Using APOGEE Stellar Abundances

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This page attempts to address some common questions about APOGEE stellar abundances that are determined from the APOGEE Stellar Parameters and Chemical Abundances Pipeline (ASPCAP). Additional details are given in Holtzman et al. (in prep.).

The APOGEE survey extracts the chemical abundances of multiple elements for the entire stellar sample. In DR17, we present abundances for 20 species: C, C I, N, O, Na, Mg, Al, Si, S, K, Ca, Ti, Ti II, V, Cr, Mn, Fe, Co, Ni, and Ce. In DR17, 3 species were not attempted: Ge, Rb, Yb and the measurements for 4 species were attempted but found to be unsuccessful: P, Cu, Nd, and ^{13}C. The accuracy of an individual element varies with the element and stellar type; certain parts of the element-star parameter space are not feasible to explore with the APOGEE data, as is discussed below. If you are interested in learning more about APOGEE's abundances and their derivation see the DR17 ASPCAP Description or Holtzman et al. (in prep.).

Overview of APOGEE Stellar Abundances

In DR17, we provide abundances for up to 20 species: C, C I, N, O, Na, Mg, Al, Si, S, K, Ca, Ti, Ti II, V, Cr, Mn, Fe, Co, Ni, and Ce. In DR17, 3 species were not attempted: Ge, Rb, Yb and 4 species were attempted but judged to be unsuccessful: P, Cu, Nd, and ^{13}C. We note that C is measured from molecules, C I is measured from neutral carbon lines, Ti is measured from neutral titanium lines, and Ti II is measured from singly ionized titanium lines.

These abundances are each reported in the bracket notation, for instance:

$$[Fe/H] = log_{10}(N_{Fe}/N_H) – log_{10}(N_{Fe}/N_H)_{Sun}.$$

APOGEE's solar scale should be close to the Grevasse et al. (2007) solar values. However, we find that abundances of some elements for stars of solar metallicity in the solar neighborhood come out with non-solar abundance ratios, which is not expected based on previous studies. In addition to the raw spectroscopic values, we provide calibrated values that have been adjusted by addition of a zeropoint to yield a median [X/M]=0 for stars in the solar neighborhood. Users interested in the details of APOGEE's abundance scale should read the DR17 ASPCAP description.

Abundances are provided in various formats: relative to hydrogen (H), relative to total metallicity (M), or relative to iron (Fe). Most users will want to use the metallicity reported by [Fe/H] and the individual elemental abundances relative to iron, e.g., [X/Fe].

As described on the DR17 ASPCAP Description, DR17 uses a new set of synthetic spectral libraries to determine parameters and abundances. This library includes non-local thermal equilibrium (NLTE) treatment for four elements: Na, Mg, K, and Ca.

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Multiple columns with stellar abundances

We provide multiple columns with APOGEE stellar abundances. The raw abundances as measured by FERRE are saved in the `FELEM` array. For a uniform presentation relative to hydrogen or metals, we populate the `X_H_SPEC` and `X_M_SPEC` arrays. Zeropoint calibrations to bring the median of solar metallicity stars in the solar neighborhood to [X/M]=0 are used to populate `X_H` and `X_M`. Finally, "named" tags giving abundances relative to iron (e.g., `MG_FE_SPEC`, `MG_FE`, etc.) are populated from the arrays, but only for objects that have not been identified as problematic.

If you are unfamiliar with APOGEE data we recommend using the "named tags": `FE_H`, and individual elemental abundances measured relative to iron, e.g., `C_FE`, or `MG_FE`. These named tags are the most conservative in how they are populated. Stars with the most suspect abundances or whose abundances are known to be wrong do not have any data in these named tags.

For more complete data, use the X_H and X_M arrays, but be aware that there may be significant issues with some of these. Consult the ASPCAPFLAG and ELEMFLAG bitmasks if you use these.

Uncertainties

Uncertainties on abundances are estimated from repeat observations of stars and can be found in named tags such as `C_FE_ERR`.

In addition to the named uncertainty tags such as `C_FE_ERR`, we also provide the raw uncertainties from ASPCAP's abundance fitting procedure in the `FELEM_ERR` array, but these generally seem to be significantly underestimated. Since the abundances are determined in a separate fit after the parameters have been determined, covariances between abundances and parameters (or other abundances) are not provided.

Quality Flags

Each element has an associated bitmask, e.g., `C_FE_FLAG`, that contains descriptive information about potential issues with the elemental abundance for each star; this is also saved in the `ELEMFLAG` following the order of elements in `FELEM`.

We note that some abundances appear to be unreliable and/or unmeasurable in some regions of parameter space. From visual inspection of trends among solar neighborhood stars, abundances become particularly challenging at our coolest effective temperatures. Based on the results, we have selected effective temperature cuts for some elements, and for stars outside of the acceptable range, we have set a `TEFF_CUT` bit in the abundance bitmask. Stars with this bit set still have the abundances populated in the abundance arrays, but they are not populated in the named tags.

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Quality of derived abundances

While some quality cuts have been applied to the values in the named abundance tags, not all elements have the same quality data. For those who are unfamiliar with APOGEE elemental abundances, we provide a general guideline for the reliability of individual elements below. However, these descriptions are very general and the quality of a given element will vary by metallicity, temperature and S/N (for instance at the lowest metallicities only a few elements remain measurable) and we encourage users to explore the data and make their own judgements.

Challenges with cooler stars

Abundances of cool stars (T_{eff}<4000 K, and especially T_{eff}<3500 K) are particularly challenging, perhaps due to the significant presence of molecular absorption and challenges in interpolating between synthetic spectra in this regime. Shallow minima in the fitting space may also contribute.

For giant stars, several elements appear to be measured in narrow sequences of abundances, sometimes multi-modal, in the coolest stars.

For dwarf stars, abundances seem systematically low, by as much as several tenths of a dex for stars with T_{eff} < 3500 K. In addition, many abundances seem to show an anonymously low dip in abundance between 4000 < T_{eff} < 5000 K that may be related to the presence of very strong lines in this range of effective temperature.

Challenges with warmer stars

At warmer effective temperatures, lines from many elements become weak or disappear. Hotter than 7000 K, it is difficult to determine any abundances, and no calibrated abundances are populated in DR17.

Elements in Giants

DR17 ASPCAP considered measurements for 27 chemical species. However, abundances for Ge, Rb, and Yb were not attempted in D17 and have no measurements. Abundances for P, Cu, Nd, ^{13}C were deemed unsuccessful in DR17 by the ASPCAP team and these values are only present in the raw FERRE output. The remaining 20 species were evaluated for their over all quality as follows:

- ☆ **Most Reliable:** *species that are precisely measured, measured over a wide range of stellar parameters, and follow trends expected from the literature*
- ☆ **Reliable:***species that are less precisely measured, measured over a narrower range of stellar parameters, and follow trends consistent with literature*
- ☆ **Less Reliable:** *less precisely measured, measured over a narrow range of stellar parameters, and have apparent chemical trends consistent with literature*
- ☆ **Deviant:** *measured, but the results deviate from literature expectations*

We stress that these are *general evaluations* and users are advised to independently evaluate chemical species of interest for their sample pursuant to their science goal.

Evaluations of DR17 Chemical Abundances for Giants

Most Reliable:	C, N, O, Mg, Al, Si, Mn, Fe, Ni
Reliable:	C I, Na, K, Ca, Co, Ce
Less Reliable:	S, V, Cr
Deviant in DR17:	Ti, Ti II
Unsuccessful in DR17:	P, Cu, Nd
Not attempted:	Ge, Rb, Yb

Elements in Dwarfs

DR17 ASPCAP considered measurements for 27 chemical species, but APOGEE's abundances for dwarfs are typically not as precise as for giants and the overall quality of these abundances may be slightly lower. As for giants, abundances for Ge, Rb, and Yb were not attempted in D17 and have no measurements. Abundances for P, Ti II, Co, Cu, Ce, Nd, ^{13}C were deemed unsuccessful for dwarfs in DR17 by the ASPCAP team and these values are only in the raw FERRE output. The remaining 17 species were evaluated for their over all quality as follows:

- ☆ **Most Reliable:** *species that are precisely measured, measured over a wide range of stellar parameters, and follow trends expected from the literature*
- ☆ **Reliable:***species that are less precisely measured, measured over a narrower range of stellar parameters, and show vague chemical patterns*
- ☆ **Less Reliable:** *less precisely measured, measured over a narrow range of stellar parameters, and show vague chemical patterns*
- ☆ **Deviant:** *measured, but the results do not show coherent chemical patterns*

We stress that these are *general evaluations* and users are advised to independently evaluate chemical species of interest for their sample pursuant to their science goal.

Evaluations of DR17 Chemical Abundances for Dwarfs

Most Reliable:	C, Mg, Si, Fe, Ni
Reliable:	C I, O, Al, K, Ca, Mn
Less Reliable:	N, S
Deviant in DR17:	Na, Ti, V, Cr
Unsuccessful in DR17:	P, Ti II, Co, Cu, Ce, Nd
Not attempted:	Ge, Rb, Yb

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Systematics in abundances of stars across the HR Diagram

Measuring stellar abundances is a challenging endeavor, and it is difficult to measure them consistently across the HR diagram. While APOGEE applies some basic quality cuts and zero-point calibrations to dwarf and giant abundances, the strength and measurability of spectral lines vary across the HR diagram, so some systematic trends and features may still be found in APOGEE's chemical abundances. Users should exercise caution when comparing the abundances of stars across the HR diagram. To minimize systematic trends, you may not want to compare samples that span a wide range of stellar parameters, or you may need to apply corrections. The only calibrations applied to the abundances are simplistic zero-point corrections, although we do adopt different zero-point corrections for giants (log g < 3.8) and dwarfs.

Particularly difficult parts of the HR diagram are cool stars (with temperatures below $\sim$ 3500 K) due to frequent line blending with strong molecular lines and in "hot" stars (with temperatures above $\sim$ 6000 K) whose atomic and molecular lines are very weak. There are also several elements that have systematic temperature trends for dwarfs cooler than $\sim$ 4500 K.

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What else should I watch out for?

Users should be aware that the precision of abundance measurements decreases with decreasing signal-to-noise (S/N) ratios. APOGEE's target for precision chemical abundances is a S/N of 100, however most elements can be well measured down to a S/N of 70. The precision as a function of S/N differs from element to element depending on the strength of their lines.

Be aware that outliers may not be astrophysical and should be checked to assess the quality of their abundances. Users interested in outliers should consult the `ASPCAPFLAG` bitmask and `STARFLAG` bitmask for those stars to see if they have any quality warnings and may be interested in investigating the spectra of those stars to inspect the lines of their element of interest (see the Using Spectra for details about investigating APOGEE spectra). See the Tutorials for a detailed walk-through of how to investigate a star that appears to be an outlier.

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