Vega Project

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Abstract

In stellar atmosphere modeling, the effect of rotation is often implemented as rotational broadening applied on top of a non-rotating synthetic spectrum. However, this approach does not work for fast rotators ($v_{eq} > 200\,km/s$), where gravity darkening starts to be prominent. The need for this correction is significant for the main-sequence stars hotter than F7-type. We currently work on a new model atmosphere grid for A- and B-type main sequence stars. The parameter space is extended for equatorial velocity and inclination to provide synthetic spectra and colors corrected for gravity darkening. The model atmosphere grid is calculated using an innovative HPC pipeline developed on top of Red Hat® OpenShift® Container Platform.

Motivation

The gravity-darkening effect alters not only the spectral energy distribution in the continuum but also the shape of spectral line profiles, as shown by Maeder & Peytremann (1970). The luminosity of a fast rotator is just slightly lower than the one of the non-rotating counterpart; however, the mean effective temperature appears to be significantly lower. Fast rotators appear redshifted on an H-R diagram compared to slow rotators with the same composition and mass. At the same time, the apparent effective temperature strongly varies with the inclination of the rotation axis. A pole-on-oriented rotating star appears hotter than the same star oriented perpendicular to the line of sight.

Thanks to CHARA/MIRC, we can perform image reconstruction of the surface of nearby rapid rotators (Figure 1). Contrary to what was anticipated, the gravity-darkening exponent β of the A- and B-type stars turned out to be significantly lower than 1 (Monnier et al. 2014), which is in agreement with the gravity-darkening model proposed by Espinosa Lara & Rieutord (2011).

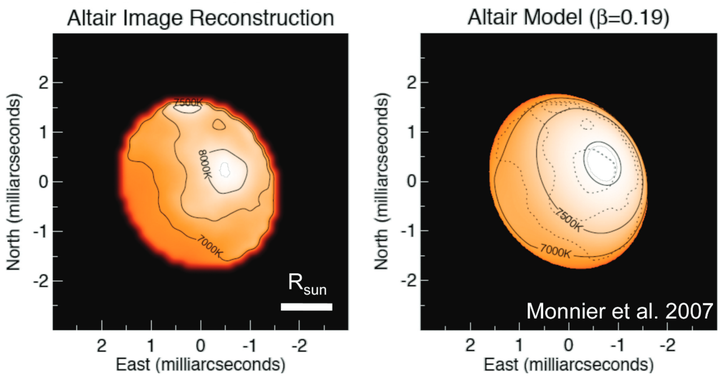

Fig. 1: First reconstructed image of a MS star other than Sun compared to a model (Monnier et al. 2007).

The inclination of the rotational axis of individual stars is mostly unknown. The construction of a model atmosphere grid covering A- and B-type MS stars can provide a tool to constrain the previously unknown inclination of the rotation axis.

Since the position of rotating stars on an H-R diagram depends on rotational velocity and axial tilt, neglecting the population of the fast rotators in a star cluster could undermine the cluster age and distance determination given by isochrone fitting.

Model

Our gravity darkening model follows the method by Espinosa Lara & Rieutord (2011). To calculate the specific intensity of individual surface points, we use 1D model atmosphere code; ATLAS12 (Kurucz 2013) for $T_{eff} < 12\,000$ K and TLUSTY code (Hubeny et al. 2021) for $T_{eff} > 12\,000$ K. The resulting integrated spectrum is corrected for the rotational broadening given by computed $v_{eq} \sin i$ value. As explained by Pérez Hernández et al. (1999), rotational broadening does not change equivalent width, so passband convolution can be calculated before applying the rotational broadening correction.

Challenges

The parameter space of the new model atmosphere grid is defined by Table 1.

Parameter	Range	Step
Effective Temperature	$10\,000\,K \leq T_{eff} \leq 30\,000\,K$	200 K
Surface Gravity	$1 \leq \log g \leq 5$	1 dex
Metallicity	$+0.5 \leq [Fe/H] \leq -2$	0.5 dex
Microturbulence	$0\,km/s \leq \xi \leq 4\,km/s$	$1\,km/s$
Equatorial Velocity	$150\,km/s \leq v_{eq} \leq 250\,km/s$	$50\,km/s$
Inclination of Rotational Axis	$5° \leq i \leq 90°$	5°, 10°

Tab. 1: Parameter space of the new model atmosphere grid.

It covers 100 points in effective temperature × 20 points in surface gravity × 5 points in metallicity × 5 points in microturbulence × 6 points in equatorial velocity × 10 points in inclination. To reach good surface coverage, we use approx. 10^4 surface points. As a result, we need to perform 10^{10} 1D model atmosphere calculations in total to complete the grid. To get at least close to this goal, we needed to parallelize all independent computational tasks. At the same time, we dedicated a new computing cluster to fulfill this goal.

Architecture

The underlying architecture of the Vega Project is summarized in Figure 2. The project is built on top of the Red Hat® OpenShift® Container Platform deployed in a bare-metal cluster and consists of multiple controllers.

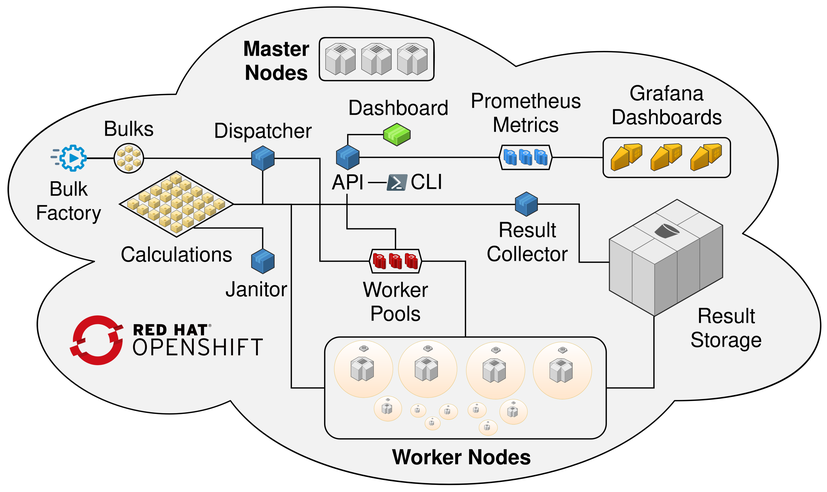

Fig. 2: A scheme of the Vega project architecture.

- *Dispatcher* manages *Calculation Bulks*, is responsible for creating individual *Calculations*, and assigns them to the available *Worker Nodes*.
- *Janitor* is in charge of cleaning up all the obsolete *Calculations*, e.g., those beyond their retention time.
- *Result Collector* gathers the results of each completed *Calculation* and stores them in an NFS storage.
- *API* integrates all controllers and exposes information about all objects.
- *Worker Pools* enable sharing of the cluster resources among multiple projects.
- *Bulk Factory* dynamically generates *Calculation Bulks* on demand.

Calculation Pipeline

The pipeline (Figure 3) runs the independent calculations in parallel while maximizing utilization of the available resources.

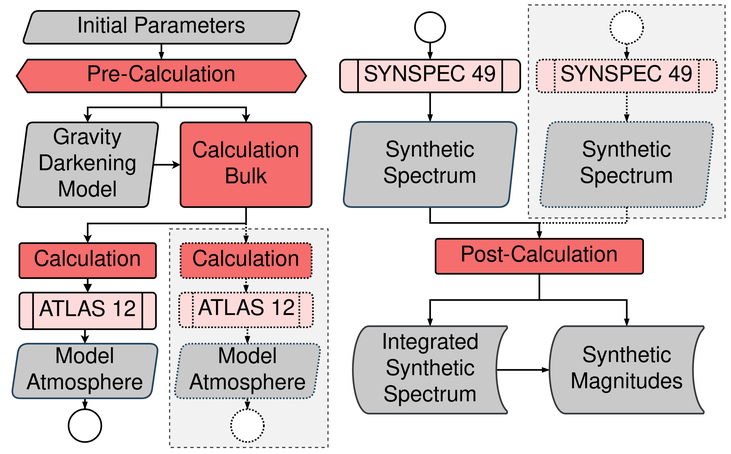

Fig. 3: A diagram of the Vega project pipeline.

Conclusion

Construction of model atmospheres for A- and B-type main-sequence stars that incorporate robust gravity darkening model (Espinosa Lara & Rieutord 2011) can give us the more precise position of a star on an H-R diagram, especially in the case of fast rotators, leading to more accurate stellar parameters. The possibility of inverse calculation to determine the axial tilt of individual stars enables us to perform an extensive study of the inclination distribution in the Milky Way Galaxy and the Magellanic Clouds. The Red Hat® OpenShift® Container Platform allowed us to parallelize the calculation in a modular and scalable way without modifying the original model atmosphere code.

Acknowledgements

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