

MSG: A software package for interpolating stellar spectra in pre-calculated grids

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Summary

While the spectrum of the light emitted by a star can be calculated by simulating the flow of radiation through each layer of the star's atmosphere, this process is computationally expensive. Therefore, it is often far more efficient to pre-calculate spectra over a grid of photospheric parameters, and then interpolate within this grid. MSG (short for Multidimensional Spectral Grids) is a software package that implements this interpolation capability.

Statement of Need

There are a wide variety of stellar spectral grids published in the astronomical literature — examples include Lanz & Hubeny (2003), Lanz & Hubeny (2007), Kirby (2011), de Laverny et al. (2012), Husser et al. (2013), Allende Prieto et al. (2018), Chiavassa et al. (2018) and Zsargó et al. (2020). However, the ecosystem of software packages that offer users the ability to interpolate in these grids is much more limited:

- FERRE (Allende-Prieto & Apogee Team, 2015) supports piecewise-cubic interpolation in an arbitrary number of photospheric parameters, but is restricted to grids with rectilinear boundaries. Moreover, as a monolithic executable it is not well suited to modular embedding within other projects.
- Starfish (Czekala et al., 2015) offers a Python API supporting piecewise-linear interpolation in an arbitrary number of photospheric parameters (see Mészáros & Allende Prieto, 2013 for a discussion of the limitations of linear schemes).
- stsynphot (STScI Development Team, 2020) also offers a Python API supporting piecewise-linear interpolation, but is restricted to three photospheric parameters and a hard-coded selection of grids.

The limitations of these packages stem in part from their purpose: each has a broader focus than spectral interpolation alone. Guided by the Unix philosophy of 'make each program do one thing well' (McIlroy et al., 1978), this motivates us to develop MSG.

Capabilities

MSG is implemented as a software library with Python, Fortran 2008 and C bindings. These APIs each provide routines for interpolating specific intensity and flux spectra. They are underpinned by OpenMP-parallelized Fortran code that performs energy-conservative interpolation in wavelength λ , parametric interpolation in direction cosine μ using limb-darkening laws, and C^1 -continuous cubic tensor-product interpolation in an arbitrary number of photospheric parameters (effective temperature T_{eff} , surface gravity g , metallicity $[\text{Fe}/\text{H}]$, etc.). Although the topology of grid points must remain Cartesian, their distribution along each separate

dimension need not be uniform. Attempts to interpolate in regions with missing data (e.g., ragged grid boundaries and/or holes) are signalled gracefully via exceptions (Python) or returned status codes (Fortran and C).

To minimize disk space requirements, MSG grids are stored in HDF5 container files with a flexible and extensible schema. Tools are provided that can create these files from existing grids in other formats. Rather than reading an entire grid into memory during program start-up (which is slow and may not even be possible, given that some grids can be hundreds of gigabytes in size), MSG loads data into a cache only when needed; and once the cache size reaches a user-specified limit, data are evicted using a least-recently-used algorithm.

In addition to specific intensity and flux, MSG can evaluate associated quantities such as moments of the radiation field. It can also convolve spectra on-the-fly with filter/instrument response functions, to provide corresponding photometric colors. Therefore, it is a straightforward and complete solution to synthesizing observables (spectra, colors, etc.) for stellar models, and serves as an ideal seasoning to add flavor to stellar astrophysics research.

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