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

Observations: F. Millour, M. Wittkowki, P. Cruzalèbes, O. Chesneau, P. Kervella, G. Perrin, B. Lopez

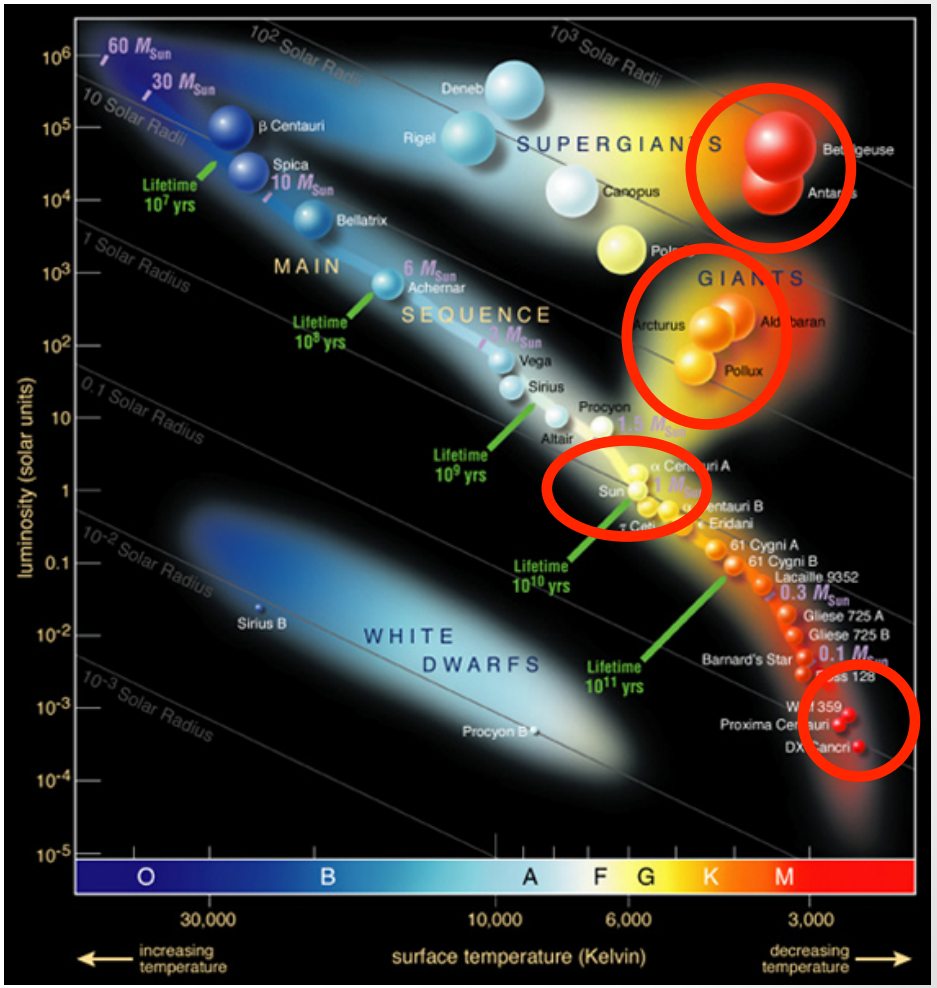
Outline

- 3D hydrodynamical simulations of stellar atmosphere
- VLTI-AMBER image of massive evolved star VX Sgr
- Conclusions

Introduction

- 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.



Outline

- 3D hydrodynamical simulations of stellar atmosphere
- VL
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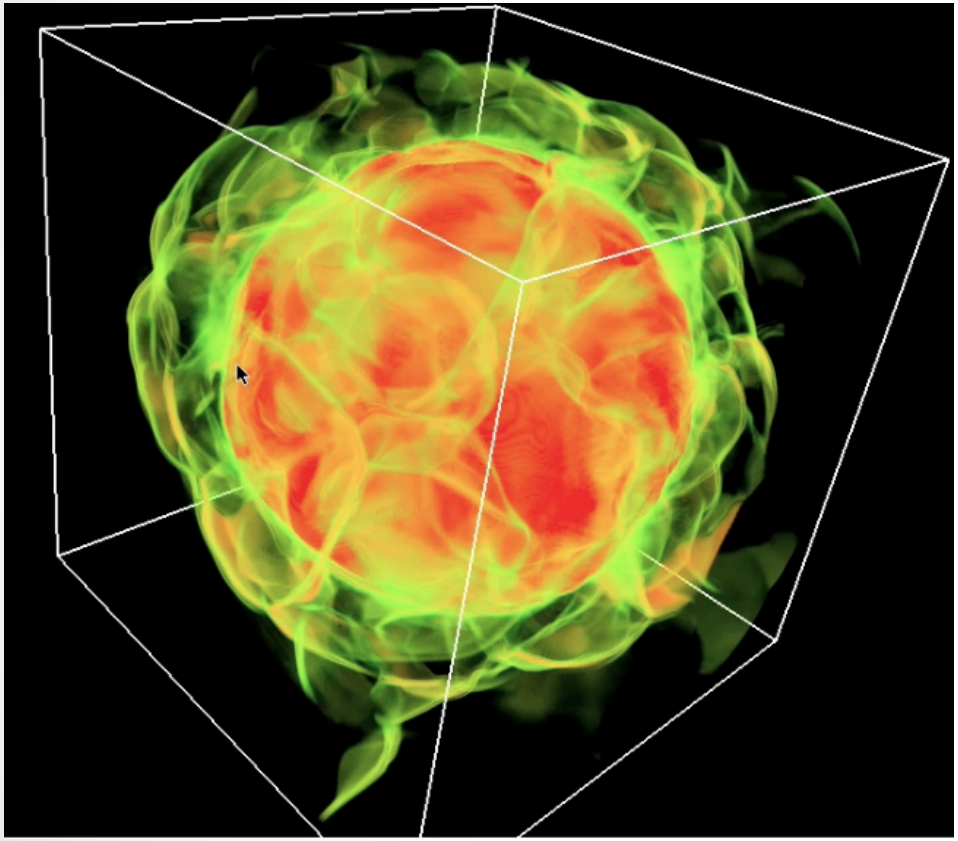
- Con

3D hydrodynamical simulations of stellar atmosphere



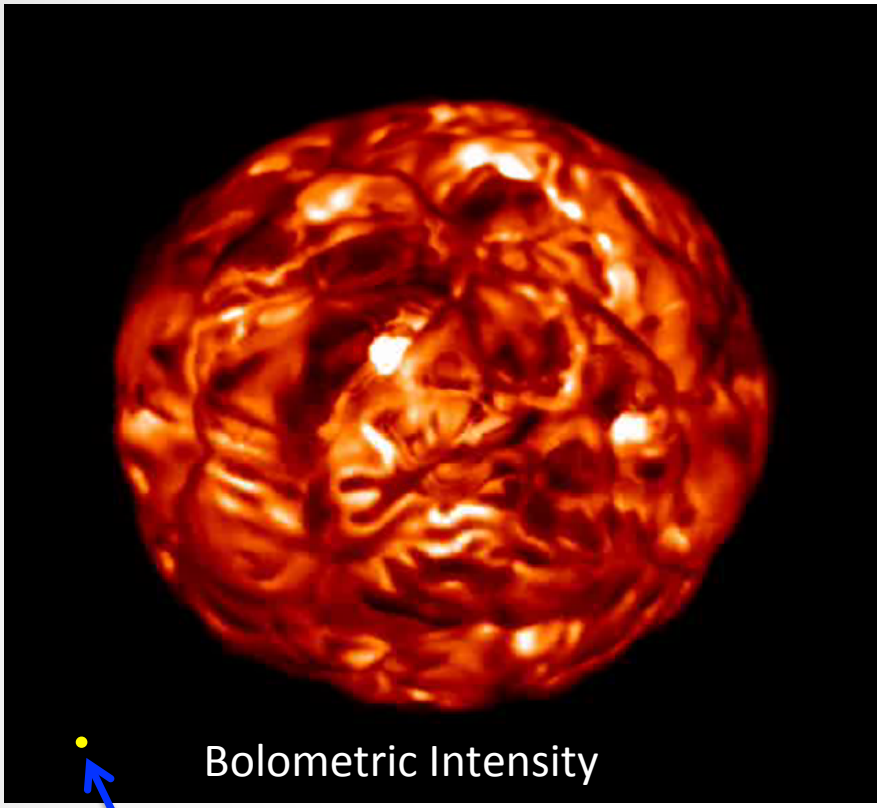
Realistic 3D simulations of stellar convection

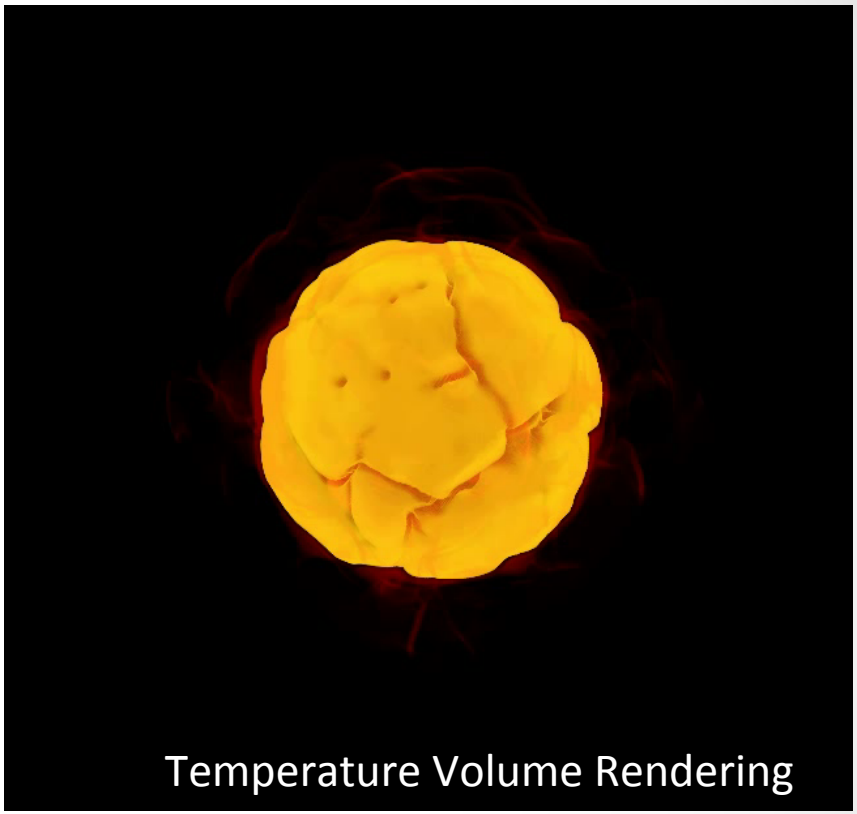
Numerical grid : 200^3 - 300^3 - 500^3

- 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

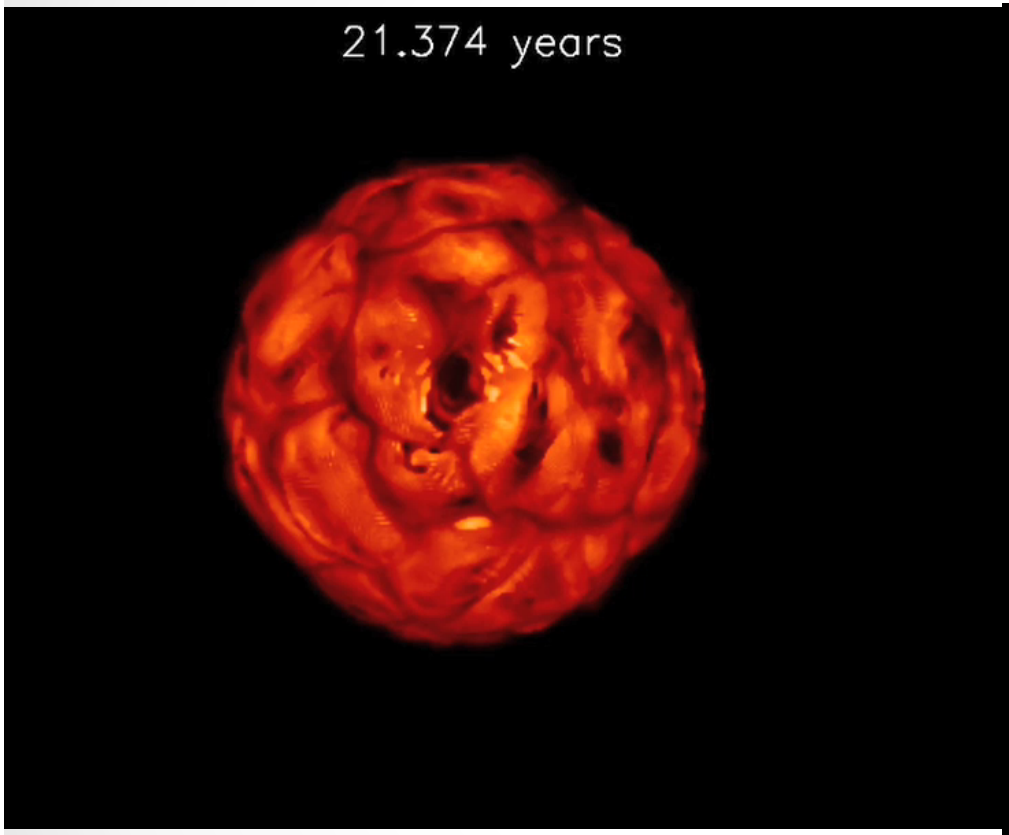




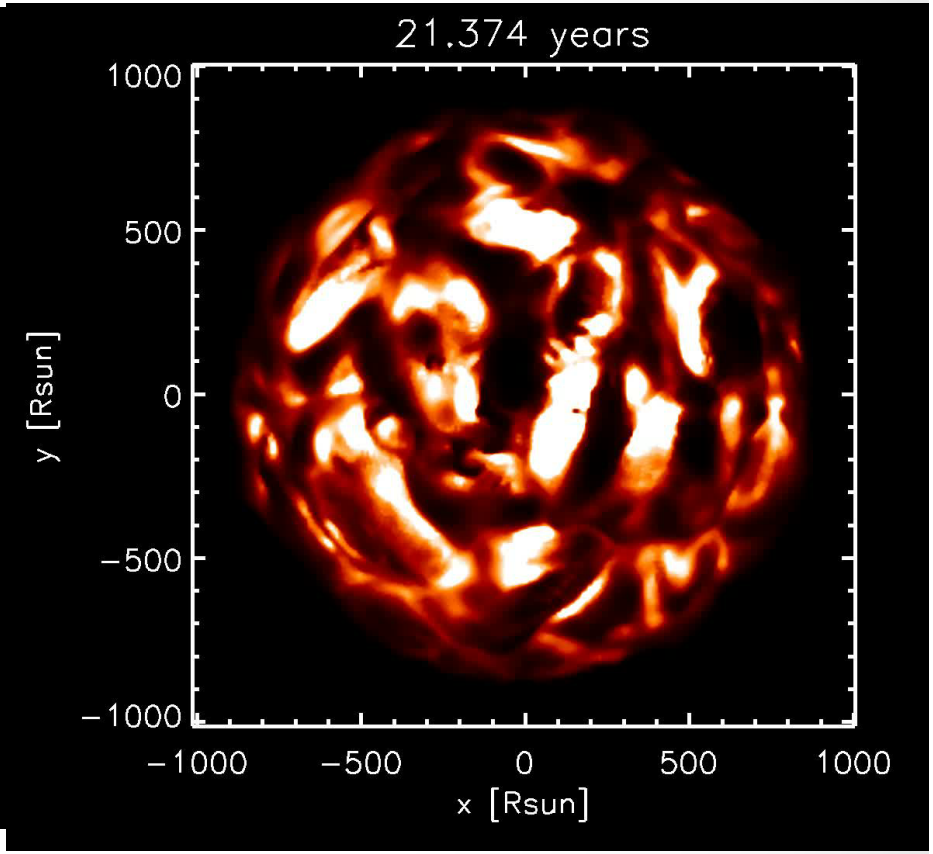
Sun

3D hydrodynamical simulations of stellar atmosphere

H band



Optical band

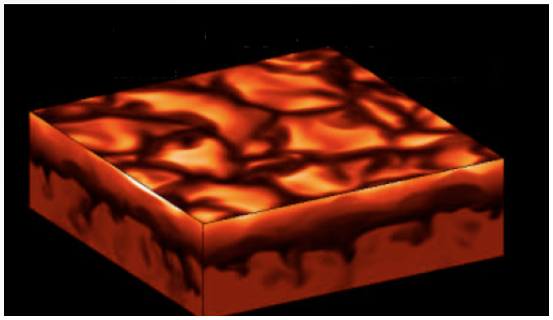


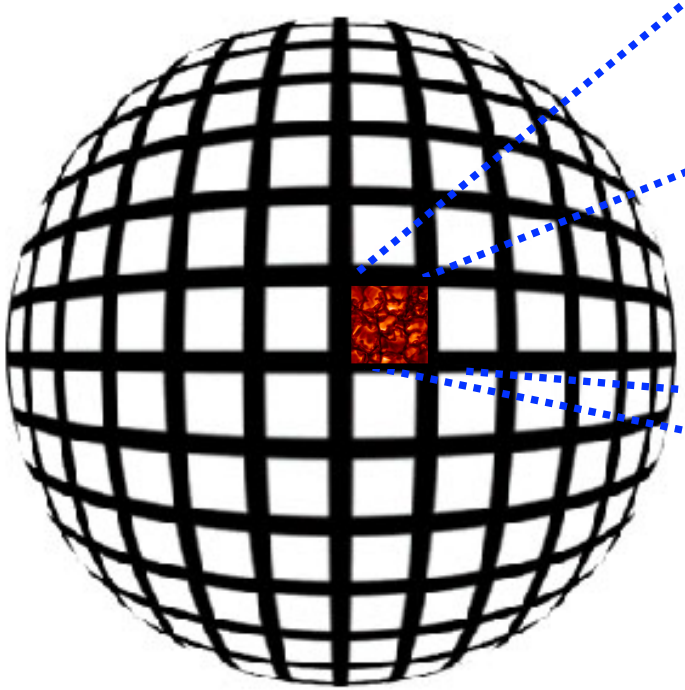
Large convective cells up to 60% of the radius. TIMECALE… decades

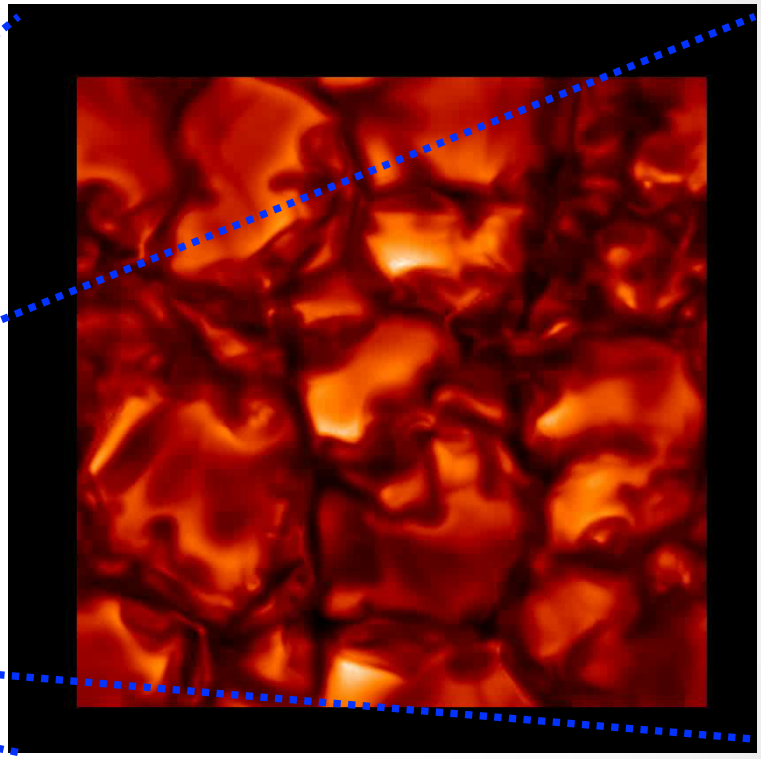
Smaller convective cells on top of large sctructures. TIMESCALE… weeks to months

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

3D hydrodynamical simulations of stellar atmosphere

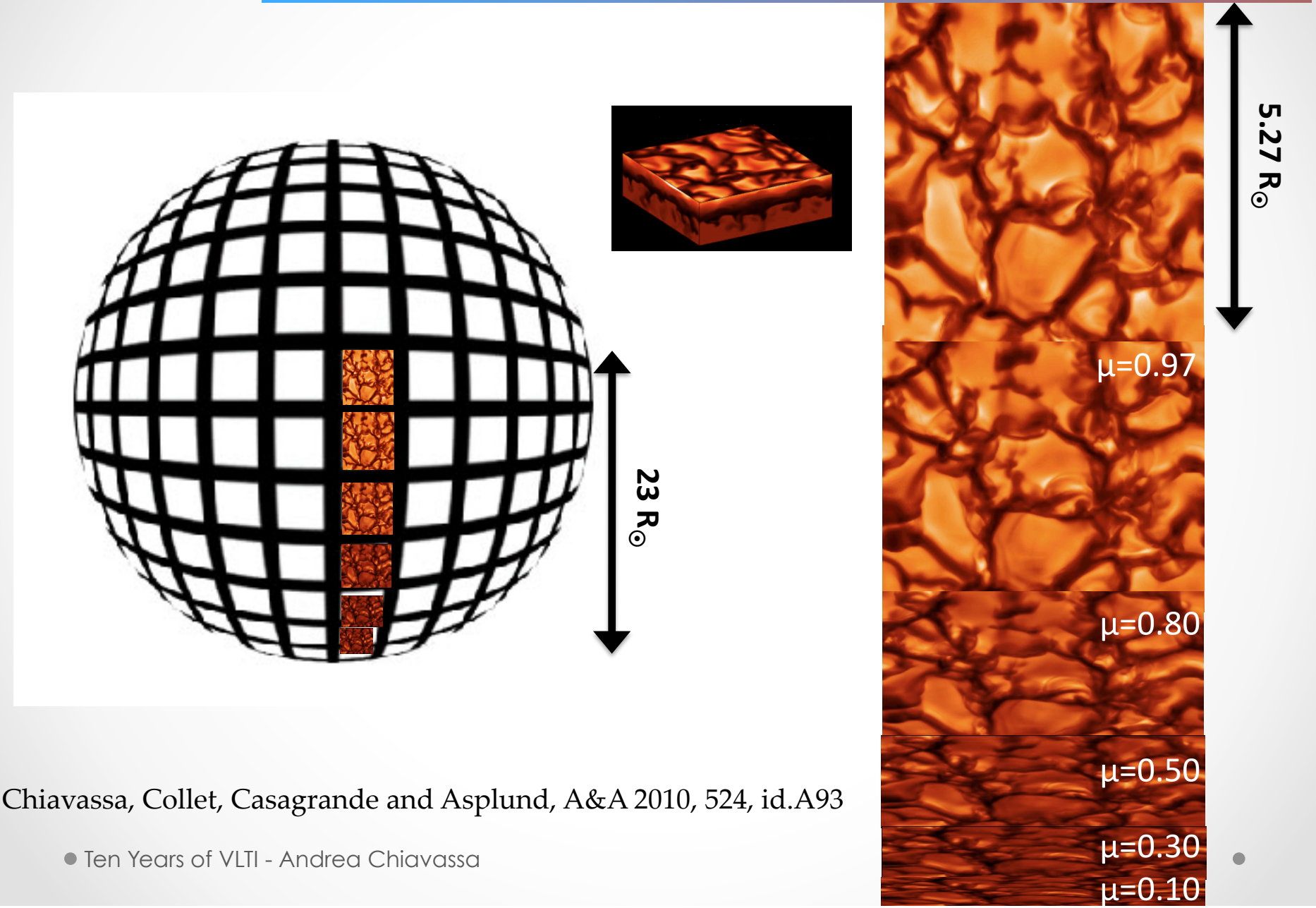






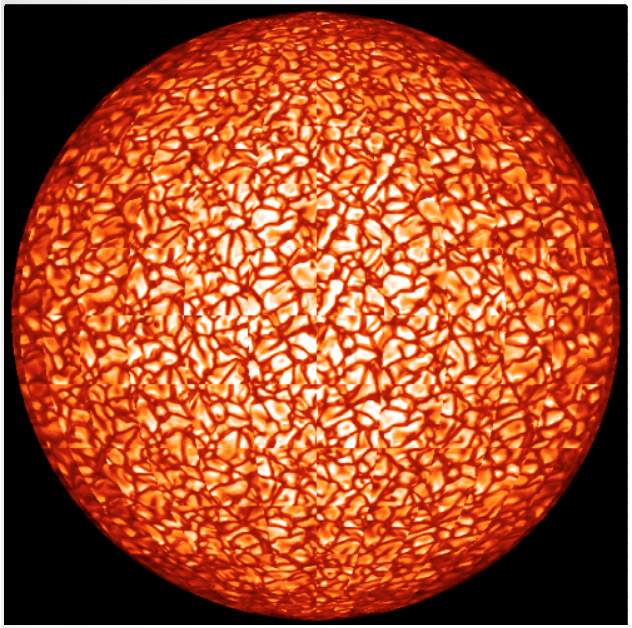
LOCAL SIMULATIONS
used to compute K giants, main sequence stars and the Sun

3D hydrodynamical simulations of stellar atmosphere

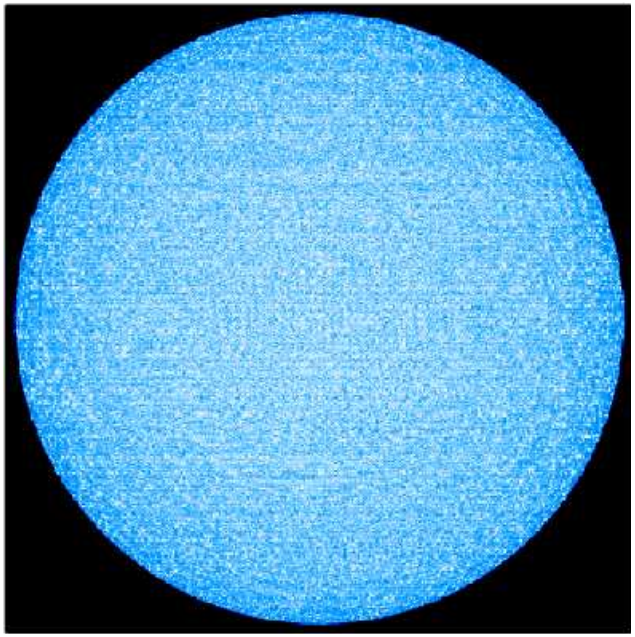


Chiavassa, Collet, Casagrande and Asplund, A&A 2010, 524, id.A93

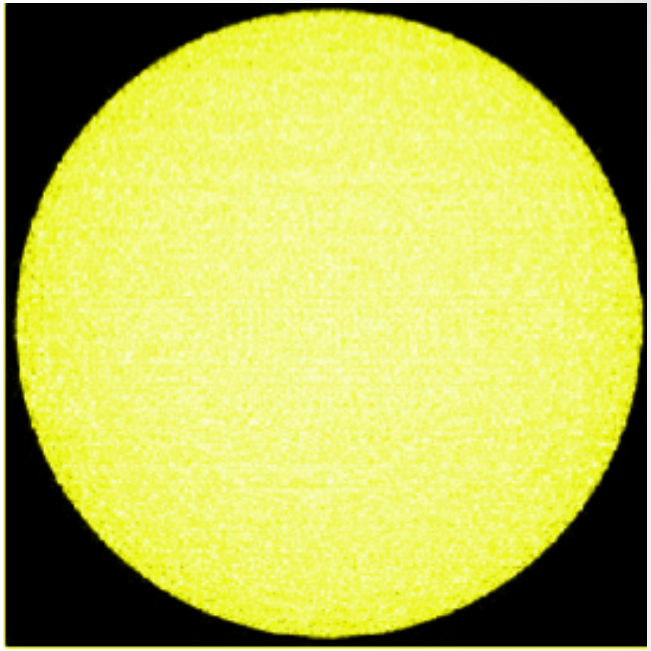
3D hydrodynamical simulations of stellar atmosphere



Red giant stars



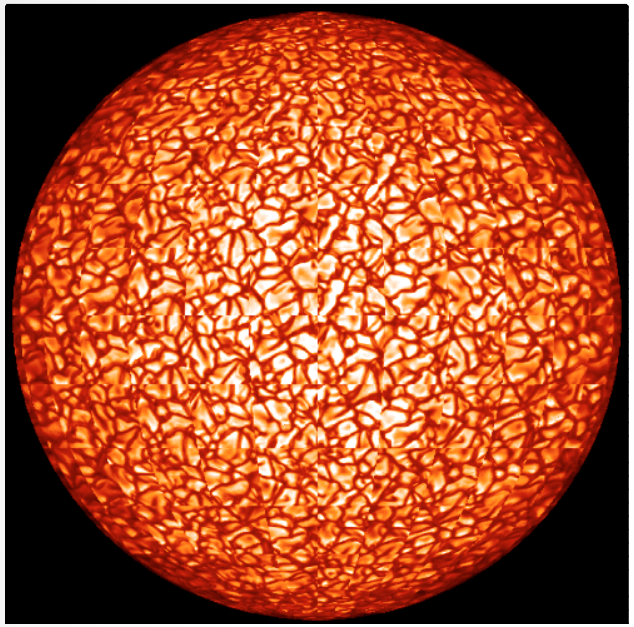
Procyon like stars



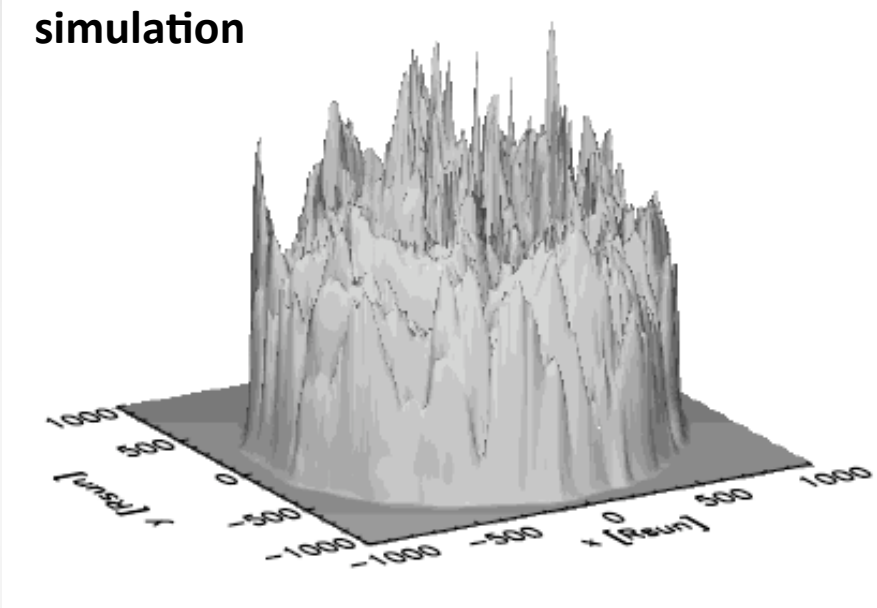
Solar like stars

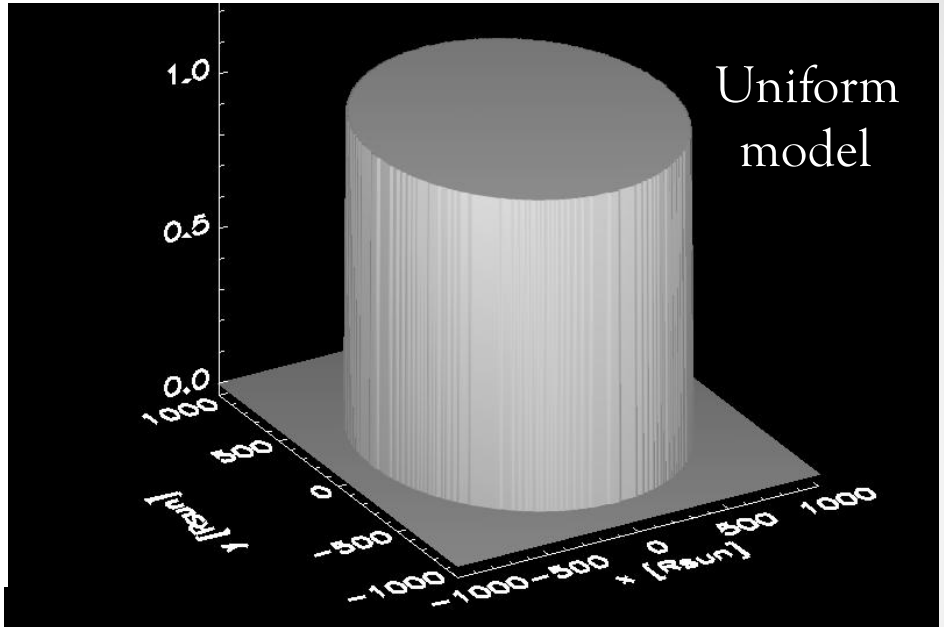
3D hydrodynamical simulations of stellar atmosphere

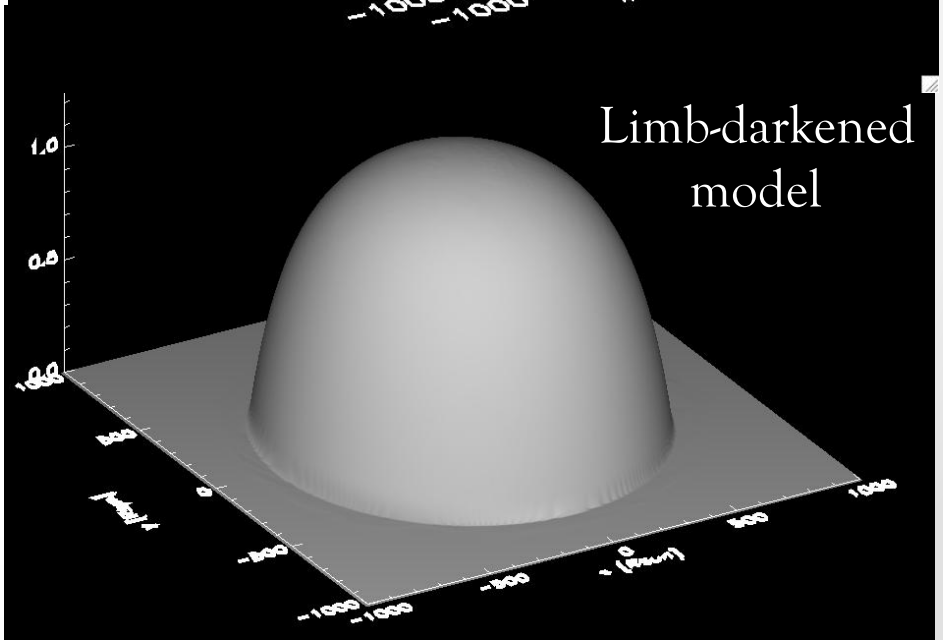
simulation



3D hydrodynamical simulations of stellar atmosphere

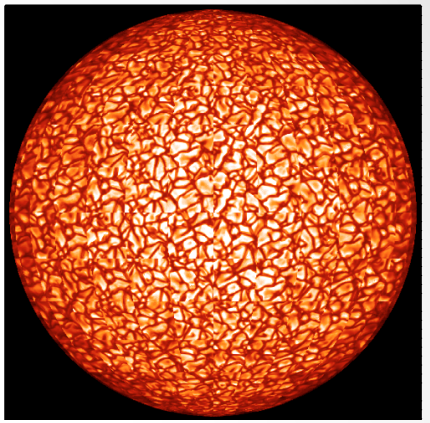




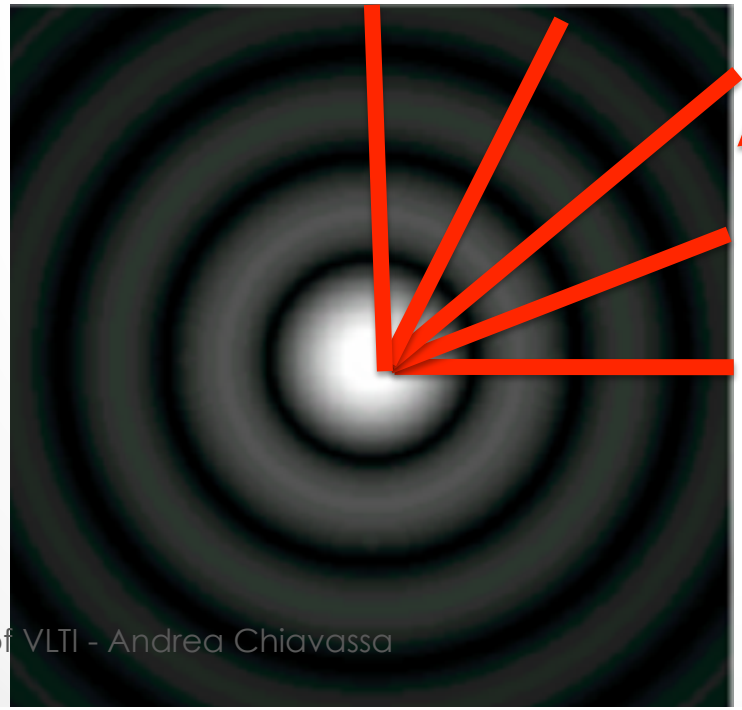


3D hydrodynamical simulations of stellar atmosphere

INPUT:
Snapshots of synthetic images at different wavelength/filters

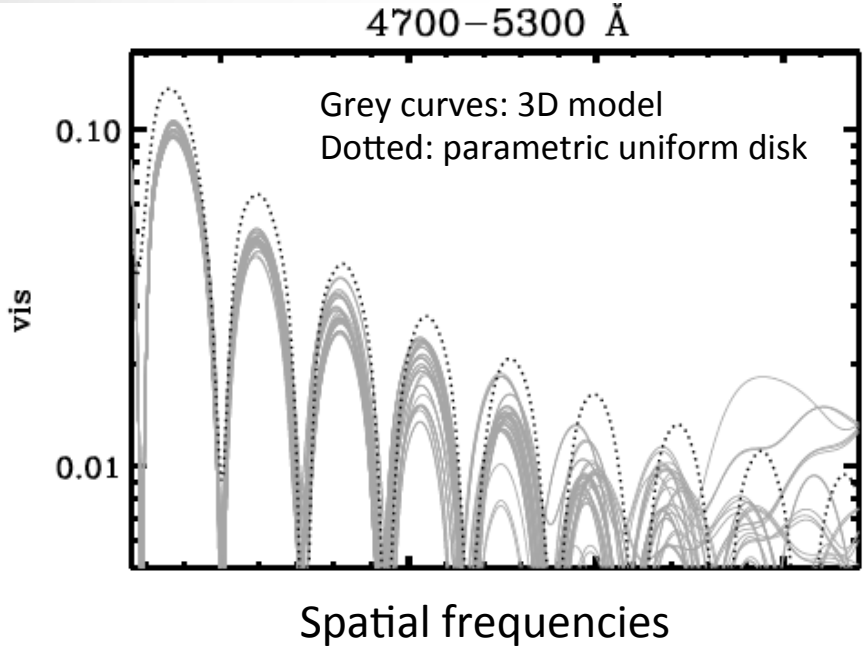


Fourier Transform



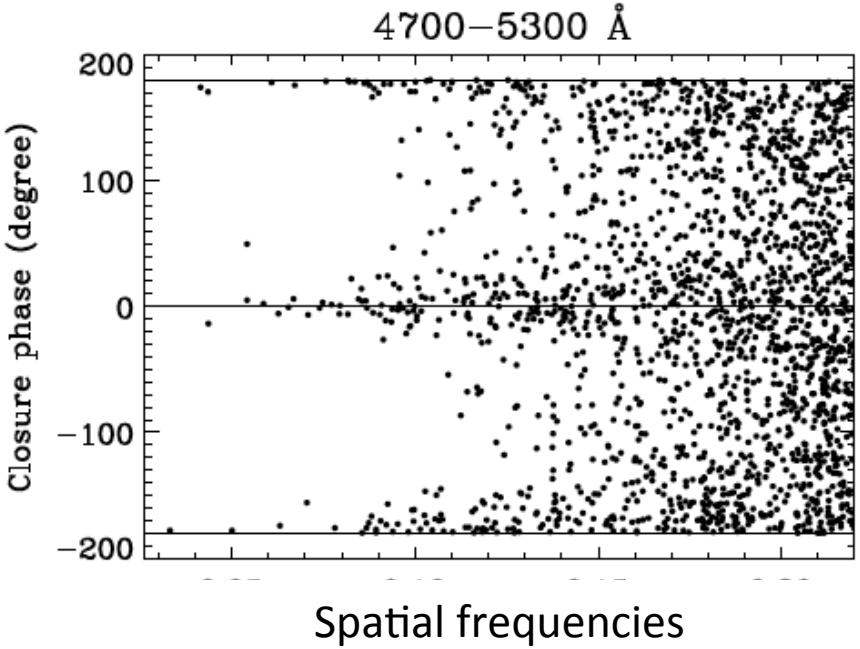
The interferometric observables

Predicted Visibilities



Deviations from symmetric sources!!!

Predicted Closure Phases



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

Chiavassa, Collet, Casagrande and Asplund, A&A 2010, 524, id.A93

Outline

- 3D
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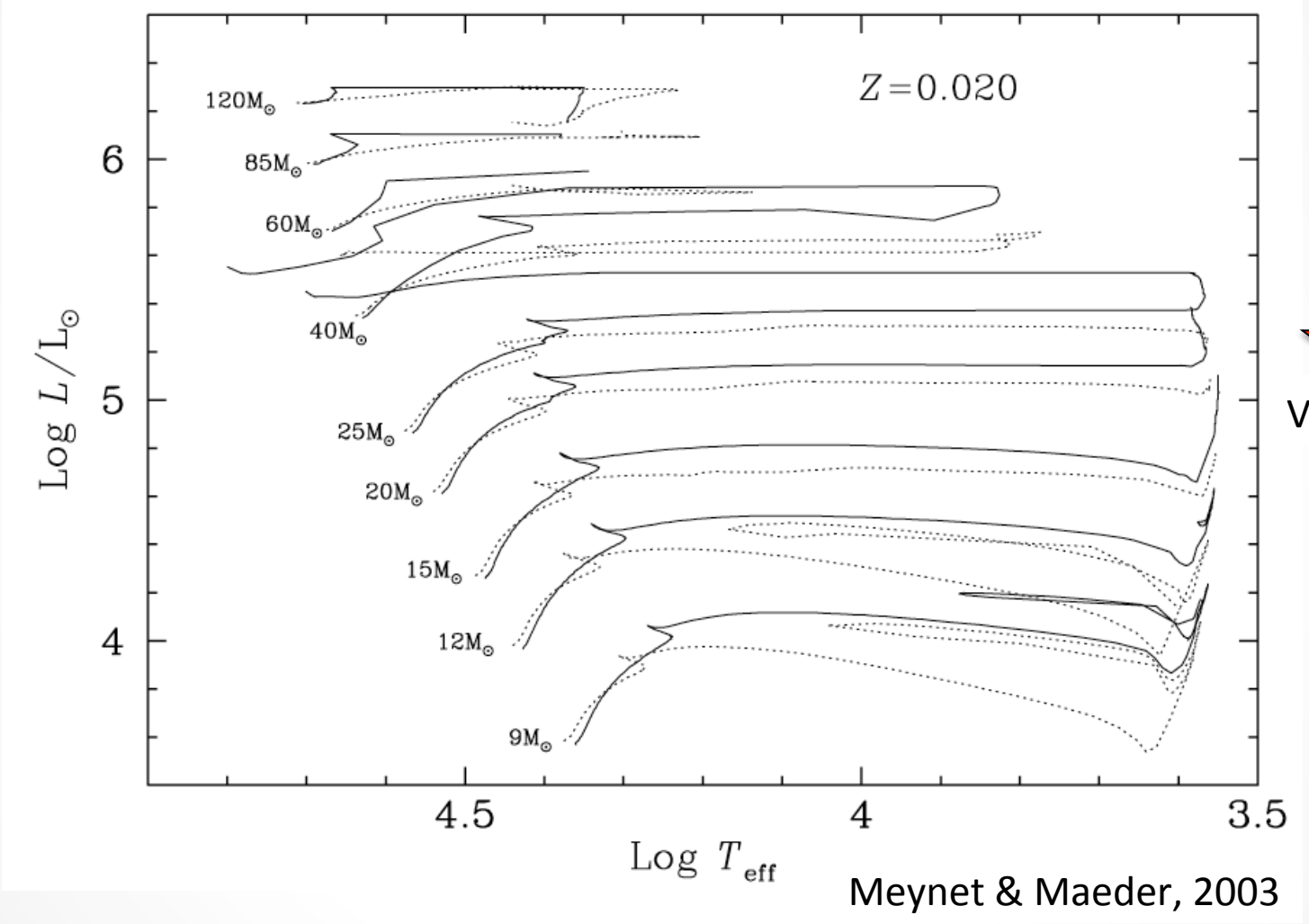
- VLTI-AMBER image of massive evolved star VX Sgr
- Con

VLTI-AMBER image of massive evolved star VX Sgr



Meynet & Maeder, 2003

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

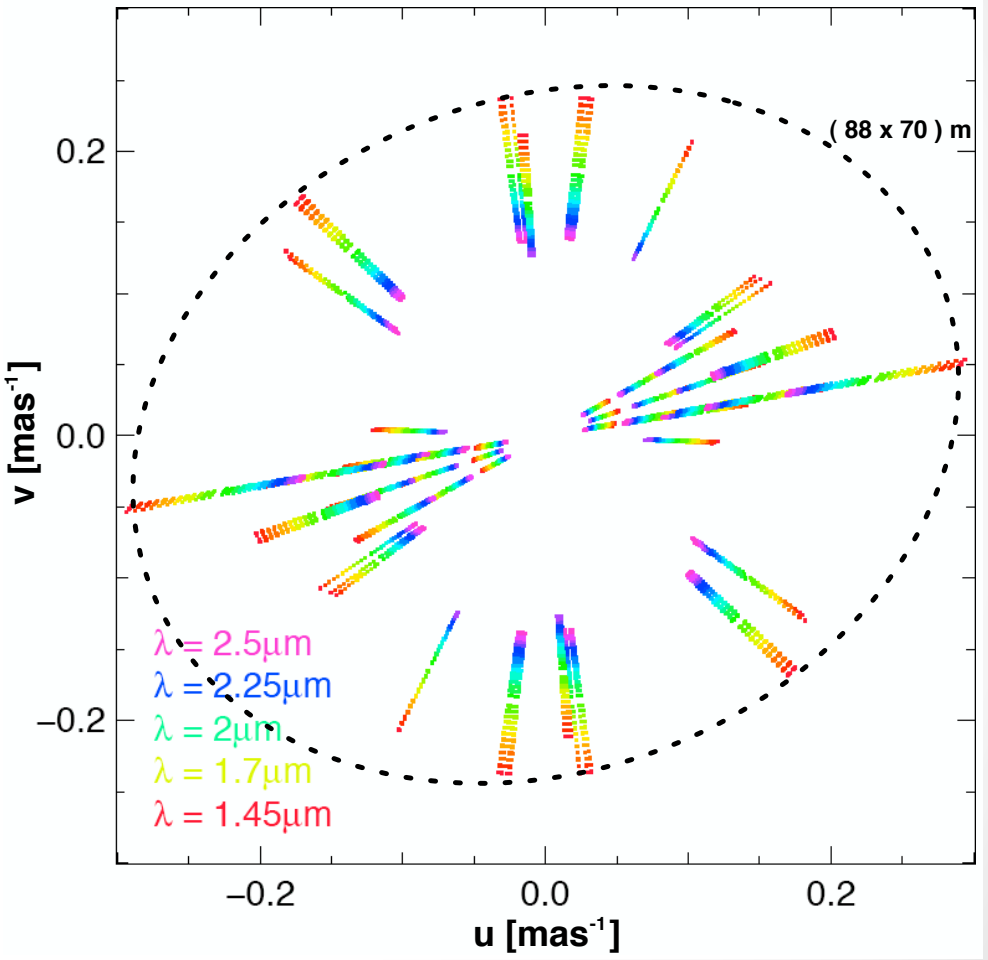
VLTI-AMBER image of massive evolved star VX Sgr

Observations beetwen May-July 2008

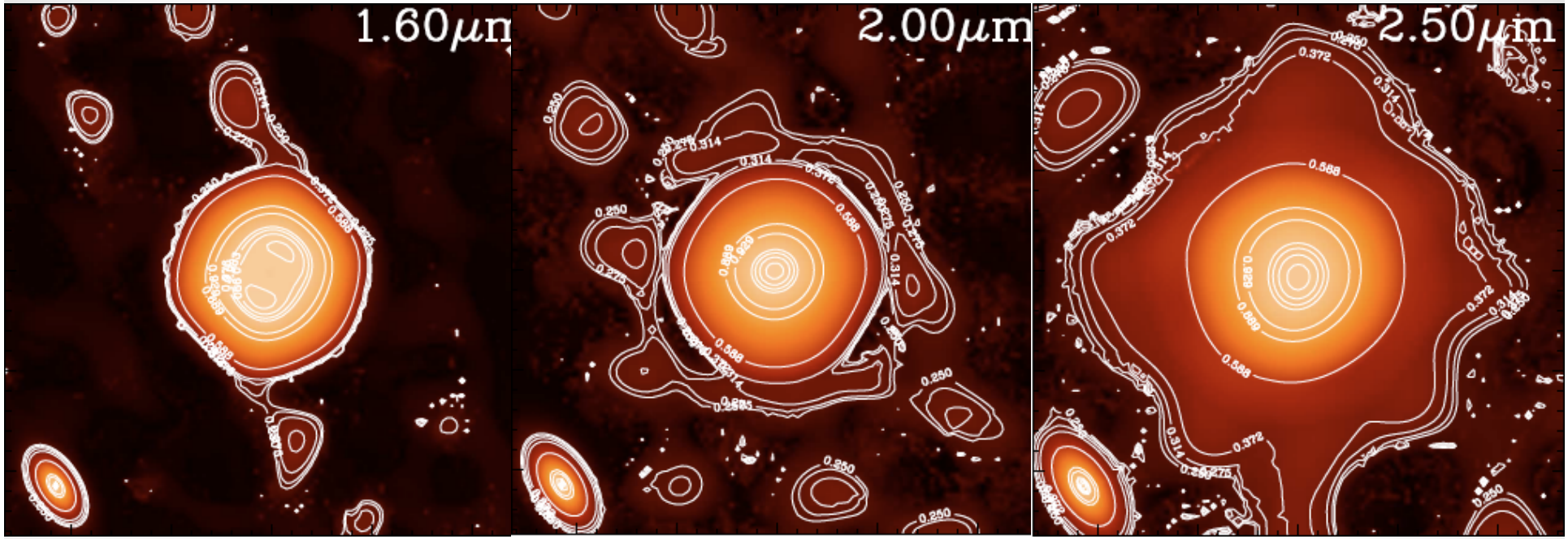
Low resolution AMBER data with FINITO (H-K band)

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



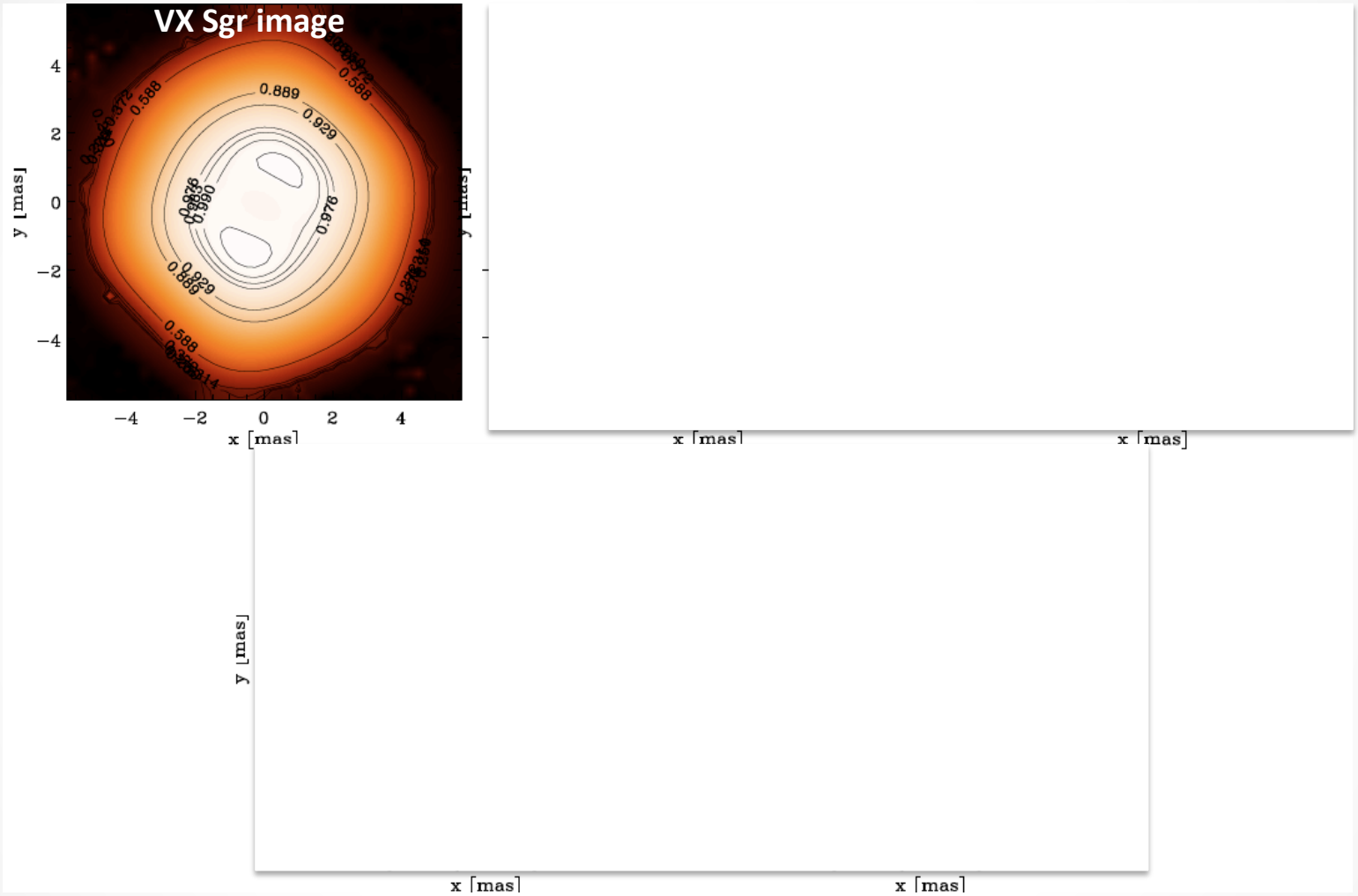
H^- minimum opacity

Contributing molecules?

Contributing molecules?

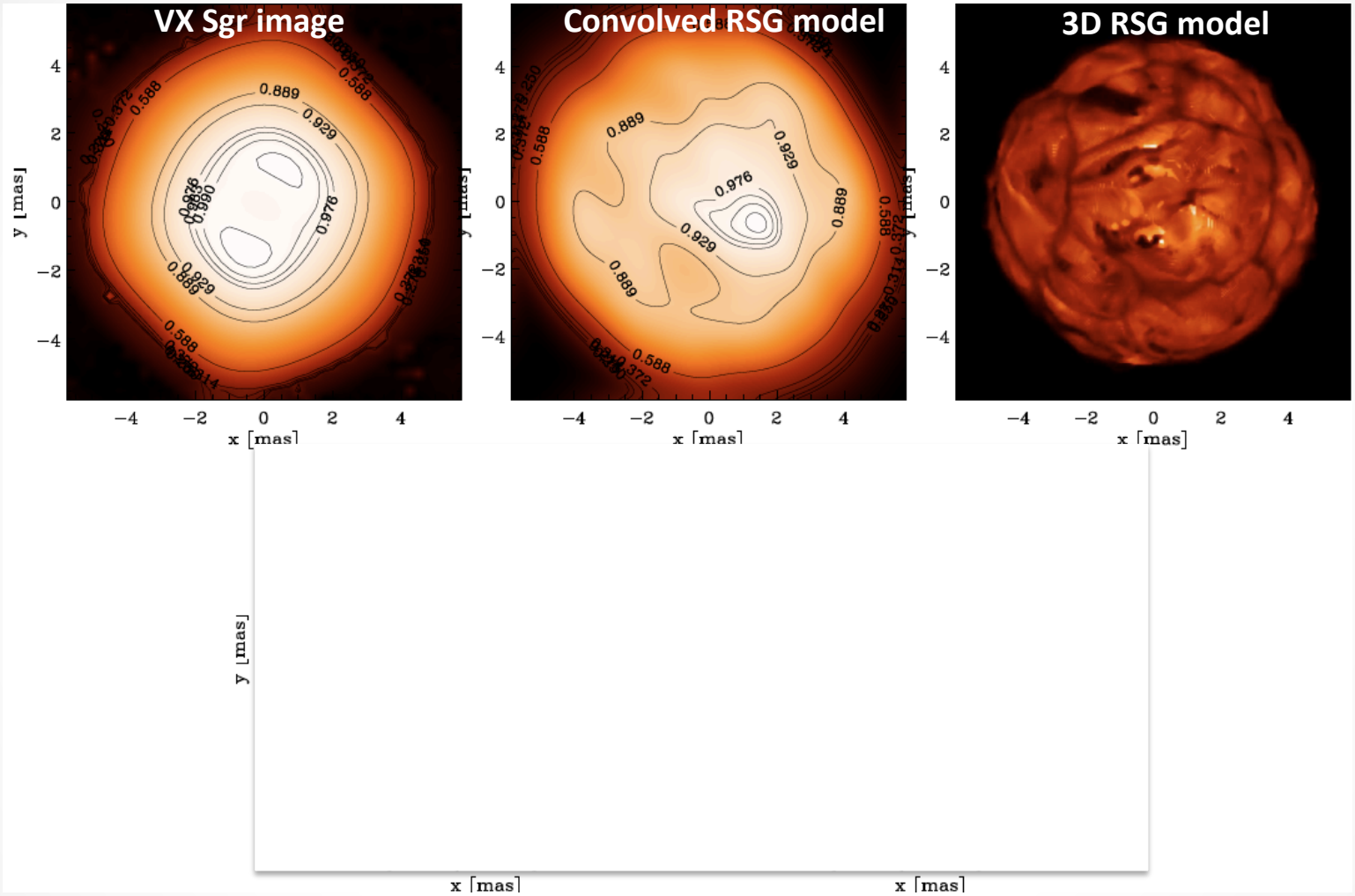
Chiavassa, Lacour, Millour et al., A&A 2010, 511, id.A51 → reconstruction done with MIRA software (Thiébaut 2008, Cotton et al. 2008, Le Besnerais et al. 2008)

VLTI-AMBER image of massive evolved star VX Sgr



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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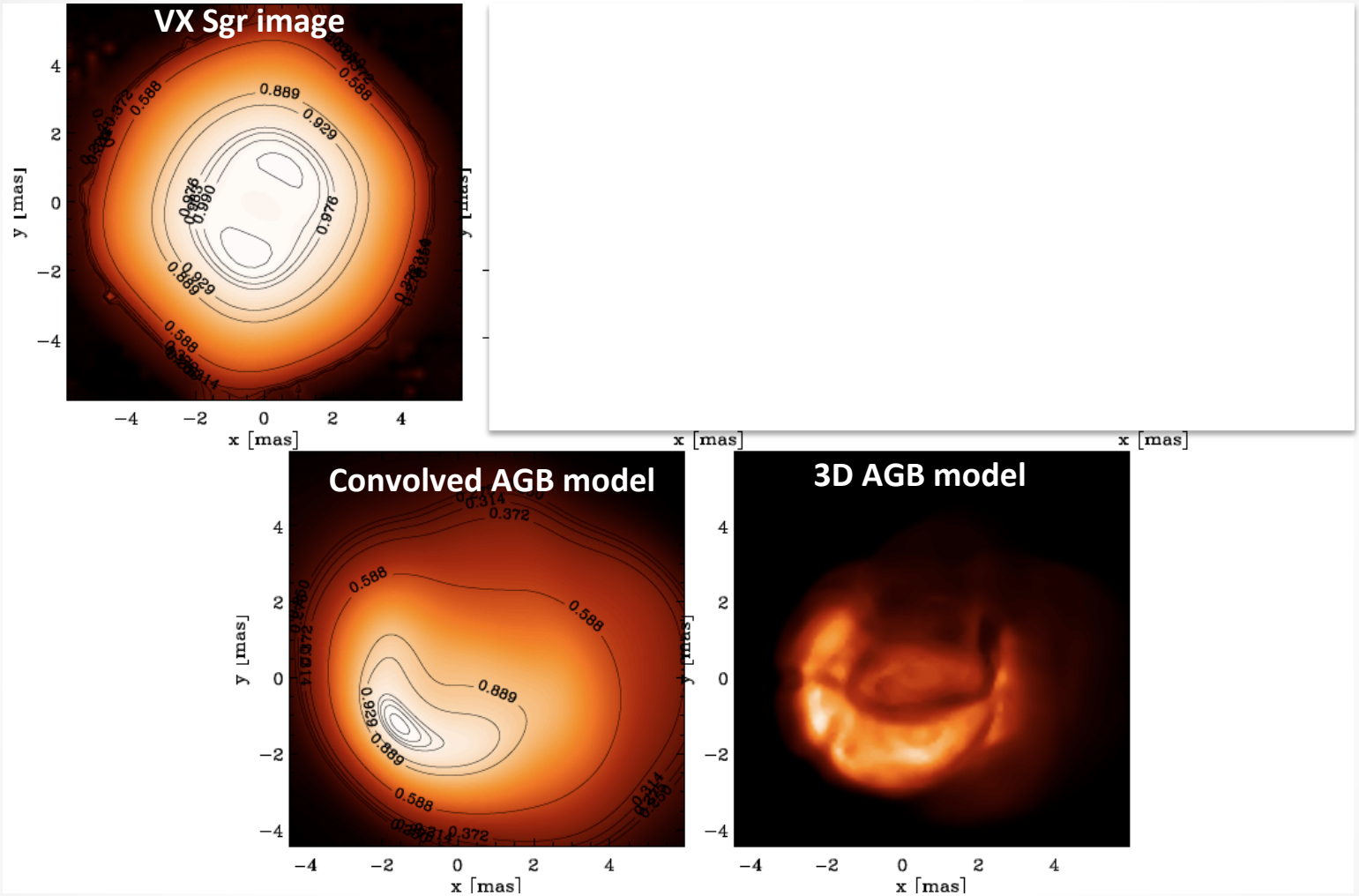

Interferometric imaging to constrain 3D models in terms of:
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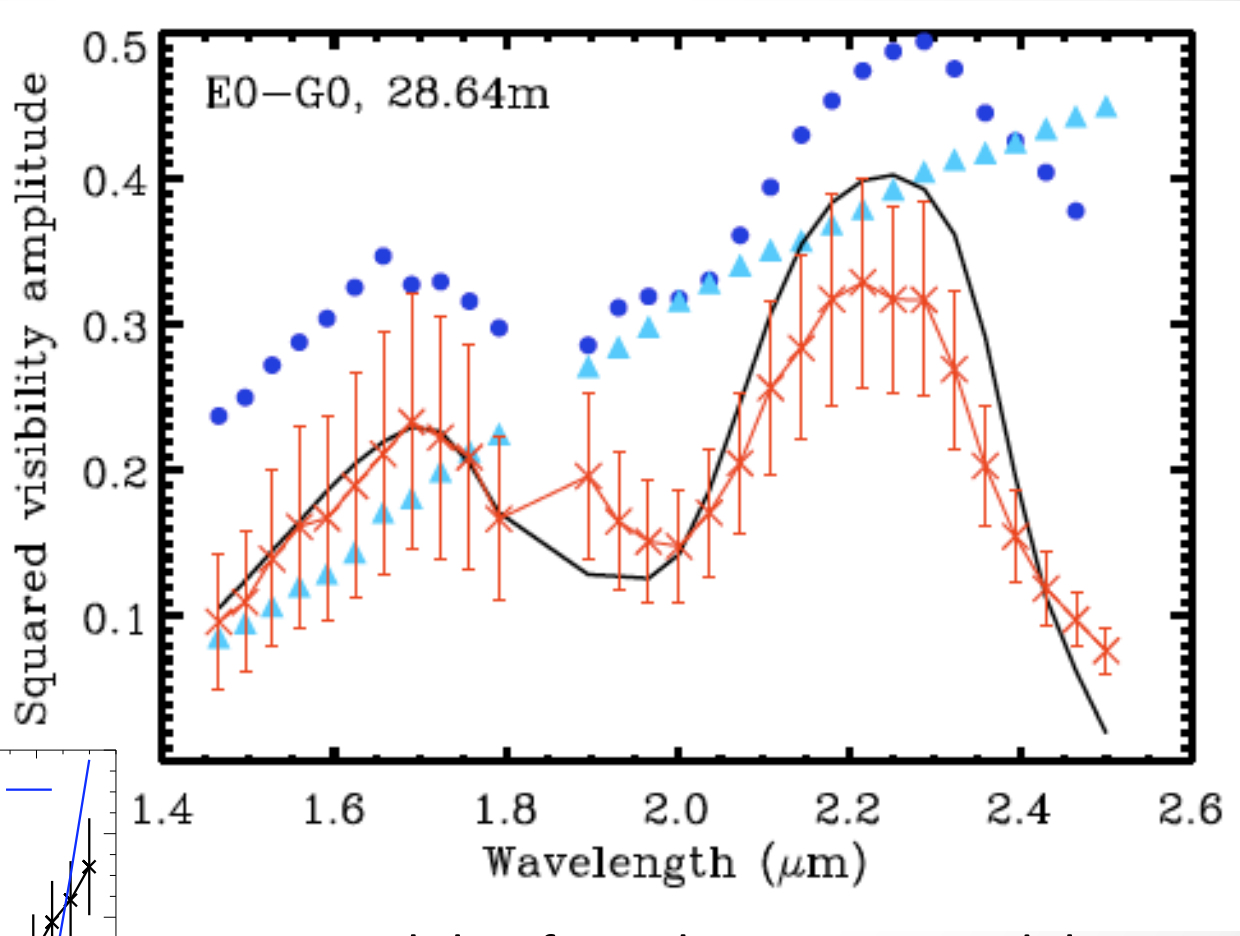
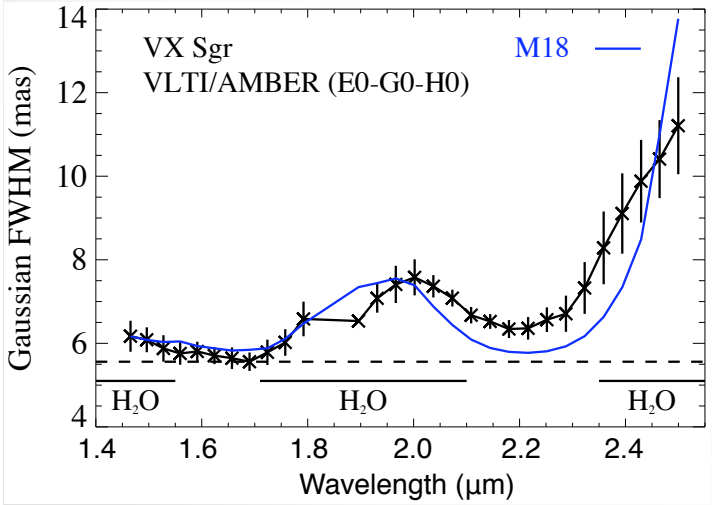
VLTI-AMBER image of massive evolved star VX Sgr

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

Outline

- 3D
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- VL
  ev

- Conclusions

3D predictions are for:

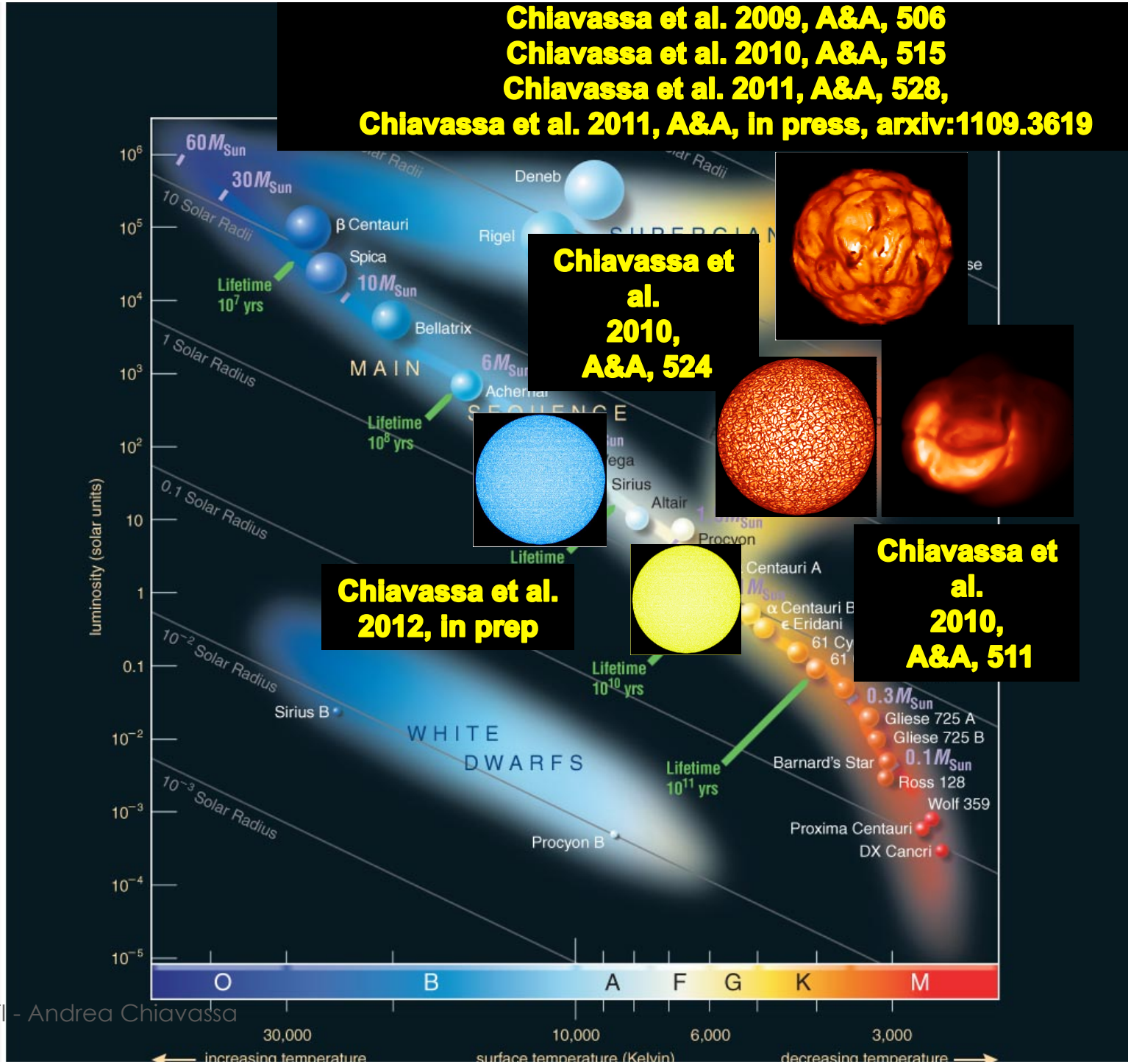
Red supergiants

AGBs

K Giants

Main sequence

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



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