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The Dusty Evolved Star Kit (DESK): A Python package for fitting the Spectral Energy Distribution of Evolved Stars

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Software

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Summary

One of the few ways that we can understand the environment around dusty stars and how much material they contribute back to the Universe, is by fitting their brightness at different wavelengths with models that account for how the energy transfers through the dust. Codes for creating models have been developed and refined (Elitzur & Ivezić, 2001; Ueta & Meixner, 2003), but a code for easily fitting data to grids of realistic models has been up-to-this-point unavailable.

The `DESK` is a python package designed to compare the best fits of different stellar samples and model grids for a better understanding of the results and their uncertainties. The package fits the Spectral Energy Distribution (SED) of evolved stars, using photometry or spectra, to grids of radiative transfer models using a least-squares method. The package includes newly created grids using a variety of different dust species, and state-of-the-art dust growth grids (Nanni et al., 2019). Early versions of the code have been used in (Goldman et al., 2019; Goldman et al., 2018, 2017; Orosz et al., 2017)

Statement of need

To understand the ranges and estimated errors of fitted results, they must be compared to results from different model grids. Results from these grids (e.g. luminosity, mass-loss rate) can vary dramatically as a result of the unknown dust properties and geometry of evolved stars (Sargent et al., 2010; Srinivasan, Sargent, & Meixner, 2011; Wiegert, Groenewegen, Jorissen, Decin, & Danilovich, 2020). This is especially true of the oxygen-rich Asymptotic Giant Branch (AGB) stars. Adding to this challenge is the fact that models are calculated based on measured values of the dust (optical constants) which can not be interpolated over. A robust method for testing different model grids will be particularly important given the wealth of infrared data to come from the James Webb Space Telescope (JWST).

User interface

The package can be installed using `pip` and imported within python. Using "entrypoints", the package can also be accessed from any terminal prompt once installed. The fitting method uses a brute-force technique to ensure a true best fit. New grids of multi-dimensional radiative transfer models will be added to the model grid library as they are developed. The available model grids for this version are listed in Table 1.

Figures

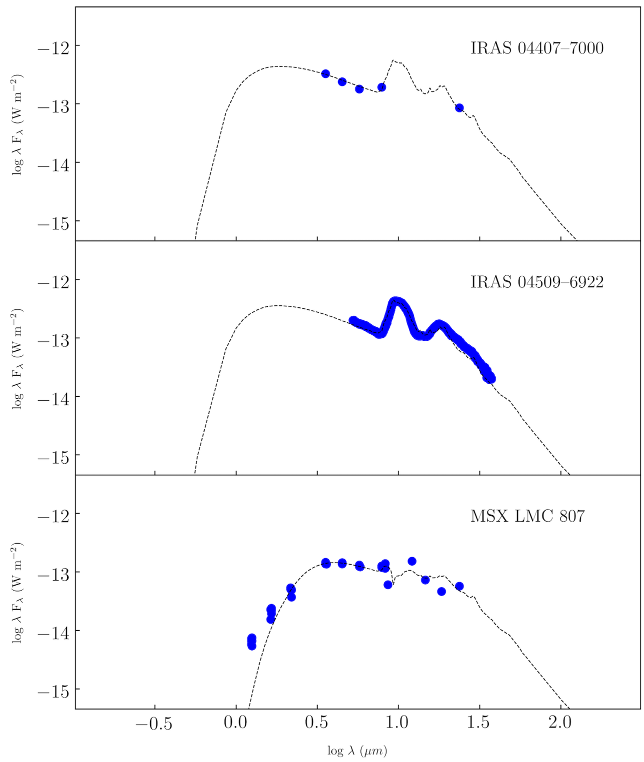

Figure 1: An example of three massive oxygen-rich AGB stars in the Large Magellanic Cloud (LMC) galaxy fit with the default oxygen-rich model grid (Oss-Orich-bb). These three example sources can be fit, and this figure can be created, using the command `desk fit` and then the command `desk sed`.

Table 1: The model grids available with this version. Shown is the name, size, atmospheric model chemical type of either oxygen (O) or carbon (C), the atmospheric model, and a brief description.

Grid name	Size	Type	Atmospheric model	Optical constants	References
Oss-Orich-aringer	2,000	O	COMARCS	Warm silicates	1, 6
Oss-Orich-bb	2,000	O	Black body (BB)	Warm silicates	6
Crystalline-20-bb	2,000	O	BB	80% warm silicates, 20% crystalline silicates	4, 6
corundum-20-bb	2,000	O	BB	80% warm silicates, 20% corundum silicates	2, 6
big-grain	2,000	O	BB	Warm silicates with higher maximum dust grain size of 0.35	6
fifth-iron	500	O	BB	80% warm silicates, 20% iron grains	3, 6
half-iron	500	O	BB	50% warm silicates, 50% iron grains	3, 6
one-fifth-carbon	500	O	BB	80% warm silicates, 20% carbonaceous grains	6, 7
arnold-palmer	500	O	BB	50% warm silicates, 50% carbonaceous grains	6, 7
Zubko-Crich-aringer	2,000	C	COMARCS	Amorphous carbon grains	1, 7
Zubko-Crich-bb	2,000	C	BB	Amorphous carbon grains	7
H11-LMC	90,899	C	COMARCS	Dust-growth grid with 1/2 solar metallicity	5
H11-SMC	91,058	C	COMARCS	Dust-growth grid with 1/5 solar metallicity	5
J1000-LMC	85,392	C	COMARCS	Dust-growth grid with 1/2 solar metallicity	5
J1000-SMC	85,546	C	COMARCS	Dust-growth grid with 1/5 solar metallicity	5

References: **1**: Aringer et al. (2016), **2**: Begemann et al. (1997), **3**: Henning et al. (1995), **4**: Jaeger et al. (1998), **5**: Nanni et al. (2019), **6**: Ossenkopf et al. (1992), **7**: Zubko et al. (1996)

References

Aringer, B., Girardi, L., Nowotny, W., Marigo, P., & Bressan, A. (2016). Synthetic photometry for M and K giants and stellar evolution: hydrostatic dust-free model atmospheres and chemical abundances, *457*(4), 3611–3628. doi:10.1093/mnras/stw222

Begemann, B., Dorschner, J., Henning, T., Mutschke, H., Gürtler, J., Kömpe, C., & Nass, R. (1997). Aluminum Oxide and the Opacity of Oxygen-rich Circumstellar Dust in the 12-17 Micron Range, *476*(1), 199–208. doi:10.1086/303597

Elitzur, M., & Ivezić, Ž. (2001). Dusty winds - I. Self-similar solutions, *327*, 403–421. doi:10.1046/j.1365-8711.2001.04706.x

Goldman, S. R., Boyer, M. L., McQuinn, K. B., Sloan, G. C., McDonald, I., Loon, J. T. van, Zijlstra, A. A., et al. (2019). AGB stars in the nearby dwarf galaxy: Leo p. *ApJ*, *884*, 152. doi:10.3847/1538-4357/ab418a

Goldman, S. R., van Loon, J. T., Gómez, J. F., Green, J. A., Zijlstra, A. A., Nanni, A., Imai, H., et al. (2018). A dearth of OH/IR stars in the Small Magellanic Cloud, *473*, 3835–3853. doi:10.1093/mnras/stx2601

Goldman, S. R., van Loon, J. T., Zijlstra, A. A., Green, J. A., Wood, P. R., Nanni, A., Imai, H., et al. (2017). The wind speeds, dust content, and mass-loss rates of evolved AGB and RSG stars at varying metallicity, *465*(1), 403–433. doi:10.1093/mnras/stw2708

Henning, T., Begemann, B., Mutschke, H., & Dorschner, J. (1995). Optical properties of oxide dust grains., *112*, 143.

Jaeger, C., Molster, F. J., Dorschner, J., Henning, T., Mutschke, H., & Waters, L. B. F. M. (1998). Steps toward interstellar silicate mineralogy. IV. The crystalline revolution, *339*, 904–916.

Nanni, A., Groenewegen, M. A. T., Aringer, B., Rubele, S., Bressan, A., Loon, J. T. van, Goldman, S. R., et al. (2019). The mass-loss, expansion velocities, and dust production rates of carbon stars in the magellanic clouds, *487*, 502–521. doi:10.1093/mnras/stz1255

Orosz, G., Imai, H., Dodson, R., Rioja, M. J., Frey, S., Burns, R. A., Etoka, S., et al. (2017). Astrometry of OH/IR Stars Using 1612 MHz Hydroxyl Masers. I. Annual Parallaxes of WX Psc and OH138.0+7.2, *153*. doi:10.3847/1538-3881/153/3/119

Ossenkopf, V., Henning, T., & Mathis, J. S. (1992). Constraints on cosmic silicates., *261*, 567–578.

Sargent, B. A., Srinivasan, S., Meixner, M., Kemper, F., Tielens, A. G. G. M., Speck, A. K., Matsuura, M., et al. (2010). The mass-loss return from evolved stars to the large magellanic cloud. II. Dust properties for oxygen-rich asymptotic giant branch stars, *716*, 878–890. doi:10.1088/0004-637X/716/1/878

Srinivasan, S., Sargent, B. A., & Meixner, M. (2011). The mass-loss return from evolved stars to the Large Magellanic Cloud. V. The GRAMS carbon-star model grid, *532*, A54. doi:10.1051/0004-6361/201117033

Ueta, T., & Meixner, M. (2003). 2-dust: A dust radiative transfer code for an axisymmetric system, *586*, 1338–1355. doi:10.1086/367818

Wiegert, J., Groenewegen, M. A. T., Jorissen, A., Decin, L., & Danilovich, T. (2020). How to disentangle geometry and mass-loss rate from AGB-star spectral energy distributions – The case of EP Aqr. *arXiv e-prints*, arXiv:2008.11525. Retrieved from http://arxiv.org/abs/2008.11525

Zubko, V. G., Mennella, V., Colangeli, L., & Bussoletti, E. (1996). Optical constants of cosmic carbon analogue grains - I. Simulation of clustering by a modified continuous distribution of ellipsoids, *282*(4), 1321–1329. doi:10.1093/mnras/282.4.1321