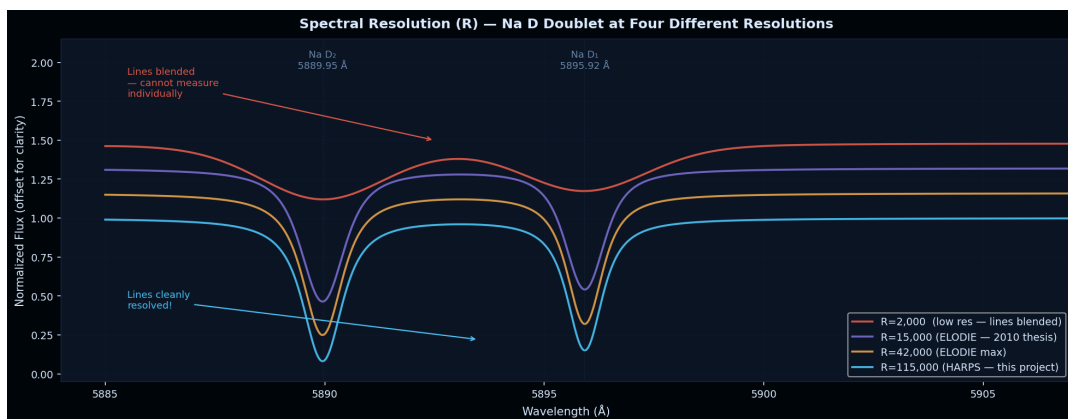


Figure 2. The Na D doublet shown at four different spectral resolutions. At  $R=2,000$  (red), the two lines are completely blended and unresolvable. At  $R=115,000$  (HARPS, blue), both lines are cleanly resolved. Higher resolution also reveals the line wings — critical for accurate EW measurement.



## 2. Line Profiles and Broadening

Real spectral lines are not infinitely sharp — they are broadened by several physical mechanisms. Understanding broadening is essential for choosing the right profile model (Gaussian vs Voigt) and for measuring accurate equivalent widths.

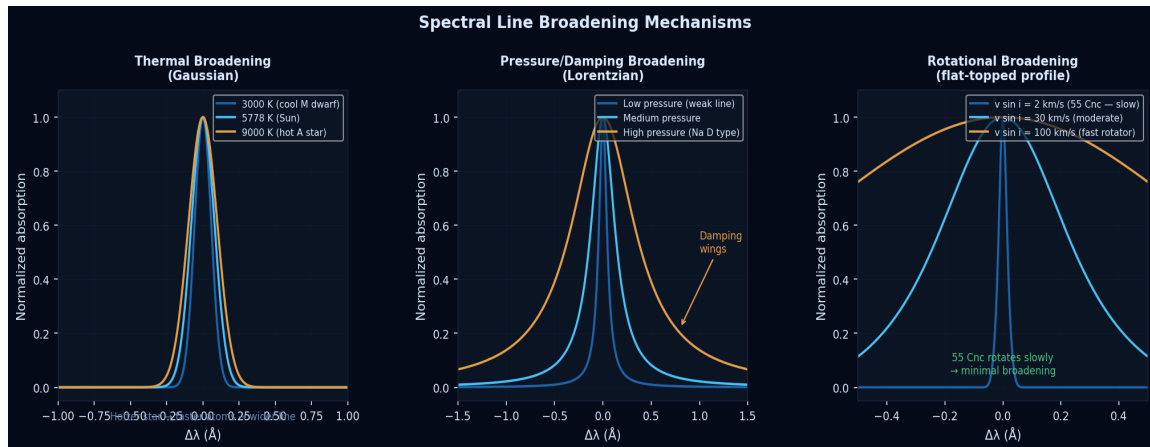


Figure 3. The three main broadening mechanisms. Left: thermal broadening (Gaussian) — hotter stars have broader lines because atoms move faster. Centre: pressure/damping broadening (Lorentzian) — higher pressure widens the line wings. Right: rotational broadening — fast-rotating stars show flat-topped lines because different parts of the star surface move toward and away from us simultaneously. 55 Cancri A rotates slowly ( $v \sin i = 2.3$  km/s), so rotational broadening is negligible.

### Thermal Broadening

<b>Definition</b>	Broadening of a spectral line caused by the random thermal velocities of atoms in the stellar photosphere. Atoms moving toward/away from us Doppler-shift the absorbed wavelength, smearing the line into a Gaussian shape.
<b>Plain English</b>	Imagine a thousand sodium atoms all absorbing light at 5895.92 Å. But they're not sitting still — they're moving randomly (thermal motion). Atoms moving toward us absorb slightly bluer wavelengths; atoms moving away absorb slightly redder ones. The result: the absorption is spread over a small wavelength range, creating a bell-curve (Gaussian) shaped line.
<b>Units</b>	Wavelength (Å); characterized by Gaussian $\sigma$ or FWHM
<b>Example</b>	For 55 Cnc (Teff = 5196 K), thermal broadening gives $\sigma_{\text{thermal}} \approx 0.07\text{--}0.10$ Å for typical lines.
<b>See also</b>	Gaussian profile, FWHM, Voigt profile

### Pressure Broadening / Damping

<b>Definition</b>	Broadening caused by collisions between the absorbing atom and surrounding gas particles, which perturb the atom's energy levels and allow
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	absorption over a range of wavelengths. Creates Lorentzian-shaped wings extending far from the line centre.
<b>Plain English</b>	When sodium atoms collide with neighbouring hydrogen and helium atoms thousands of times per second in the dense photosphere, the collisions momentarily shift the energy levels, allowing absorption at wavelengths slightly offset from 5895.92 Å. This creates broad "wings" on either side of the line core. The Na D lines are extreme examples — their wings extend $\pm 3$ Å from centre.
<b>Units</b>	Wavelength (Å); characterised by damping constant $\gamma_{\text{vdW}}$ (van der Waals) in angular frequency units
<b>Example</b>	Na D lines (EW $\approx 480$ mÅ): heavily damped, broad wings. A weak Fe I line (EW $\approx 50$ mÅ): negligible damping wings. Voigt profile required for lines with EW $> 150$ mÅ.
<b>See also</b>	Voigt profile, Lorentzian, Damping constant

## Gaussian Profile

<b>Definition</b>	A bell-curve shaped line profile: $F(\lambda) = 1 - A \times \exp(-\frac{1}{2}((\lambda-\lambda_0)/\sigma)^2)$ . Describes lines dominated by thermal and instrumental broadening.
<b>Plain English</b>	The same bell curve as a normal distribution in statistics. For weak lines (EW $< 80$ mÅ), the Gaussian is an excellent approximation because thermal broadening dominates. For strong lines (Na D, Mg b), the Gaussian misses the pressure-broadened wings and underestimates the EW by up to 25%.
<b>Units</b>	Depth A (dimensionless, 0 to 1), width $\sigma$ (Å)
<b>Example</b>	A Fe I line at 5328 Å with EW = 75 mÅ: well-fitted by Gaussian. Error vs Voigt $< 2\%$ .
<b>See also</b>	Voigt profile, Lorentzian, Thermal broadening

## Lorentzian Profile

<b>Definition</b>	A profile with broader, slower-decaying wings than a Gaussian: $L(x) = 1/(1 + (x/\gamma)^2)$ . Describes lines dominated by pressure/damping broadening.
<b>Plain English</b>	Named after physicist Hendrik Lorentz. Falls off as $1/x^2$ instead of the Gaussian's $\exp(-x^2)$ — much slower. This means it captures the damping wings of strong lines. However, a pure Lorentzian overestimates the core depth. The correct profile for stellar lines is the Voigt (convolution of Gaussian + Lorentzian).
<b>Units</b>	Half-width $\gamma$ (Å)
<b>Example</b>	The damping wings of Na D extend several Angstroms — clearly Lorentzian in shape.
<b>See also</b>	Gaussian profile, Voigt profile, Pressure broadening

<b>Voigt Profile</b> ( <i>VOIGT</i> )	
<b>Definition</b>	The mathematically correct line profile for stellar absorption lines: the convolution of a Gaussian (thermal + instrumental broadening) and a Lorentzian (pressure/damping broadening). Implemented efficiently using the Faddeeva function.
<b>Plain English</b>	For weak lines, the Voigt profile automatically reduces to a Gaussian (the Lorentzian component is negligible). For strong lines, the Voigt profile captures the broad wings that a pure Gaussian misses. This is why we use Voigt as our standard fit for all lines with $EW > 80 \text{ m}\text{\AA}$ .
<b>Units</b>	Four parameters: amplitude, centre wavelength ( $\text{\AA}$ ), Gaussian FWHM ( $\text{\AA}$ ), Lorentzian FWHM ( $\text{\AA}$ )
<b>Example</b>	Na D1 at $5895.92 \text{ \AA}$ : Voigt fit with $fwhm\_G \approx 0.16 \text{ \AA}$ , $fwhm\_L \approx 0.40 \text{ \AA}$ . $EW \approx 480 \text{ m}\text{\AA}$ . Using Gaussian instead would give $EW \approx 360 \text{ m}\text{\AA}$ — 25% too small.
<b>See also</b>	Gaussian profile, Lorentzian, EW, Damping

<b>Rotational Broadening</b> ( $v \sin i$ )	
<b>Definition</b>	Broadening caused by stellar rotation. The near limb moves away from us; the far limb moves toward us. Both absorb at slightly different wavelengths, broadening lines and flattening their tops.
<b>Plain English</b>	A spinning star has one edge moving toward you (blueshifted) and the other edge moving away (redshifted). Both edges have the same absorption lines, but shifted in opposite directions. The result is a line that appears wider and more flat-topped than a non-rotating star. $v \sin i$ is the rotation speed times the sine of the inclination angle (how tilted the rotation axis is relative to our line of sight).
<b>Units</b>	km/s
<b>Example</b>	55 Cancri A: $v \sin i = 2.3 \text{ km/s}$ — very slow rotator. Rotational broadening is negligible. The Sun: $v \sin i \approx 2 \text{ km/s}$ . A hot A-type star like Vega: $v \sin i \approx 20 \text{ km/s}$ — significantly broadened.
<b>See also</b>	FWHM, Spectral resolution

### 3. Stellar Parameters

Four numbers completely describe the model atmosphere of a main-sequence FGK star. Getting these right is fundamental — errors in stellar parameters propagate into every elemental abundance we measure.

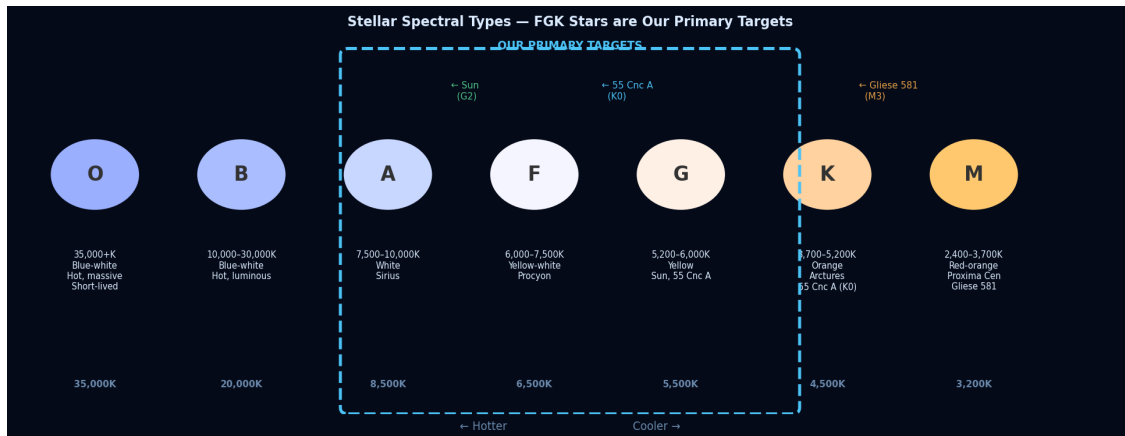


Figure 4. Stellar spectral types from hot blue O stars to cool red M dwarfs. Our primary targets (FGK stars, highlighted) span 3,700–7,500 K and include the Sun (G2), 55 Cancri A (K0), and HD 89307 (G0). Gliese 581 (M3) falls outside this range and requires special treatment.

#### Teff — Effective Temperature ( $T_{\text{eff}}$ )

<b>Definition</b>	The temperature of a perfect blackbody that would emit the same total power as the star. In practice: the temperature of the outer photosphere where visible light escapes.
<b>Plain English</b>	Teff is the single most important parameter for a star. It determines which atoms are ionized vs neutral, which controls which absorption lines appear. A star at 5196 K (55 Cnc) looks slightly more orange than the Sun (5778 K) because it emits relatively more red light. Hotter = bluer = more energetic photons.
<b>Units</b>	Kelvin (K)
<b>Example</b>	55 Cnc: $T_{\text{eff}} = 5196 \pm 24$ K (from CHARA interferometry). Sun: 5778 K. A-type star Vega: 9600 K.
<b>See also</b>	Spectral type, log g, Model atmosphere

#### log g — Surface Gravity

<b>Definition</b>	The base-10 logarithm of the gravitational acceleration at the stellar surface, in cgs units ( $\text{cm/s}^2$ ). Determines atmospheric pressure, which affects line widths and the balance between neutral and ionized atoms.
<b>Plain English</b>	A higher log g means stronger gravity at the surface → denser, higher-pressure atmosphere → more collision broadening → stronger

	damping wings. For dwarfs ( $\log g \approx 4.4$ ) vs giants ( $\log g \approx 2.0$ ), the same spectral line can look completely different. We use Fe I vs Fe II balance to determine $\log g$ (see §4.2 of methodology).
<b>Units</b>	$\log_{10}(\text{cm/s}^2)$ — "dex" (dimensionless logarithm)
<b>Example</b>	55 Cnc: $\log g = 4.41$ . Sun: $\log g = 4.44$ . A red giant: $\log g \approx 2.0$ (much lower pressure).
<b>See also</b>	Teff, Ionization equilibrium, Fe I, Fe II

### Microturbulence ( $\xi$ ) *(xi, "zy")*

<b>Definition</b>	A velocity parameter representing small-scale, non-thermal motions in the stellar photosphere (convective turbulence). Typically 0.8–1.5 km/s for FGK dwarfs. Suppresses saturation of strong lines.
<b>Plain English</b>	Even after accounting for thermal and rotation broadening, strong lines still appear broader than a pure thermal model predicts. This excess broadening is modelled as microturbulence — tiny swirling motions in the photosphere smaller than a mean free path. If $\xi$ is wrong, strong lines and weak lines give different abundances. We derive $\xi$ by requiring all Fe I lines, regardless of strength, to give the same iron abundance.
<b>Units</b>	km/s (velocity)
<b>Example</b>	55 Cnc: $\xi \approx 0.9$ km/s (typical for K dwarfs). Sun: $\xi \approx 1.0$ km/s.
<b>See also</b>	Microturbulence check (§4.2), Curve of growth, EW

### [Fe/H] — Iron Abundance / Metallicity

<b>Definition</b>	The logarithmic ratio of iron abundance in a star relative to the Sun. Used as a proxy for overall "metallicity" (abundance of all heavy elements). $[\text{Fe}/\text{H}] = 0.00$ by definition for the Sun.
<b>Plain English</b>	$[\text{Fe}/\text{H}] = \log(N_{\text{Fe}}/N_{\text{H}})_{\text{star}} - \log(N_{\text{Fe}}/N_{\text{H}})_{\text{Sun}}$ . Each +0.10 dex represents ~26% more iron than the previous level. +0.32 dex (55 Cnc) means roughly twice the solar iron abundance. Stars with more metals are more likely to host planets.
<b>Units</b>	dex (dimensionless logarithmic ratio)
<b>Example</b>	55 Cancri A: $[\text{Fe}/\text{H}] = +0.32$ (metal-rich — twice solar). Sun: $[\text{Fe}/\text{H}] = 0.00$ . HD 89307: $[\text{Fe}/\text{H}] = -0.14$ (slightly metal-poor). Gliese 581: $[\text{Fe}/\text{H}] = -0.33$ .
<b>See also</b>	Metallicity, $[\text{X}/\text{H}]$ , $[\text{X}/\text{Fe}]$ , dex

### Spectral Type (OBAFGKM)

<b>Definition</b>	A classification system for stars based on their surface temperature and the pattern of absorption lines in their spectra. From hottest (O) to coolest (M).
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<b>Plain English</b>	The mnemonic "Oh Be A Fine Girl/Guy, Kiss Me" helps remember the sequence. Each type is subdivided 0–9 (e.g., G2 = slightly hotter than G5). The Sun is G2V — G-type, subtype 2, V = main sequence ("V" is the Roman numeral 5, for luminosity class V).
<b>Units</b>	Unitless classification
<b>Example</b>	Sun: G2V. 55 Cancri A: K0IV-V. HD 89307: G0V. Gliese 581: M3V.
<b>See also</b>	Teff, Main sequence

## 4. Abundance Notation and Units

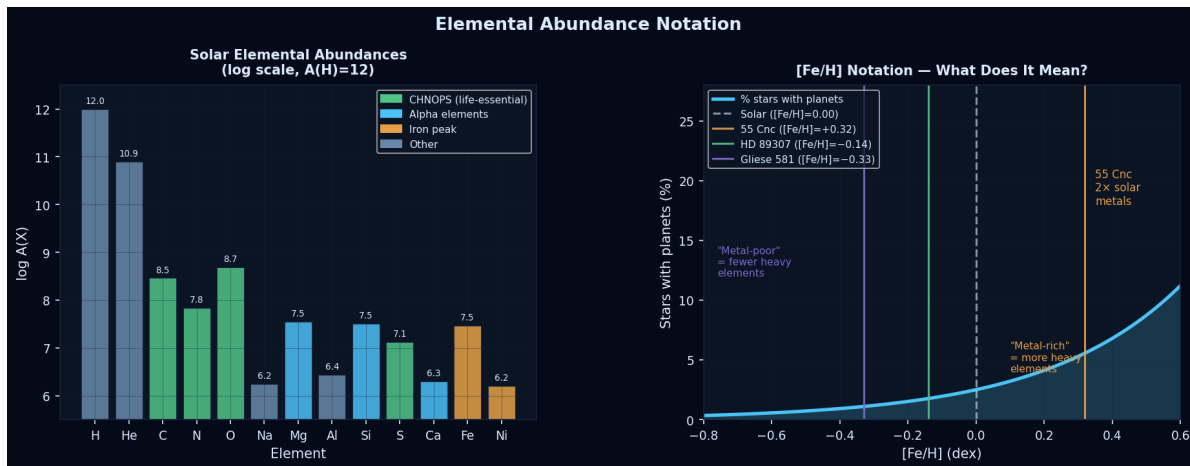


Figure 5. Left: Solar elemental abundances on the logarithmic A(X) scale — hydrogen = 12.00 by definition. Life-essential CHNOPS elements (green), alpha elements (blue), and iron-peak elements (orange) are highlighted. Right: [Fe/H] notation explained, showing how metallicity correlates with the probability of hosting planets. 55 Cancri A at [Fe/H] = +0.32 is at the high-metallicity end.

dex	
<b>Definition</b>	Short for "decimal exponent." A logarithmic unit used throughout astronomy. A difference of 1.0 dex represents a factor of 10 in the actual quantity.
<b>Plain English</b>	1.0 dex = factor of 10. 0.3 dex ≈ factor of 2. 0.1 dex ≈ factor of 1.26 (26% difference). So when we say [Fe/H] = +0.32, it means 55 Cnc has 10 <sup>0.32</sup> ≈ 2.1 times more iron than the Sun.
<b>Units</b>	Dimensionless (logarithmic)
<b>Example</b>	[Fe/H] = +0.32 → factor of ~2.1 more iron than Sun. σ = 0.05 dex → ~12% uncertainty in actual abundance.
<b>See also</b>	[Fe/H], [X/H], A(X)

A(X) — Astronomical Abundance Scale	
<b>Definition</b>	The logarithmic abundance of element X on a scale where hydrogen = 12.00. Defined as $A(X) = \log(N_X/N_H) + 12$ , where $N_X$ and $N_H$ are the number of atoms per unit volume.
<b>Plain English</b>	Why +12? Because hydrogen is the most abundant element in stars — about 10 <sup>12</sup> times more abundant than the least abundant elements. Adding 12 makes all abundances positive and manageable. A(H) = 12.00 always. A(Fe) = 7.46 for the Sun means there are 10 <sup>(7.46-12)</sup> = 10 <sup>(-4.54)</sup> iron atoms per hydrogen atom — roughly 1 iron per 35,000 hydrogens.
<b>Units</b>	Dimensionless (logarithmic)

<b>Example</b>	$A(\text{Fe})_{\text{Sun}} = 7.46$ (Asplund 2021). $A(\text{Na})_{\text{Sun}} = 6.24$ . $A(\text{Fe})_{55\text{Cnc}} \approx 7.78$ ( $[\text{Fe}/\text{H}] = +0.32$ above solar).
<b>See also</b>	$[\text{X}/\text{H}]$ , dex

## $[\text{X}/\text{H}]$ — Elemental Abundance Ratio

<b>Definition</b>	The abundance of element X in a star relative to the Sun, on the logarithmic dex scale. $[\text{X}/\text{H}] = A(\text{X})_{\text{star}} - A(\text{X})_{\text{Sun}}$ .
<b>Plain English</b>	The brackets [ ] are standard notation for "abundance relative to the Sun." $[\text{Fe}/\text{H}] = 0.00$ means the same iron as the Sun. $[\text{C}/\text{H}] = +0.20$ means 60% more carbon than the Sun. This notation removes the very large numbers of $A(\text{X})$ and focuses on differences from solar.
<b>Units</b>	dex
<b>Example</b>	$[\text{Fe}/\text{H}] = +0.32$ (55 Cnc iron). $[\text{Na}/\text{H}] = +0.37$ (estimated sodium). $[\text{O}/\text{H}] = +0.12$ (estimated oxygen — less enhanced than Fe).
<b>See also</b>	$[\text{X}/\text{Fe}]$ , $A(\text{X})$ , dex

## $[\text{X}/\text{Fe}]$ — Abundance Ratio Relative to Iron

<b>Definition</b>	The abundance of element X relative to iron (rather than hydrogen). $[\text{X}/\text{Fe}] = [\text{X}/\text{H}] - [\text{Fe}/\text{H}]$ . Reveals nucleosynthetic patterns independent of overall metallicity.
<b>Plain English</b>	If a star is metal-rich ( $[\text{Fe}/\text{H}] = +0.32$ ), ALL elements tend to be more abundant — that's just what metal-rich means. $[\text{X}/\text{Fe}]$ asks: "is element X enhanced or depleted RELATIVE to iron?" Alpha elements (Mg, Si, Ca) enhanced relative to iron ( $[\alpha/\text{Fe}] > 0$ ) means the star formed early in galactic history, before Type Ia supernovae had time to add iron.
<b>Units</b>	dex
<b>Example</b>	$[\text{Mg}/\text{Fe}] = +0.05$ for 55 Cnc: slightly enhanced Mg relative to Fe — typical for a mildly metal-rich K dwarf. $[\alpha/\text{Fe}] = -0.10$ would indicate iron-rich galactic chemical evolution.
<b>See also</b>	$[\text{X}/\text{H}]$ , Alpha-element enhancement, Galactic chemical evolution

## C/O Ratio

<b>Definition</b>	The ratio of carbon to oxygen atoms in a stellar photosphere (or planetary composition). Solar C/O = 0.55. Below ~0.8: oxygen-rich chemistry (silicates). Above ~0.8: carbon-rich chemistry (SiC, graphite).
<b>Plain English</b>	This is the most important single number for predicting rocky planet composition. On Earth, minerals like quartz ( $\text{SiO}_2$ ), olivine ( $\text{Mg}_2\text{SiO}_4$ ), and feldspar dominate because oxygen is more abundant than carbon (C/O ~ 0.01).

	in Earth's crust). If a star has $C/O > 0.8$ , its planets might instead have silicon carbide (SiC) or graphite — possibly even diamond — instead of silicates. The contested $C/O$ measurement for 55 Cancri (0.78 or $>1?$ ) is a primary science goal of this project.
<b>Units</b>	Dimensionless ratio
<b>Example</b>	Sun: $C/O = 0.55$ . Earth crust: $C/O \ll 1$ (oxygen dominant). Carbon planets (hypothetical): $C/O > 0.8$ .
<b>See also</b>	[C/H], [O/H], Planetary composition

## 5. Model Atmospheres and LTE

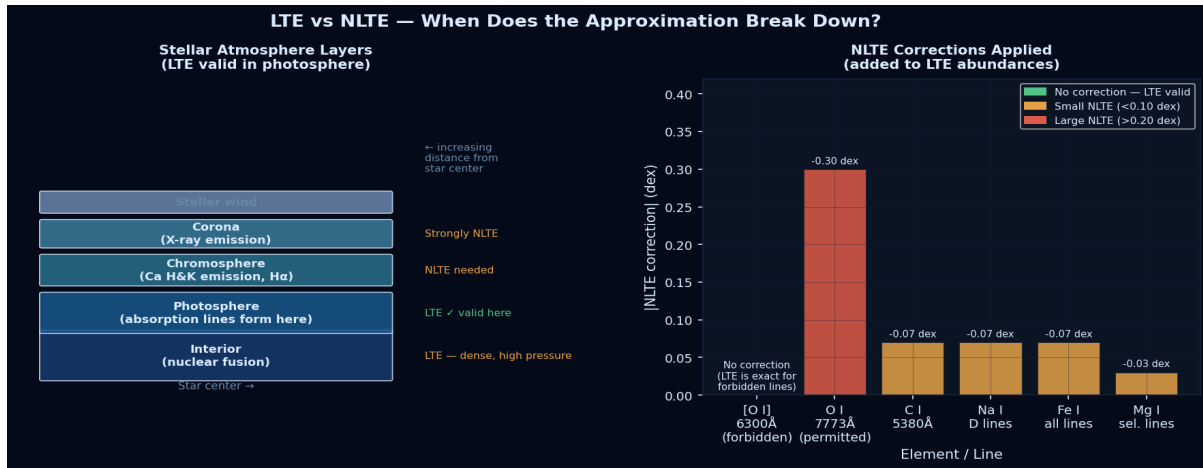


Figure 6. Left: stellar atmosphere layers from the dense interior (LTE valid) through the photosphere (where absorption lines form and LTE is a good approximation) to the chromosphere and corona (NLTE effects become important). Right: NLTE correction magnitudes for key lines. The forbidden [O I] line at 6300 Å requires NO correction — a key reason it is our preferred oxygen indicator.

Model Atmosphere	
<b>Definition</b>	A mathematical model of the physical conditions (temperature, pressure, density, opacity) in a stellar atmosphere as a function of depth, computed from equations of radiative transfer and hydrostatic equilibrium.
<b>Plain English</b>	Without a model atmosphere, we can't convert an absorption line depth into an abundance — we wouldn't know the temperature and pressure conditions where the line was formed. ATLAS9 (Kurucz) provides pre-computed grids of model atmospheres parameterized by $T_{\text{eff}}$ , $\log g$ , $[M/H]$ , and $\xi$ .
<b>Units</b>	N/A — abstract mathematical model
<b>Example</b>	ATLAS9 model for 55 Cnc: $T_{\text{eff}}=5196$ K, $\log g=4.41$ , $[M/H]=+0.32$ . Each model has 64 atmospheric layers with T, P, density at each depth.
<b>See also</b>	ATLAS9, LTE, $T_{\text{eff}}$ , $\log g$

ATLAS9 / Castelli-Kurucz	
<b>Definition</b>	The industry-standard grid of 1D, plane-parallel, LTE model atmospheres for FGK stars, developed by Dr. Robert Kurucz (Harvard) and updated by Castelli & Kurucz (2003). Used in the Exoplanet Codex pipeline.
<b>Plain English</b>	ATLAS9 has been the backbone of stellar abundance analysis since the 1970s. The fact that it's still the standard in 2026 reflects how well the fundamental physics was captured. It's fast, well-tested, and matches observations of FGK dwarfs extremely well. MARCS (Sweden) is an alternative grid used for cross-validation.

<b>Units</b>	N/A — software package and data grid
<b>Example</b>	For 55 Cnc, we interpolate the ATLAS9 grid to exactly $T_{\text{eff}}=5196$ K, $\log g=4.41$ . The model predicts how deep each absorption line should be for a given elemental abundance.
<b>See also</b>	LTE, Model atmosphere, MARCS

## LTE — Local Thermodynamic Equilibrium

<b>Definition</b>	The assumption that each small volume of the photosphere is in thermal equilibrium at the local temperature $T$ , so that the Boltzmann and Saha equations correctly describe the distribution of atoms across energy levels and ionization states.
<b>Plain English</b>	LTE is like assuming that every tiny parcel of stellar gas behaves as a perfect "black box" responding only to its local temperature — not to radiation from other layers or from outside the star. This is an excellent approximation in the dense photospheres of FGK dwarfs, where collisions are so frequent that local thermal equilibrium is maintained. It breaks down in low-density regions (chromosphere, corona).
<b>Units</b>	N/A — physical approximation
<b>Example</b>	LTE valid for: photosphere of FGK dwarfs, most absorption lines. LTE breaks down for: O I 7771-7775 Å triplet (requires NLTE correction of $-0.20$ to $-0.40$ dex); resonance lines of Na I, Li I.
<b>See also</b>	NLTE, Model atmosphere, Saha equation

## NLTE — Non-Local Thermodynamic Equilibrium

<b>Definition</b>	The condition where the radiation field or collisional rates are insufficient to maintain LTE, so the actual level populations differ from Boltzmann/Saha predictions. NLTE corrections are additive offsets applied to LTE abundances.
<b>Plain English</b>	Some spectral lines form partly in the low-density outer photosphere where the radiation field (photons from deep inside the star) "pumps" atoms into higher energy states than thermal collisions alone would produce. This changes the line depth in ways the LTE model can't capture. We apply published NLTE correction grids (Amarsi et al. 2021) to fix this.
<b>Units</b>	Correction in dex, typically $-0.03$ to $-0.40$ dex
<b>Example</b>	O I 7773 Å: NLTE correction $\approx -0.30$ dex. Na I D: $-0.07$ dex. [O I] 6300 Å: 0.00 dex (no correction needed — forbidden lines form under LTE).
<b>See also</b>	LTE, Forbidden line, Amarsi et al.

## Forbidden Line

<b>Definition</b>	A spectral transition that is prohibited under electric-dipole selection rules but can occur via magnetic-dipole or electric-quadrupole transitions. Denoted with brackets: [O I] for the forbidden oxygen line.
<b>Plain English</b>	In high-density environments (like a photosphere), atoms are constantly colliding and de-exciting before they can emit or absorb via forbidden transitions. But in the photosphere, the forbidden [O I] 6300.304 Å line can still form because it's observed as an ABSORPTION line against the bright continuum. The key advantage: forbidden lines form strictly under LTE — no NLTE correction needed, making them cleaner oxygen abundance indicators.
<b>Units</b>	N/A — type of atomic transition
<b>Example</b>	[O I] 6300.304 Å: the most important forbidden line for stellar oxygen abundance work. [N II] 6583 Å, [S II] 6716 Å are also used in nebular spectroscopy. Note: the Ni I blend at 6300.336 Å is only 0.032 Å away — a key systematic for C/O measurements.
<b>See also</b>	LTE, NLTE, [O I], Ni I blend

## 6. Nucleosynthesis and Element Groups

The elements in a star did not form in that star — they were forged in supernovae and other stars over billions of years of galactic chemical evolution. Understanding which process made each element explains the patterns we see in stellar abundances.

Alpha Elements ( $\alpha$ )	
<b>Definition</b>	Elements with atomic masses that are integer multiples of the helium nucleus (alpha particle, mass 4): O, Ne, Mg, Si, S, Ar, Ca, Ti. Produced primarily by massive stars and Type II supernovae.
<b>Plain English</b>	These elements are produced by a process called alpha capture — successive fusion of helium nuclei onto heavier elements. They're called "alpha elements" because each step adds one alpha particle (helium nucleus). Since they come from short-lived massive stars, they were abundant early in galactic history. The ratio $[\alpha/\text{Fe}]$ tells us WHEN a star's birth cloud was enriched.
<b>Units</b>	N/A — element classification
<b>Example</b>	High $[\alpha/\text{Fe}]$ (e.g., +0.3) = old star formed before Type Ia SNe contributed iron. Low $[\alpha/\text{Fe}]$ ( $\sim 0$ ) = star formed after the galaxy had been enriched with iron from Type Ia SNe. 55 Cnc has solar $[\alpha/\text{Fe}]$ — consistent with its $\sim 10$ Gyr age.
<b>See also</b>	Iron-peak elements, Type II supernova, $[\alpha/\text{Fe}]$ , Galactic chemical evolution

Iron-Peak Elements	
<b>Definition</b>	Elements near iron in the periodic table (V, Cr, Mn, Fe, Co, Ni) that have the highest nuclear binding energy per nucleon. Produced primarily by Type Ia supernovae.
<b>Plain English</b>	Iron is the "most stable" nucleus — you can't release energy by fusing iron into heavier elements or splitting it into lighter ones. Elements near iron share this high stability. Type Ia supernovae (white dwarf explosions in binary systems) are the primary source, enriching the galaxy with iron-peak elements over billion-year timescales.
<b>Units</b>	N/A — element classification
<b>Example</b>	Ni/Fe ratio in rocky planets predicts core composition. Co and Cr trace the relative contributions of Type Ia vs Type II supernovae.
<b>See also</b>	Alpha elements, Type Ia supernova, $[\text{Fe}/\text{H}]$

CHNOPS ( <i>SAY-nops</i> )	
<b>Definition</b>	The six elements essential for all known life: Carbon (C), Hydrogen (H), Nitrogen (N), Oxygen (O), Phosphorus (P), Sulfur (S). Their relative abundances in a star predict whether its planets could host life.

<b>Plain English</b>	These six elements make up ~98% of all living matter on Earth. Carbon forms the backbone of organic molecules. Hydrogen and oxygen combine to make water. Nitrogen is in DNA and proteins. Phosphorus is in ATP (the cell's energy currency) and DNA. Sulfur is in amino acids. Phosphorus is now recognised as the LIMITING nutrient — it's the scarcest of the six in most stellar environments and varies by 10× across FGK stars.
<b>Units</b>	N/A — element group acronym
<b>Example</b>	The CHNOPS habitability index compares a star's C:N:O:P:S ratios to the "Redfield ratio" — the composition of marine organisms on Earth.
<b>See also</b>	Habitability, Redfield ratio, P I lines

### s-process Elements (Barium, Yttrium, Europium)

<b>Definition</b>	Elements heavier than iron formed by the slow neutron capture process (s-process) in AGB (Asymptotic Giant Branch) stars. Include Ba, Y, Zr, La, Ce, Nd.
<b>Plain English</b>	When iron nuclei slowly capture neutrons (one at a time), with time between each capture for the nucleus to beta-decay, you build up s-process elements. This happens inside evolved giant stars. The ratio Y/Mg is a stellar "chemical clock" — young stars have more Y relative to Mg because more AGB stars have had time to enrich the galaxy.
<b>Units</b>	N/A — nucleosynthesis process
<b>Example</b>	Ba II 5853.67 Å is a strong, easily measurable s-process line. Y II 4883 Å traces galactic age.
<b>See also</b>	r-process, Alpha elements, Galactic chemical evolution

## 7. Pipeline and Analysis Terms

HARPS	
<b>Definition</b>	High Accuracy Radial velocity Planet Searcher. A spectrograph at the ESO 3.6m telescope, La Silla, Chile. Spectral resolution $R \sim 115,000$ , wavelength coverage 3780–6910 Å. The primary instrument for Exoplanet Codex spectroscopy.
<b>Plain English</b>	HARPS was built to measure stellar radial velocities to 1 m/s precision — accurate enough to detect the wobble caused by an Earth-sized planet. This extreme precision requires high spectral resolution, which is exactly what we need for abundance work. It is also why we have 88 archival HARPS spectra of 55 Cancri — it was a prime target for planet searches.
<b>Units</b>	$R = \lambda/\Delta\lambda = 115,000$ (dimensionless)
<b>Example</b>	HARPS can resolve features separated by 0.05 Å at 5800 Å. ELODIE (used in 2010 thesis): $R \sim 42,000$ .
<b>See also</b>	ELODIE, Spectral resolution, ESO archive

S/N — Signal-to-Noise Ratio	
<b>Definition</b>	The ratio of the signal (flux) to the noise (random fluctuations) in a spectrum. Higher S/N = cleaner, more precise measurements.
<b>Plain English</b>	Every spectrum has noise — random fluctuations from photon counting statistics. $S/N = 200$ means the signal is 200 times the noise. For abundance work, $S/N > 200$ is the minimum; $S/N > 400$ is preferred. Weak lines like P I (EW $\approx 12$ mÅ) require $S/N > 300$ for a reliable measurement.
<b>Units</b>	Dimensionless ratio
<b>Example</b>	55 Cnc single HARPS exposure: $S/N \approx 100$ . Co-added 88 spectra: $S/N \approx \sqrt{88} \times 100 \approx 940$ .
<b>See also</b>	Co-adding, Photon noise, EW uncertainty

Radial Velocity (RV)	
<b>Definition</b>	The component of a star's velocity along our line of sight (toward or away from us). Measured from the Doppler shift of spectral lines. Must be corrected before co-adding spectra.
<b>Plain English</b>	If a star moves toward us, all its spectral lines shift to shorter (bluer) wavelengths. If it moves away, they shift to longer (redder) wavelengths. The formula: $\Delta\lambda/\lambda = v/c$ . 55 Cnc has a systemic RV of +27.58 km/s (receding at 27.58 km/s). Its 5-planet system causes additional RV variation of $\pm 100$ m/s — small but significant when co-adding spectra.
<b>Units</b>	km/s

<b>Example</b>	55 Cnc systemic RV = +27.58 km/s. At 5895 Å, this shifts all lines by: $5895 \times 27.58/299792 \approx 0.54$ Å.
<b>See also</b>	Doppler shift, Barycentric correction, Co-adding

## Barycentric Correction

<b>Definition</b>	A correction applied to observed wavelengths to remove the component of Earth's orbital motion along the line of sight to the star. Applied automatically by the ESO HARPS pipeline.
<b>Plain English</b>	Earth orbits the Sun at ~30 km/s. Depending on the time of year and direction of observation, Earth is moving toward or away from the target star at up to $\pm 30$ km/s. This shifts all spectral lines by up to $\pm 0.6$ Å at 5800 Å. The barycentric correction transforms wavelengths to what would be measured from the solar system barycentre (centre of mass).
<b>Units</b>	km/s velocity correction; Angstroms wavelength shift
<b>Example</b>	The ESO HARPS pipeline applies the barycentric correction to all S1D spectra automatically — we only need to apply the stellar systemic RV correction separately.
<b>See also</b>	Radial velocity, Doppler shift

## Curve of Growth

<b>Definition</b>	The relationship between the equivalent width of a spectral line and the abundance of the absorbing element. Has three regimes: linear, flat (saturated), and damping.
<b>Plain English</b>	If you add more iron atoms to a stellar atmosphere, iron lines get deeper. But the relationship is not simple. Weak lines grow linearly with abundance (more atoms = proportionally deeper). Strong lines saturate (the core is already black — adding more atoms doesn't help). Very strong lines eventually grow again via pressure-broadened wings. The curve of growth tells us which regime each line is in.
<b>Units</b>	Axes: $\log(\text{abundance})$ vs $\log(\text{EW}/\lambda)$ (both dimensionless)
<b>Example</b>	Fe I at 5328 Å (EW=75 mÅ): linear regime. Na D (EW=480 mÅ): damping regime. A flat-part line: sensitive to microturbulence $\xi$ .
<b>See also</b>	Equivalent width, Microturbulence, Voigt profile

## VALD3 — Vienna Atomic Line Database

<b>Definition</b>	The primary online database for atomic and molecular spectral line data, providing wavelengths, excitation potentials, oscillator strengths ( $\log gf$ ), and damping constants for hundreds of millions of spectral transitions.
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<b>Plain English</b>	VALD3 is to stellar spectroscopists what the NIST Standard Reference Materials are to chemists — the authoritative source for atomic data. Before we can calculate abundances from an EW measurement, we need to know the transition probability (log gf) of that line. VALD3 provides this for every line we use. Free registration required at <a href="http://vald.astro.uu.se">vald.astro.uu.se</a> .
<b>Units</b>	N/A — online database
<b>Example</b>	For 55 Cnc, we submitted an "Extract Stellar" request to VALD3 with $T_{\text{eff}}=5196$ K, $\log g=4.41$ , $[M/H]=0.32$ , returning ~15,000 detectable lines across 3780–6910 Å.
<b>See also</b>	log gf, NIST, Excitation potential

## log gf — Oscillator Strength

<b>Definition</b>	The logarithm of the product of the statistical weight (g) and the oscillator strength (f) for an atomic transition. Determines the transition probability — how likely an atom is to absorb a photon of that wavelength.
<b>Plain English</b>	log gf is the "volume knob" for how strong a spectral line is. A high log gf (e.g., 0.0) means a highly probable transition — a strong line. A low log gf (e.g., -5.0) means a very improbable transition — a weak line. For the same abundance, a line with higher log gf will have a larger EW. Poorly known log gf values are a major source of systematic uncertainty in abundance work — we only use NIST grades A and B.
<b>Units</b>	Dimensionless (logarithmic)
<b>Example</b>	Na I D1: log gf = -0.184 (NIST grade A+). Fe I at 5328 Å: log gf = -1.466 (NIST grade A). [O I] 6300 Å: log gf = -9.717 (very weak transition — forbidden line).
<b>See also</b>	NIST quality grades, Oscillator strength, EW

## NIST Quality Grades (A+, A, B, C, D)

<b>Definition</b>	Quality grades assigned by the National Institute of Standards and Technology to oscillator strength (log gf) measurements, based on their estimated uncertainty.
<b>Plain English</b>	Not all log gf values are equally reliable. Laboratory measurements vary in precision. NIST grades each value: A+ (<1% uncertainty), A (<3%), B (<10%), C (<25%), D (>25%). We only use grades A+, A, and B in the Codex pipeline. Using a grade C or D log gf value could introduce a 0.1–0.3 dex systematic error — swamping our actual measurement precision.
<b>Units</b>	Letter grade (A+, A, B, C, D)
<b>Example</b>	We measure ~200 lines total but include only ~140 in our primary analysis after filtering for NIST grade $\geq$ B.
<b>See also</b>	log gf, Systematic uncertainty, NIST



## 8. Key Science Outputs

Mg/Si Ratio	
<b>Definition</b>	The ratio of magnesium to silicon abundance in a stellar photosphere, used to predict the dominant silicate minerals in rocky planets.
<b>Plain English</b>	Magnesium and silicon are the two main ingredients of rock-forming silicates. Their ratio determines the mineral balance: $Mg/Si > 1$ → olivine-dominated mantle ( $Mg_2SiO_4$ , like Earth's upper mantle). $Mg/Si < 1$ → pyroxene-dominated ( $MgSiO_3$ ). This directly predicts whether an exoplanet would have an olivine or pyroxene-rich interior — which affects volcanism, plate tectonics, and potentially habitability.
<b>Units</b>	Dimensionless atomic ratio
<b>Example</b>	Sun: $Mg/Si = 1.05$ . Earth: $Mg/Si \approx 1.02$ . Mars: $Mg/Si \approx 0.95$ . 55 Cnc A: $Mg/Si \approx 0.93$ (literature) — slight pyroxene tendency.
<b>See also</b>	C/O ratio, Fe/Si, Rocky planet composition

Fe/Si Ratio	
<b>Definition</b>	The ratio of iron to silicon abundance, used to predict the core mass fraction of rocky planets.
<b>Plain English</b>	Iron sinks to the core during planetary formation (iron is denser than silicates). Higher Fe/Si in the host star means more iron in the planet, and therefore a larger iron core relative to the mantle. Earth's Fe/Si is higher than solar because of core formation — a large iron core (32% of Earth's mass) concentrated the iron.
<b>Units</b>	Dimensionless atomic ratio
<b>Example</b>	Sun: $Fe/Si = 0.86$ (by mass). Earth: $Fe/Si = 1.69$ (enriched due to large core).
<b>See also</b>	Mg/Si, C/O ratio, Core mass fraction

[ $\alpha$ /Fe] — Alpha Enhancement	
<b>Definition</b>	The mean enhancement of alpha elements relative to iron: $[\alpha/Fe] = \text{mean}([Mg/Fe], [Si/Fe], [Ca/Fe], [Ti/Fe])$ . A tracer of galactic chemical evolution and stellar age.
<b>Plain English</b>	Early in the Milky Way's history, only massive short-lived stars had died, producing alpha elements but little iron. Over time, Type Ia supernovae (which take ~1 billion years to explode) added large amounts of iron, gradually lowering $[\alpha/Fe]$ . Old stars (formed early) have high $[\alpha/Fe]$ ; young stars (like the Sun) have near-solar $[\alpha/Fe]$ .
<b>Units</b>	dex

<b>Example</b>	55 Cnc ( $[\alpha/\text{Fe}] \approx 0$ ): solar-ratio alpha elements — typical for a 10 Gyr old thin-disk star. Metal-poor halo stars ( $[\alpha/\text{Fe}] \approx +0.4$ ): very old, formed before Type Ia SNe.
<b>See also</b>	Alpha elements, Type Ia supernova, Galactic chemical evolution

## CHNOPS Habitability Index

<b>Definition</b>	A quantitative score comparing a star's measured C:N:O:P:S abundance ratios to the "Redfield ratio" — the elemental composition of marine organisms on Earth. Provides a normalised measure of bio-essential element availability.
<b>Plain English</b>	Life on Earth (and presumably elsewhere) needs certain elements in approximately certain ratios. The Redfield ratio (C:N:P = 106:16:1 in marine organisms) is the starting point. By comparing a star's CHNOPS ratios to this biological benchmark, we get a number that captures "how well does this system's chemistry match the chemistry of life?" A score of 1.0 = identical to Redfield. Scores < 1.0 indicate depletion in one or more bio-essential elements.
<b>Units</b>	Dimensionless index (Redfield-normalised)
<b>Example</b>	A star depleted in phosphorus by 10× relative to carbon would score poorly on the CHNOPS index even if C, N, O, and S look fine — because P is the limiting nutrient.
<b>See also</b>	CHNOPS, Redfield ratio, P I lines, Astrobiology