

## GAVO TOOLS FOR THE ANALYSIS OF STARS AND NEBULAE

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### ABSTRACT

Within the framework of the German Astrophysical Virtual Observatory (GAVO), we provide synthetic spectra, simulation software for the calculation of NLTE model atmospheres, as well as necessary atomic data. This will enable a VO user to directly compare observation and model-atmosphere spectra on three levels: The easiest and fastest way is the use of our pre-calculated flux-table grid in which one may inter- and extrapolate. For a more precise analysis of an observation, the VO user may improve the fit to the observation by the calculation of individual model atmospheres with fine-tuned photospheric parameters via the WWW interface TMAW. The more experienced VO user may create own atomic-data files for a more detailed analysis and calculate model atmosphere and flux tables with these.

Key words: Stars: atmospheres, Stars: AGB and post-AGB, Stars: early type.

### 1. INTRODUCTION

In the last two decades, we have developed TMAP<sup>1</sup>, the Tübingen NLTE Model-Atmosphere Package (Werner, 1986; Werner et al., 2003; Rauch & Deetjen, 2003). TMAP has been successfully employed to calculate fully line-blanketed model atmospheres for hot, compact stars, e.g. Rauch et al. (2007), under the assumptions of hydrostatic and radiative equilibrium, plane-parallel geometry, and non-local thermodynamic equilibrium (NLTE).

In contrast to fully line-blanketed LTE simulations, such NLTE calculations are still a domain of specialists. Our previous analyses concentrated on pre-white dwarfs like, e.g., central stars of planetary nebulae but our simulations can be easily utilized to white dwarfs, hot subdwarfs, neutron stars, and accretion disks in cataclysmic variables or X-ray binaries. We have presently arrived at a high level of sophistication and include opacities of all elements from hydrogen to nickel.

<sup>1</sup><http://astro.uni-tuebingen.de/~rauch/TMAP/TMAP.html>

For other simulation software which might be included in GAVO in future, the experience with TMAP within this project will help to extend the VO spectral analysis to other stellar spectral types.

### 2. SPECTRAL ANALYSIS VIA GAVO

We aim to provide synthetic spectra in order to compare these directly to observed spectra within the VO. In the case of stellar spectra (Sect. 2.1), flux tables will be provided from the X-ray to the infrared wavelength range (Fig. 3).

#### 2.1. Stars

Based on TMAP (Sect. 1), GAVO aims to provide (please note that the given URLs will change to the GAVO portal<sup>2</sup> later)

- Synthetic Spectra (TMAF<sup>3</sup>)
- Simulation Software (TMAW<sup>4</sup>)
- Atomic Data (TMAD<sup>5</sup>)

With this offer, the way to a reliable spectral analysis for the VO user is threefold:

- A fast and easy spectral analysis is provided for an observation-orientated VO user who may analyze the performed observations with existing model-flux grids (TMAF) which are ready to use and well-suited for inter- or extrapolation (within limits). The grids span generally over a wide range of effective

<sup>2</sup><http://www.g-vo.org/portal/>

<sup>3</sup><http://astro.uni-tuebingen.de/~rauch/TMAF/TMAF.html>

<sup>4</sup><http://astro.uni-tuebingen.de/~rauch/TMAW/TMAW.shtml>

<sup>5</sup><http://astro.uni-tuebingen.de/~rauch/TMAD/TMAD.html>

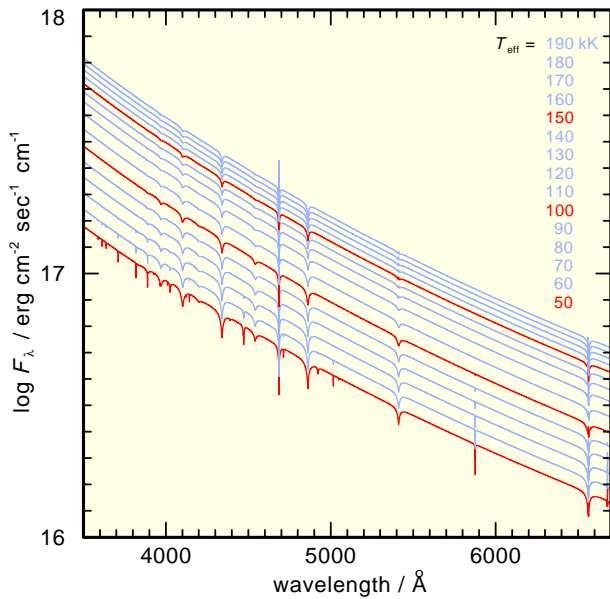


Figure 1. Example of our pre-calculated flux-table grids ( $\log g = 7$ ,  $\{X_{\text{H}}\} = \{X_{\text{He}}\} = 0.5$ ) which are available via TMAF.

temperature ( $T_{\text{eff}} = 50 - 190$  kK) and surface gravity ( $\log g = 5 - 9$ ) for different chemical compositions, e.g., pure H, pure He, H+He (Fig. 1), He+C+N+O, H - Ca (Rauch, 1997), and H - Ni (Rauch, 2003).

- For more detailed investigations of a specific object, where the use of pre-calculated model-grid fluxes is not sufficient, the VO user may calculate individual model atmospheres based on standard model atoms – neither profound knowledge of theory nor experience with the software is here a pre-requisite. The photospheric parameters  $T_{\text{eff}}$ ,  $\log g$ , and mass fractions  $\{X_i\}$  for  $i \in [\text{H}, \text{He}, \text{C}, \text{N}, \text{O}]$  can be adjusted in order to improve the fit to the observation. This is performed via TMAW, a WWW service within GAVO.
- For more experienced observers and theoreticians, who want to compare e.g. their own simulations with results of TMAP, the creation and upload of own atomic-data files is possible. We will provide model atoms which are suited for the use by TMAP. These may be adjusted for an individual object.

TMAW is a WWW interface which provides both, WWW access to existing model-flux grids as well as the possibility to calculate models and fluxes using individual parameters. A scheme of the data flow is shown in Fig. 3. The TMAW user has to enter the photospheric parameters via the TMAW interface (Sect. 2).

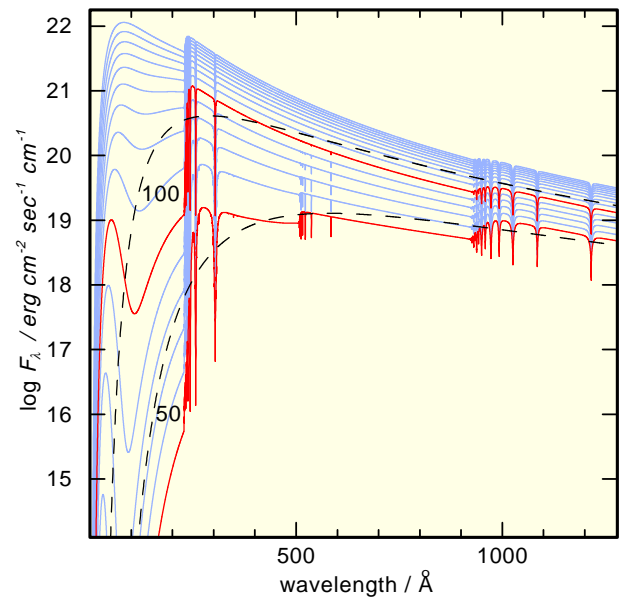


Figure 2. Flux tables calculated from the same models as shown in Fig. 1. For  $T_{\text{eff}} = 50$  kK and 100 kK, blackbody flux distributions are shown in order to demonstrate the deviations.

If a suitable model is already available in the GAVO database at the ARI<sup>6</sup>, it is offered to the VO user. This is done using preset tolerance limits in order to speed up this process and to avoid the calculation of models at unreasonable small grid steps. In case that the VO user accepts this model, only the requested individual flux table will be calculated and then sent to the VO user together with the requested standard flux table. If the search is negative, a complete new model will be calculated at the IAAT<sup>7</sup>.

Depending on the requested  $T_{\text{eff}}$  and  $\{X_i\}$ , an atomic-data file is created using either predefined model atoms or a VO user-created atomic-data file which has to be uploaded before.

The standard calculation starts with the computation of a model in grey approximation which is followed by a NLTE model-atmosphere calculation in a number of steps (first, a so-called “continuum” model is calculated which considers no line opacities and subsequently, a “line” model is calculated which accounts for line-blanketing in addition). Once the model is converged (relative corrections in temperature, densities, occupation numbers less than  $10^{-4}$  in all depth points), a VO user-requested flux table as well as the three standard flux tables (Fig.3) are calculated.

As soon as the model has been calculated, a standard output will be sent to the VO user by email. It comprises flux tables ( $\lambda$ ,  $F_\lambda$ ,  $F_\lambda/F_{\lambda,\text{cont}}$ ) for a selected wavelength range and resolution, plus one of the three standard flux

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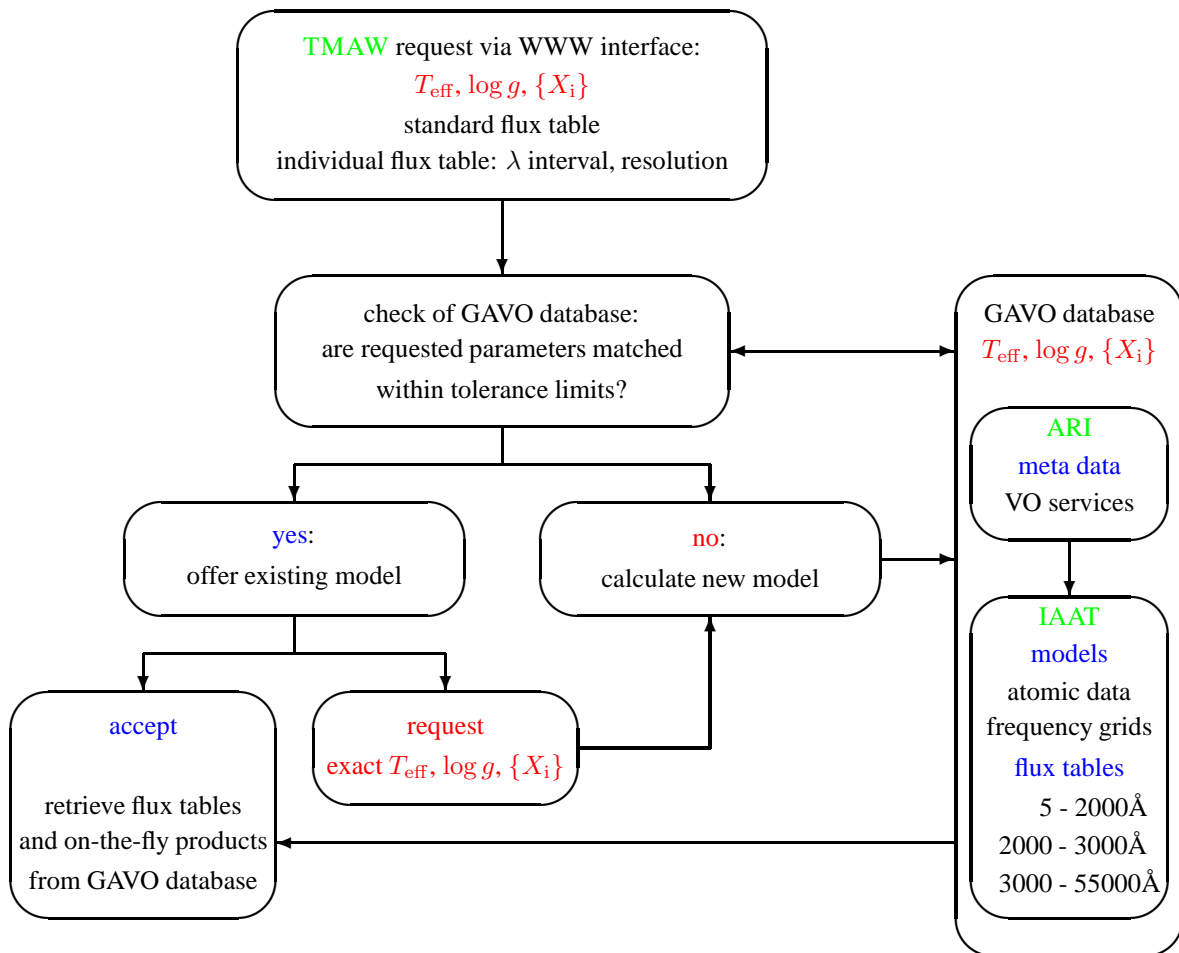


Figure 3. Scheme of TMAW. The VO user sends a flux-table request to the GAVO database by entering the photospheric parameters in TMAW. If a suitable model is available within tolerance limits, this is offered to the VO user. In case that the parameters are not exactly matched, the VO user may decide to request a model with the exact parameters. TMAW will start a model-atmosphere calculation at the IAAT then. As soon as the model is converged, the VO user can retrieve the flux table and various on-the-fly products from the GAVO database.

tables, a plot of the flux table and the output from the last iteration of the TMAP model-atmosphere calculation.

Simultaneously, the meta data of the calculated model will be sent to the ARI database which therefore will be growing in time. The model atmosphere, the respective atomic data and frequency grid files, as well as the standard flux tables remain in the database at the IAAT.

## 2.2. Nebulae

For the analysis of ionized nebulae, a variety of photoionization codes exists. Although realistic model-atmosphere fluxes are used sometimes, it is still common to use easy-to-calculate blackbody-flux distributions to

simulate the exciting star. Examples for deviations are shown, e.g., in Rauch (1997), Armsdorfer et al. (2003), and Osterbrock & Ferland (2006).

One of the standard flux tables (5 – 2000 Å, binned to 0.1 Å intervals, cf. Fig. 2) is well suited as ionizing spectrum for photoionization models of planetary nebulae. Such tables are already used, e.g., by CLOUDY (Ferland et al., 1998) and MOCASSIN (Ercolano et al., 2005). MOCASSIN is already able to deal with TMAP flux tables (e.g. Ercolano et al., 2003) and consequently, we will set up a WWW interface for the control of MOCASSIN which makes directly use of model-atmosphere fluxes within the GAVO database. However, any photoionization code may benefit from the synthetic spectra provided by GAVO.

### 3. CONCLUSIONS AND FUTURE PLANS

Within this GAVO project, we will set up the basics to provide spectral analysis for the VO user. The principal idea has to be that for a VO user this task should be as easy as to collect spectra of an object from the VO. Thus, we will provide spectral analysis for hot, compact stars with our TMAP models at three levels.

The use of model-grid fluxes appears to be the easiest and fastest way for the VO user and it is unimportant how these have been calculated, i.e. no knowledge about the code is necessary. The calculation of model-grid fluxes with other codes like PHOENIX (Hauschildt & Baron, 1999), WRUNIQ (Gräfener et al., 2003), or WM-basic (Pauldrach, 2003), which, e.g., account for mass loss and stellar winds could extend the database considerably.

The easy use of other codes via WWW interfaces like TMAW is highly desirable. This work will be done by the respective working groups.

A more general problem is the use of uniformly formatted model atoms for the different existing model-atmosphere codes like proposed for TMAD by Rauch & Deetjen (2003). This requires a concerted action by all modeling groups.

Precise spectral analysis requires extended grids of elaborated model atmospheres. In the framework of GRID computing (Foster, 2005, 2006), the calculation of model-atmosphere grids and flux tables, e.g. via TMAW, is an excellent application to efficiently calculate synthetic spectra on reasonable time scales.

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### REFERENCES

- Armsdorfer B., Kimeswenger S., & Rauch T. 2003, in: *Proc. IAU Symp. 209. Planetary Nebulae: Their Evolution and Role in the Universe*, eds. S. Kwok, M. Dopita, R. Sutherland, p. 511
- Ercolano, B., Barlow, M. J., Storey, P. J., Liu, X.-W., Rauch, T., & Werner, K. 2003, *MNRAS*, 344, 1145
- Ercolano, B., Barlow, M. J., & Storey, P. J. 2005, *MNRAS*, 362, 1038
- Ferland, G. J., Korista, K. T., Verner, D. A., Ferguson, J. W., Kingdon, J. B., & Verner, E. M. 1998, *PASP*, 110, 761
- Foster, I. 2005, in: *Proceedings of the IFIP International Conference on Network and Parallel Computing (NPC 2005)*, 2
- Foster, I. 2006, in: *The Virtual Observatory in Action: New Science, New Technology, and Next Generation Facilities*, 26th meeting of the IAU, Special Session 3, 6
- Gräfener, G., Koesterke, L., & Hamann, W.-R. 2002, *A&A*, 387, 244
- Hauschildt, P. H., & Baron, E. 1999, *Journal of Computational and Applied Mathematics*, 109, 41
- Osterbrock, D. E., & Ferland, G. J. 2006, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*, 2nd Edition, University Science Books, Sausalito, California
- Pauldrach, A.W.A. 2003, in: *The Cosmic Circuit of Matter*, ed. E. Schielicke, *Reviews in Modern Astronomy*, Vol. 16, p. 133, New York: Wiley-VCH
- Rauch, T. 1997, *A&A*, 320, 237
- Rauch, T. 2003, *A&A*, 403, 709
- Rauch, T., & Deetjen, J. L. 2003, in: *Stellar Atmosphere Modeling*, eds. I. Hubeny, D. Mihalas, K. Werner, *The ASP Conference Series*, Vol. 288, p. 103
- Rauch, T., Ziegler, M., Werner, K., Kruk, J. W., Oliveira, C. M., Vande Putte, D., Migniani, R. P., & Kerber, F. 2007, *A&A* in press
- Werner, K. 1986, *A&A*, 161, 177
- Werner, K., Dreizler, S., Deetjen, J. L., et al. 2003, in: *Stellar Atmosphere Modeling*, eds. I. Hubeny, D. Mihalas, K. Werner, *The ASP Conference Series*, Vol. 288, p. 31