The Journal of Open Source Software

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

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DOI: 10.21105/joss.04602

Software

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Submitted: 05 June 2022
Published: 29 January 2023

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 $T_{\rm eff}$, surface gravity g, metallicity [Fe/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 specificintensity 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.

Acknowledgments

We are grateful to the late Keith Smith for laying the original foundations for MSG, and likewise acknowledge support from NSF grant ACI-1663696 and NASA grant 80NSSC20K0515.

References

Allende Prieto, C., Koesterke, L., Hubeny, I., Bautista, M. A., Barklem, P. S., & Nahar, S. N. (2018). A collection of model stellar spectra for spectral types B to early-M. *Astronomy & Astrophysics*, *618*, A25. https://doi.org/10.1051/0004-6361/201732484

Allende-Prieto, C., & Apogee Team. (2015). FERRE: A Code for Spectroscopic Analysis. *American Astronomical Society Meeting Abstracts*, *225*, 422.07.

Chiavassa, A., Casagrande, L., Collet, R., Magic, Z., Bigot, L., Thévenin, F., & Asplund, M. (2018). The STAGGER-grid: A grid of 3D stellar atmosphere models. V. Synthetic stellar spectra and broad-band photometry. *Astronomy & Astrophysics*, *611*, A11. https://doi.org/10.1051/0004-6361/201732147

Czekala, I., Andrews, S. M., Mandel, K. S., Hogg, D. W., & Green, G. M. (2015). Constructing a Flexible Likelihood Function for Spectroscopic Inference. *812*(2), 128. https://doi.org/10.1088/0004-637X/812/2/128

de Laverny, P., Recio-Blanco, A., Worley, C. C., & Plez, B. (2012). The AMBRE project: A new synthetic grid of high-resolution FGKM stellar spectra. *Astronomy & Astrophysics*, *544*, A126. https://doi.org/10.1051/0004-6361/201219330

Husser, T.-O., Wende-von Berg, S., Dreizler, S., Homeier, D., Reiners, A., Barman, T., & Hauschildt, P. H. (2013). A new extensive library of PHOENIX stellar atmospheres and synthetic spectra. *Astronomy & Astrophysics*, *553*, A6. https://doi.org/10.1051/0004-6361/201219058

Kirby, E. N. (2011). Grids of ATLAS9 Model Atmospheres and MOOG Synthetic Spectra. *Proceedings of the Astronomical Society of the Pacific*, *123*(903), 531. https://doi.org/10.1086/660019

Lanz, T., & Hubeny, I. (2007). A Grid of NLTE Line-blanketed Model Atmospheres of Early B-Type Stars. *Astrophysical Journal Supplement*, *169*, 83–104. https://doi.org/10.1086/511270

Lanz, T., & Hubeny, I. (2003). A Grid of Non-LTE Line-blanketed Model Atmospheres of O-Type Stars. *Astrophysical Journal Supplement*, *146*, 417–441. https://doi.org/10.1086/374373

McIlroy, M. D., Pinson, E. N., & Tague, B. A. (1978). UNIX time-sharing system: forward. *Bell System Technical Journal*, *57*(6), 1899.

Mészáros, Sz., & Allende Prieto, C. (2013). On the interpolation of model atmospheres and high-resolution synthetic stellar spectra. *Monthly Notices of the Royal Astronomical Society*, *430*(4), 3285–3291. https://doi.org/10.1093/mnras/stt130

STScI Development Team. (2020). *stsynphot: synphot for HST and JWST* (p. ascl:2010.003). Astrophysics Source Code Library, record ascl:2010.003.

Zsargó, J., Fierro-Santillán, C. R., Klapp, J., Arrieta, A., Arias, L., Valencia, J. M., Sigalotti, L. D. G., Hareter, M., & Puebla, R. E. (2020). Creating and using large grids of precalculated model atmospheres for a rapid analysis of stellar spectra. *Astronomy & Astrophysics*, *643*, A88. https://doi.org/10.1051/0004-6361/202038066