3D Modeling of Solar-Type Stars to Characterize Stellar Jitter

Irina N. Kitiashvili[1], Alan A. Wray[1], Samuel Granovsky[1-3]

[1]NASA Ames Research Center, [2]University Space Research Association, [2]New Jersey Institute of Technology

irina.n.kitiashvili@nasa.gov

Detection of Earth-mass planets requires measurements of radial velocity with extreme precision. To capture the tiny disturbances caused by a planet's motion, it is necessary to understand and characterize the host star's turbulent dynamics in order to apply proper filtering to the observational data. We take advantage of current computational and technological capabilities to develop 3D realistic models of the stellar subsurface convection and atmospheres and thereby estimate the photospheric jitter. We have identified an initial set of target stars, obtained initial conditions using the MESA code, and obtained initial 3D radiative models of the stellar surfaces and atmospheres with a spatial resolution of 50km. We present initial 3D radiative hydrodynamic model results of the planet-hosting star HD209458.

Introduction

Today's quickly improving computational capabilities allow us to generate 3D time-dependent simulations of stellar convection capable of reproducing the surface turbulent dynamics and radiation properties with a high degree of realism.

In this study, we use state-of-art 3D radiative simulations that include precise calculation of radiative transfer and turbulent magnetoconvection initialized using a realistic interior structure obtained from the MESA stellar evolution code (Paxton et al., 2011). Our previous 3D numerical simulations of different types of stars in the mass range from $1M_{Sun}$ to $1.7M_{Sun}$ (effective temperatures from 5777K to 7063K) have shown a clear organization of 'small' and 'large' granules on the stellar surface in clusters. Such structuring affects the oscillatory properties of the stellar convection (Kitiashvili et al., 2016).

The simulations are performed for computational domains covering the stellar envelopes from deep convection layers (12,000km below the photosphere) to the atmosphere. The simulations include high-precision radiative transfer calculations that are critical for validating the model results and characterizing the stellar jitter.

'StellarBox' code to perform 3D time-dependent radiative modeling (Wray et al., 2018)

- 3D rectangular geometry
- Fully conservative, Fully compressible
- Fully coupled radiation solver:
- LTE using 4 opacity-distribution-function bins
- Ray-tracing transport by Feautrier method
- 18 ray angular quadrature
- Non-ideal (tabular) EOS
- 4th order Padé spatial discretization
- 4th order Runge-Kutta time integration
- Turbulence models:

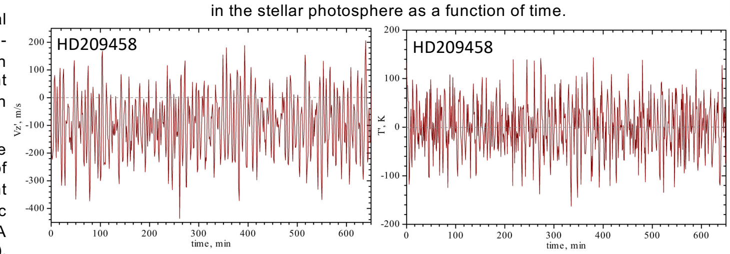
- Compressible Smagorinsky model
- Compressible Dynamic Smagorinsky model (Germano et al., 1991; Moin et al., 1991)
- MHD subgrid models (Theobald et al., 1994; Balarac et al., 2010)

- Effect of rotation
- Metallicity effects
- MPI parallelization

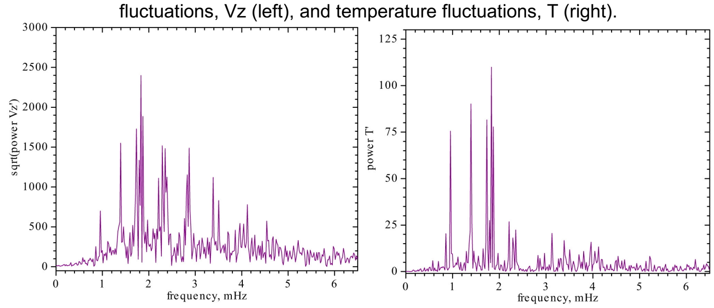
'SPINOR' code to compute high-resolution spectra of Fe I lines (Frutiger et al. 2000)

The SPINOR code was developed to solve the forward radiation transfer problem in the LTE approximation (STOPRO package) and perform inversions of observational spectro-polarimetric data. We use the STOPRO package for calculating the synthetic data of selected Fe I lines at different locations on the stellar disk, where the input parameters are the atomic data of the lines and stellar atmospheric parameters.

Radial velocity (left) and temperature fluctuations (right) in the stellar photosphere as a function of time.



Power spectrum of low-degree (radial) stellar oscillations for vertical velocity fluctuations, Vz (left), and temperature fluctuations, T (right).



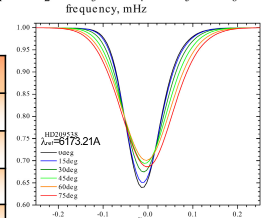
Stellar parameters

Star	Mass	Teff	log(g)	[Fe/H]*	Refs.**
HD209458	1.05	6095	4.314	-0.144	[1,2]
HD121504	1.18	6067	4.355	0.236	[3]
HD25171	1.08	6169	4.329	-0.032	[4]
HD49674	1.00	5597	4.408	0.126	[5]
HD69830	0.87	5383	4.469	0.038	[6]

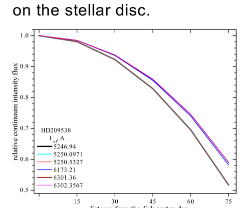
*Metallicity relative to Grevesse & Sauval (1998) solar abundances

**Stellar properties from these papers have been used as a reference for stellar parameters to calculate the initial conditions using the MESA code.

References: [1] Boyajian et al., 2015; [2] del Burgo & Allende Prieto, 2016; [3] Santos et al., 2004; [4] Moutou et al., 2011; [5] Brewer et al., 2016; [6] Tanner et al., 2015

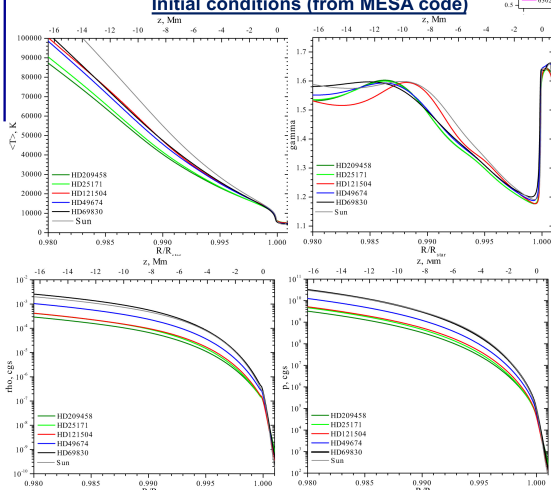


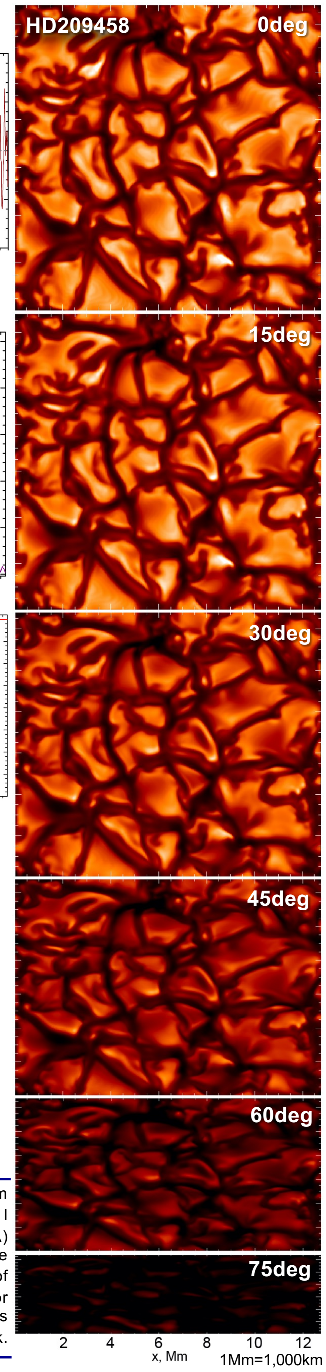
Evolution of the Fe I line shape at different locations on the stellar disc.



Center-to-limb variation of the continuum intensity for six Fe I spectral lines.

Initial conditions (from MESA code)





Synthetic continuum images of the Fe I line (6302A) computed from the radiative model of HD209458 for different locations on the stellar disk.

Conclusions: To estimate the contribution of stellar jitter, we selected several solar-type stars with detected Jupiter-size planets and performed 3D radiative modeling of these stars. The initial results reproduce the observed spectral properties of convection and oscillation, such as oscillation spectra, center-to-limb variations of line profiles, and convective blue shift. The next step is to compare the synthetic spectral data with high-resolution observations and estimate characteristics of the stellar jitter sources.

References

Balarac G. et al. 2010. ArXiV: 1010.5759.
Boyajian T. et al., 2015. MNRAS 447, p.846-857
Brewer J.M. et al., 2016. ApJS 225, article id. 32, 36 pp.
del Burgo C. & Allende Prieto C. 2016. MNRAS 463, p.1400
Germano M. et al. 1991. Physics of Fluids 3, 1760.
Grevesse N. & Sauval A.J. 1998. SSR 85, p. 161-174
Frutiger et al. 2000. A&A 358, 1109–1121.
Kitiashvili et al., 2016. ApJ 821, L17
Moin P. et al. 1991. Physics of Fluids 3, 2746.
Moutou C. et al., 2011. A&A 527, id.A63, 11 pp.
Paxton etal., 2011. ApJS 192, 35 pp.
Santos N.C. et al., 2004. A&A 415, p.1153-1166.
Tanner A. et al., 2015. ApJ 800, article id. 115, 5 pp.
Theobald M. L. et al. 1994. Physics of Plasmas 1, 3016.
Wray A.A. et al. EDP Sciences, 2018. p.39.

Acknowledgements

The work is supported by Extreme Precision Radial Velocity Foundation Science Program.