




gollum: An intuitive programmatic and visual interface for precomputed synthetic spectral model grids

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Summary

The spectra of stars, brown dwarfs, and planets are complex and information-rich. Complexity can be reduced by distilling spectra down to their fundamental stellar parameters: effective temperature, surface gravity, and iron abundance, and sometimes others such as alpha element abundance, carbon-to-oxygen ratio, or sedimentation efficiency of clouds. To a first order, these control the appearance of stellar and substellar spectra. Synthetic spectral models mimic stellar spectra across a grid of these fundamental parameters. Due to the computational constraints of modeling stellar and substellar spectra, model grids have high resolution in the spectral axis (wavelength coordinates) but are coarsely sampled over fundamental stellar parameters. Comparing these grids to data has been a challenge due to the large number of model grids, their size, their coarse sampling, and their dimensionality, making the relation between fundamental stellar parameters and spectral appearance somewhat unintuitive at times. This motivates the development of an intuitive, performant interface allowing astronomers to explore numerous model grids and compare them to data.

Statement of need

gollum is a Python package for intuitive analysis and visualization of precomputed synthetic spectra, targeted towards usage for education and exploratory research. Its API is designed to have modules dedicated to each model grid it supports, with each module then containing classes for both individual spectra and bulk grid access. The programmatic interface to spectral analysis uses method-chaining to make gollum code very readable, taking inspiration from frameworks like lightkurve ([Lightkurve Collaboration et al., 2018](#)). The visual interface in the form of interactive dashboards powered by bokeh ([Bokeh Development Team, 2018](#)) sports low-latency sliders and toggles. This allows users to tweak both fundamental stellar parameters and extrinsic parameters such as radial velocity and rotational broadening, building their intuition. gollum's modularity allows for a wide range of model grids to potentially be supported, and its performance is optimized with libraries such as numpy, scipy, astropy, and specutils to allow for quick loading and processing of large amounts of data ([Astropy Collaboration et al., 2022](#); [Earl et al., 2023](#); [Harris et al., 2020](#); [Virtanen et al., 2020](#)).

gollum appeals to use cases ranging from entry-level astronomers to seasoned researchers with its combination of intuition-building and performance. The framework has been demonstrated on high-resolution spectra of brown dwarfs from Keck-NIRSPEC using bdxda ([Kimani-Stewart](#)

et al., 2021), has experimental support for starspots, used in `acdc` (Cao et al., 2022), and its programmatic interface has been used in the analysis of IGRINS spectra with `plotspec` (Kaplan, 2023). It interoperates with `muler` (Gully-Santiago et al., 2022), a similar framework designed for observed data from échelle spectrographs, and can also be used for flux calibration and empirical telluric correction. `gollum`'s programmatic interface is being used to create an extension to the `blase` framework (Gully-Santiago & Morley, 2022; Shankar & Gully-Santiago, 2023) that will allow for inference of fundamental stellar parameters from observed spectra using interpretable machine learning and interpolation techniques, taking inspiration from other frameworks such as `starfish` (Czekala et al., 2015) that also specialize in spectroscopic inference. `gollum` currently supports PHOENIX, Sonora Bobcat, and Sonora Diamondback, model grids, and implementations for other model grids such as `CoolTLUSTY` and `Sonora Elf Owl` are in progress (Husser et al., 2013; Lacy & Burrows, 2023; Marley et al., 2021; Morley et al., 2024; Mukherjee et al., 2024).

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References

- Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., Earl, N., Starkman, N., Bradley, L., Shupe, D. L., Patil, A. A., Corrales, L., Brasseur, C. E., Nöthe, M., Donath, A., Tollerud, E., Morris, B. M., Ginsburg, A., Vaher, E., Weaver, B. A., Tocknell, J., Jamieson, W., ... Astropy Project Contributors. (2022). The Astropy Project: Sustaining and Growing a Community-oriented Open-source Project and the Latest Major Release (v5.0) of the Core Package. *Astrophysical Journal*, 935(2), 167. <https://doi.org/10.3847/1538-4357/ac7c74>
- Bokeh Development Team. (2018). *Bokeh: Python library for interactive visualization*. <https://bokeh.pydata.org/en/latest/>
- Cao, J., Gully-Santiago, M., Montet, B., & Shankar, S. (2022). `Acdc`: Disentangling AC and DC signals in spotted young stars. In *GitHub repository*. GitHub. <https://github.com/gully/acdc>
- Czekala, I., Andrews, S. M., Mandel, K. S., Hogg, D. W., & Green, G. M. (2015). Constructing a Flexible Likelihood Function for Spectroscopic Inference. *Astrophysical Journal*, 812(2), 128. <https://doi.org/10.1088/0004-637X/812/2/128>
- Earl, N., Tollerud, E., O'Steen, R., brechmos, Kerzendorf, W., Busko, I., shaileshahuja, D'Avella, D., Robitaille, T., Lim, P. L., Ginsburg, A., Homeier, D., Sipócz, B., Averbukh, J., Tocknell, J., Cherinka, B., Ogaz, S., Geda, R., Davies, J., ... Ferguson, H. (2023). *Astropy/specutils*: v1.12.0 (Version v1.12.0). Zenodo. <https://doi.org/10.5281/zenodo.10016569>
- Gully-Santiago, M., Luna, J. L., Morley, C. V., Kaplan, K., Ganesh, A., Sawczynec, E. A., Burke, J., & Krolikowski, D. M. (2022). *Astronomical échelle spectroscopy data analysis with muler* (Version v0.3.4). Zenodo. <https://doi.org/10.5281/zenodo.6539458>
- Gully-Santiago, M., & Morley, C. (2022). An Interpretable Machine-learning Framework for Modeling High-resolution Spectroscopic Data. *Astrophysical Journal*, 941(2), 200. <https://doi.org/10.3847/1538-4357/aca0a2>

- Harris, C. R., Millman, K. J., Walt, S. J. van der, Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., Kerkwijk, M. H. van, Brett, M., Haldane, A., Río, J. F. del, Wiebe, M., Peterson, P., ... Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, *585*(7825), 357–362. <https://doi.org/10.1038/s41586-020-2649-2>
- 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 and Astrophysics*, *553*, A6. <https://doi.org/10.1051/0004-6361/201219058>
- Kaplan, K. (2023). Plotspec: Python code for analyzing reduced 1D and 2D IGRINS spectra. In *GitHub repository*. GitHub. <https://github.com/kfkaplan/plotspec>
- Kimani-Stewart, K., Gonzalez-Argüeta, D., & Gully-Santiago, M. (2021). Bdexda: Interactive brown dwarf NIR spectral analysis. In *GitHub repository*. GitHub. <https://github.com/karina-ks/bdexda>
- Lacy, B., & Burrows, A. (2023). Self-consistent Models of Y Dwarf Atmospheres with Water Clouds and Disequilibrium Chemistry. *Astrophysical Journal*, *950*(1), 8. <https://doi.org/10.3847/1538-4357/acc8cb>
- Lightkurve Collaboration, Cardoso, J. V. d. M., Hedges, C., Gully-Santiago, M., Saunders, N., Cody, A. M., Barclay, T., Hall, O., Sagar, S., Turtelboom, E., Zhang, J., Tzanidakis, A., Mighell, K., Coughlin, J., Bell, K., Berta-Thompson, Z., Williams, P., Dotson, J., & Barentsen, G. (2018). *Lightkurve: Kepler and TESS time series analysis in Python*. Astrophysics Source Code Library.
- Marley, M. S., Saumon, D., Visscher, C., Lupu, R., Freedman, R., Morley, C., Fortney, J. J., Seay, C., Smith, A. J. R. W., Teal, D. J., & Wang, R. (2021). The Sonora Brown Dwarf Atmosphere and Evolution Models. I. Model Description and Application to Cloudless Atmospheres in Rainout Chemical Equilibrium. *Astrophysical Journal*, *920*(2), 85. <https://doi.org/10.3847/1538-4357/ac141d>
- Morley, C. V., Mukherjee, S., Marley, M. S., Fortney, J. J., Visscher, C., Lupu, R., Gharib-Nezhad, E., Thorngren, D., Freedman, R., & Batalha, N. (2024). The Sonora Substellar Atmosphere Models. III. Diamondback: Atmospheric Properties, Spectra, and Evolution for Warm Cloudy Substellar Objects. *arXiv e-Prints*, arXiv:2402.00758. <https://doi.org/10.48550/arXiv.2402.00758>
- Mukherjee, S., Fortney, J. J., Morley, C. V., Batalha, N. E., Marley, M. S., Karalidi, T., Visscher, C., Lupu, R., Freedman, R., & Gharib-Nezhad, E. (2024). The Sonora Substellar Atmosphere Models. IV. Elf Owl: Atmospheric Mixing and Chemical Disequilibrium with Varying Metallicity and C/O Ratios. *arXiv e-Prints*, arXiv:2402.00756. <https://doi.org/10.48550/arXiv.2402.00756>
- Shankar, S., & Gully-Santiago, M. (2023). blase3D: Interpolating the PHOENIX grid to inference fundamental stellar parameters. In *GitHub repository*. GitHub. <https://github.com/SujayShankar2001/blase3D>
- Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., van der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., ... SciPy 1.0 Contributors. (2020). SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python. *Nature Methods*, *17*, 261–272. <https://doi.org/10.1038/s41592-019-0686-2>