Imaging stellar surfaces with VLTI and 3D radiative hydrodynamics simulations

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Main collaborations
Simulations: B. Freytag, L. Bigot, R. Collet, B. Plez
Outline

- 3D hydrodynamical simulations of stellar atmosphere
- VLTI-AMBER image of massive evolved star VX Sgr
- Conclusions
• The atmosphere is the boundary to the invisible stellar interior: link between models of stars and stellar evolution and observations. Study of chemical composition due to dredge-up process and fundamental stellar parameters.

• The atmosphere is the inner boundary to the outer atmospheric region: effects on the interstellar medium, throughout radiation or mass loss. Contribution to the chemical evolution of the Galaxy.
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3D hydrodynamical simulations of stellar atmosphere

Realistic 3D simulations of stellar convection

Numerical grid: $200^3 - 300^3 - 500^3$

- Hydrodynamics
- Radiative Transfer (indispensable)
- Opacities
- Time dependent

GLOBAL SIMULATIONS
for red supergiant and AGB stars
(CO5BOLD – Freytag et al. 2002;
Chiavassa, Freytag, Masseron, Plez
2011, arxiv: 1109.3619)
3D hydrodynamical simulations of stellar atmosphere

Bolometric Intensity

Temperature Volume Rendering

Sun

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3D hydrodynamical simulations of stellar atmosphere

Large convective cells up to 60% of the radius. \textit{TIMECALE... decades}

Chiavassa, Haubois, Young et al., A&A 2010, 515, id.A12

\begin{itemize}
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\end{itemize}

Smaller convective cells on top of large structures. \textit{TIMESCALE... weeks to months}
3D hydrodynamical simulations of stellar atmosphere

LOCAL SIMULATIONS used to compute K giants, main sequence stars and the Sun

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3D hydrodynamical simulations of stellar atmosphere

3D hydrodynamical simulations of stellar atmosphere

- Red giant stars
- Procyon like stars
- Solar like stars
3D hydrodynamical simulations of stellar atmosphere
3D hydrodynamical simulations of stellar atmosphere

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3D hydrodynamical simulations of stellar atmosphere

INPUT:
Snapshots of synthetic images at different wavelength/filters

Fourier Transform
The interferometric observables

Predicted Visibilities

Predicted Closure Phases

Deviations from symmetric sources!!!

Deviations from symmetric sources (0-180 degrees)!!!


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AGB star? RSG star? Or super-AGB star?

Meynet & Maeder, 2003
Observations between May-July 2008

Low resolution AMBER data with FINITO (H-K band)

Configurations A0-D0-H0, D0-H0-G1, and E0-G0-H0.

Absolute wavelength correction done using the telluric Kitt Peak spectra (convolved to AMBER resolution)
VLTI-AMBER image of massive evolved star VX Sgr

Chiavassa, Lacour, Millour et al., A&A 2010, 511, id.A51 → reconstruction done with MIRA software

- 1.60 μm
- 2.00 μm
- 2.50 μm

H⁻ minimum opacity
Contributing molecules?
Contributing molecules?
Interferometric imaging to constrain 3D models in terms of: intensity surface contrast, convective size, temporal variations

VLTI-AMBER image of massive evolved star VX Sgr
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**VLTI-AMBER image of massive evolved star VX Sgr**

**VX Sgr DATA**
1D O-rich Mira model (Ireland et al. 2004 a,b)
3D RSG model (Chiavassa et al. 2009)
3D AGB model (Freytag & Hoefner 2008)

**Best visibility fit with 1D Mira models:**
H2O molecules strongly affect the visibility and dominant absorber
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3D predictions are for:

- Red supergiants
- AGBs
- K Giants

Main sequence

Multi-epoch & multiwavelength Imaging, interferometric, and spectrophotometric predictions for all HR diagram!

Ten Years of VLTI

Andrea Chiavassa

Chiavassa et al. 2011, A&A, 528,


Chiavassa et al. 2012, In prep

Conclusions

• **Synergy between theory and observations:** 3D hydrodynamical simulations necessary for a quantitative analysis and interferometry constrain models.

• Visible region gives a lot of spectral information!

• Multiwavelength imaging is crucial for understanding physical processes