New view on exoplanet transits: describing the granulation pattern with 3D hydrodynamical simulations of stellar convection

Andrea Chiavassa

Lagrange Laboratory, Observatoire de la Cote d'Azur

In collaboration with : F. Selsis, P. Bordé (Bordeaux), C. Pere, L. Bigot (Nice), Z. Magic (Copenhagen), R. Collet and M. Asplund (Canberra)

Paris 30 June 2015

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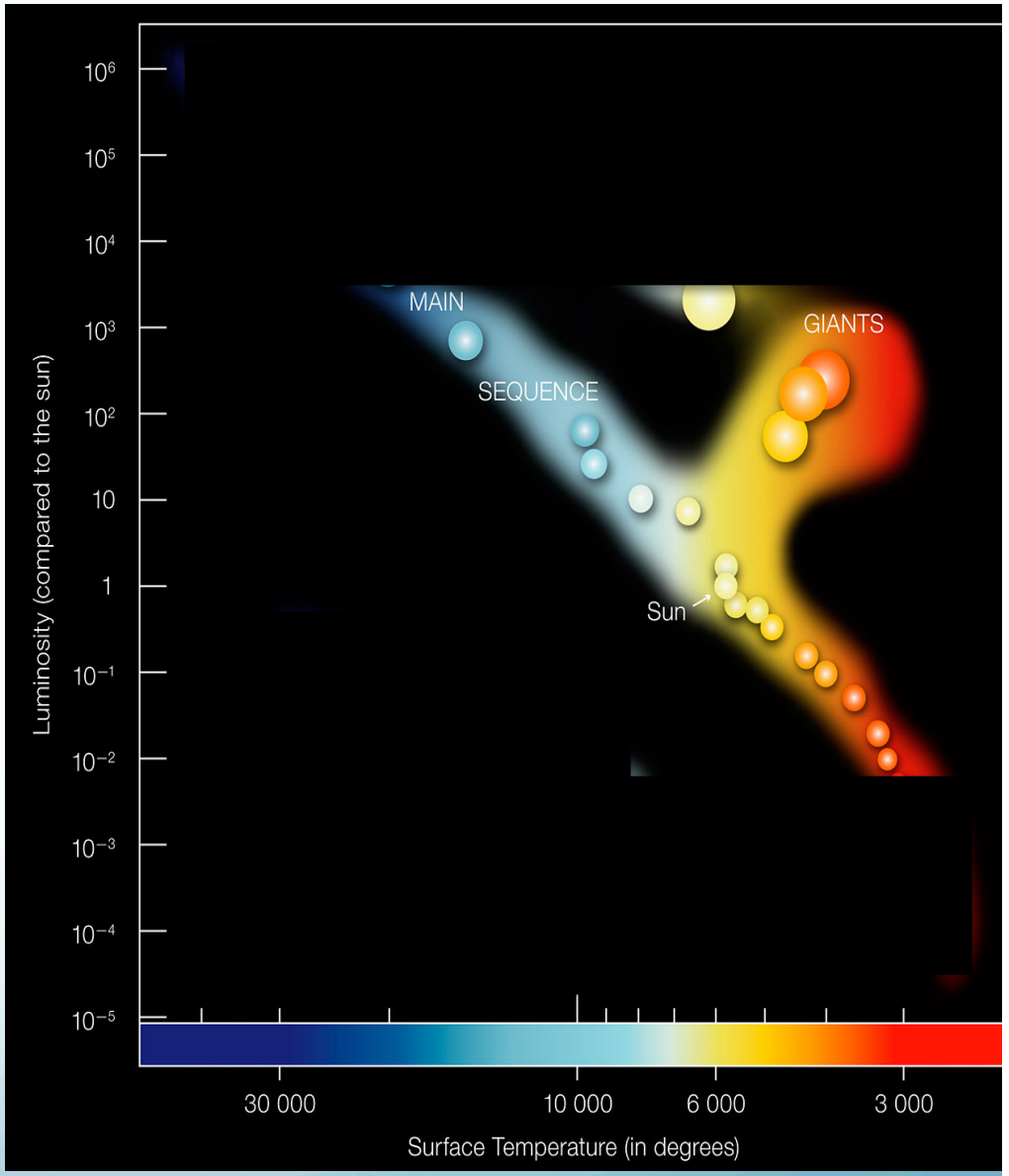
Why study the atmosphere of cool stars?

- Stellar granulation is associated with heat transport and granules are bright (hot) areas surrounded by dark (cooler) lanes that tile the stellar surface. The size/depth of the granules depend on the stellar parameters.
- Stellar granulation cause bias in stellar parameter, radial velocity, chemical abundances determinations, and exoplanet transit detections



Stagger grid: Magic, Collet, Asplund, Trampedach, Hayek, Chiavassa, Stein, Nordlund 2013, A&A, 557, A26

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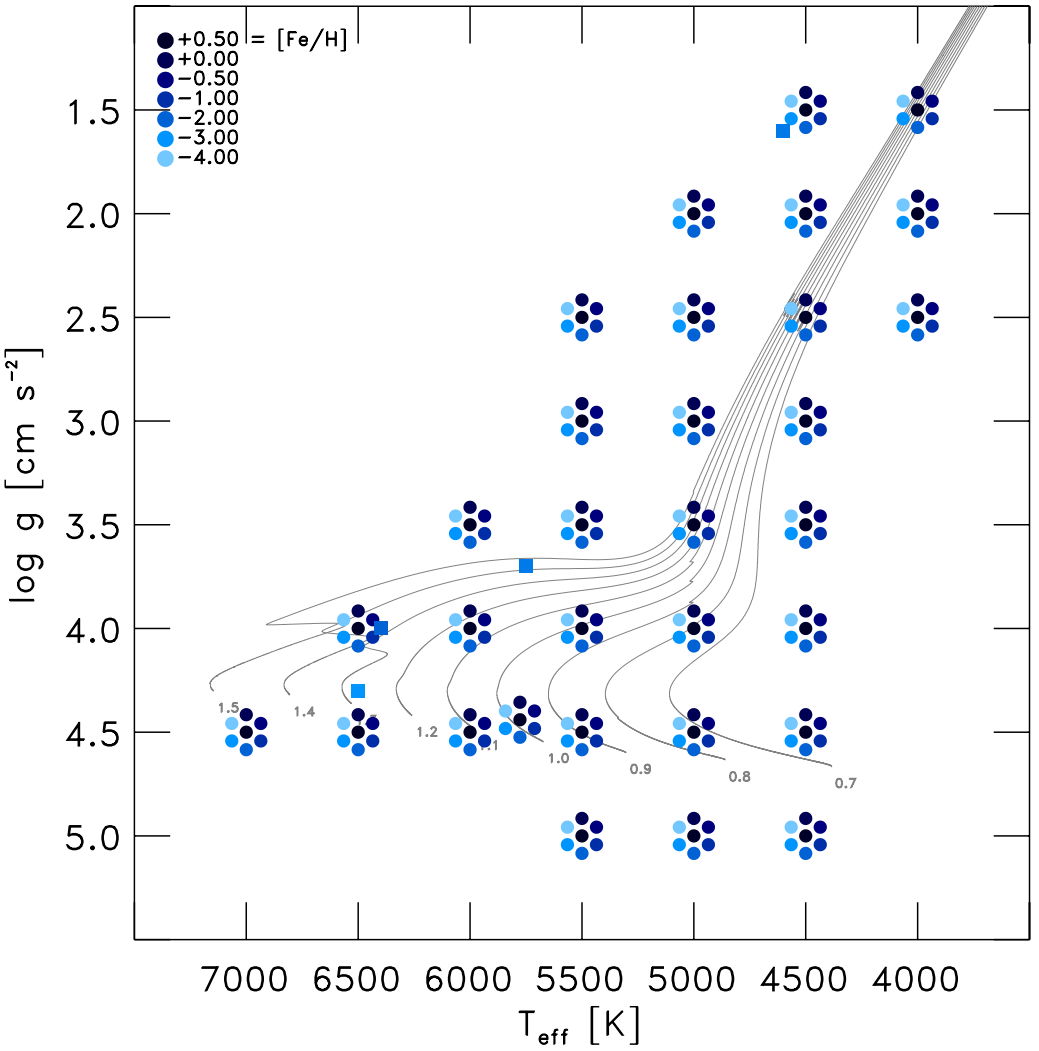


Surface Temperature (in degrees)

Stagger grid: Magic, Collet, Asplund, Trampedach, Hayek, Chiavassa, Stein, Nordlund 2013, A&A, 557, A26

Trampedach, AIP Conference Proceedings, 2007

3D hydrodynamical simulations of stellar atmosphere

Stellar atmospheric models computed with Stagger-Code (Nordlund et al. 2009)

→ 3D models = **Very realistic! → deeply checked versus observations**

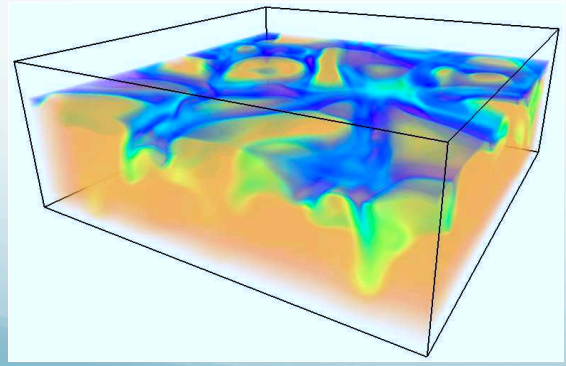
- **Hydrodynamics 3D** (Grid: 200^3 - 300^3 - 500^3), time dependent
- Solution to the equations for the compressible hydrodynamics (conservation of mass, energy, and momentum) coupled with non-local transport of radiation with detailed opacities

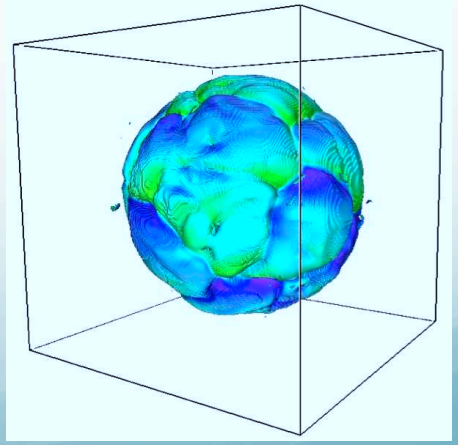
Local simulations

Main Sequence stars and red giants

Global simulations

Red supergiants and AGBs

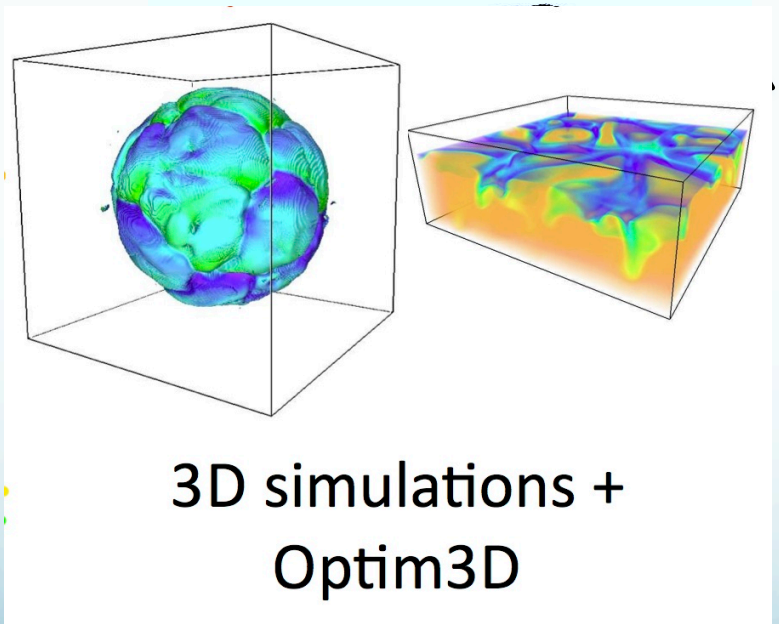




Detailed 3D radiative transfert code

OPTIM3D : 3D radiative transfer code

→ Detailed (billions of atomic and spectral lines) and fast (computational time slightly larger than 1D computation) post processing of 3D simulations.



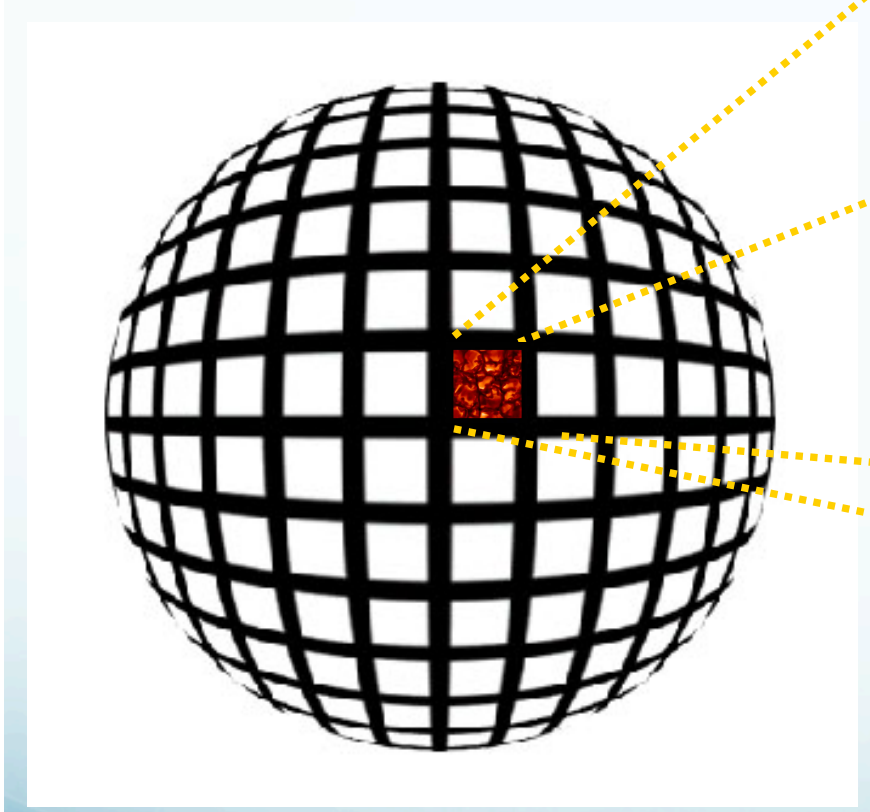
3D ➔ 200 x 200 x 100

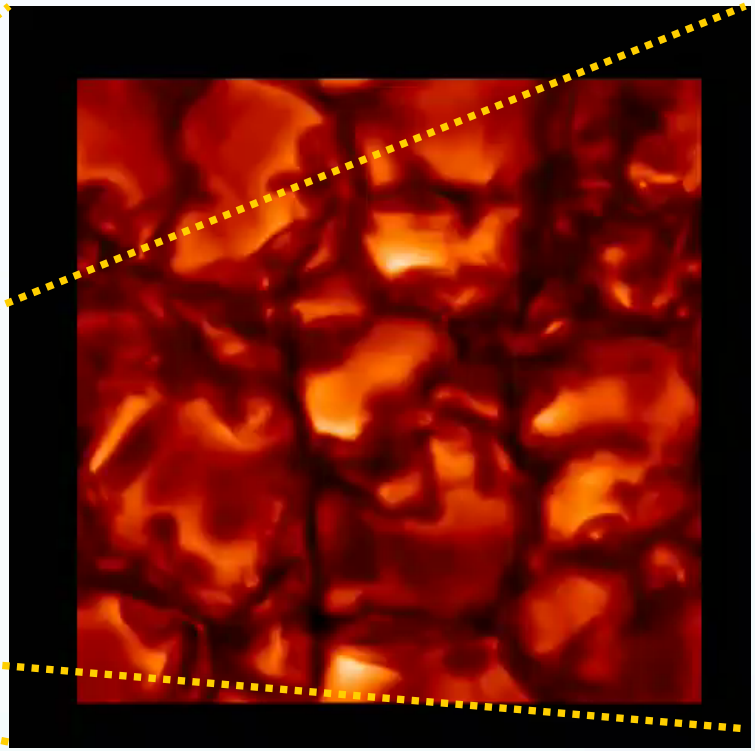
10^6 times **1D !**

Extraction of interferometric, spectroscopic, photometric, astrometric observables

Chiavassa, Plez, Josselin, Freytag 2009, A&A, 506, 1351

Computing spherical tiled images

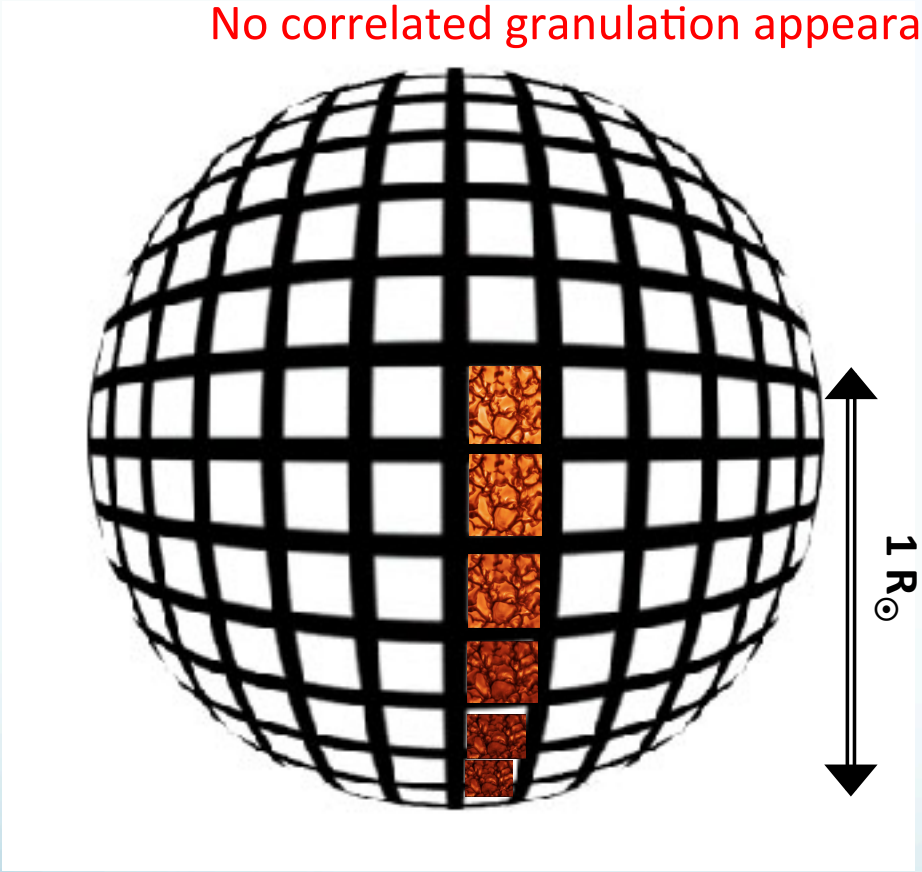


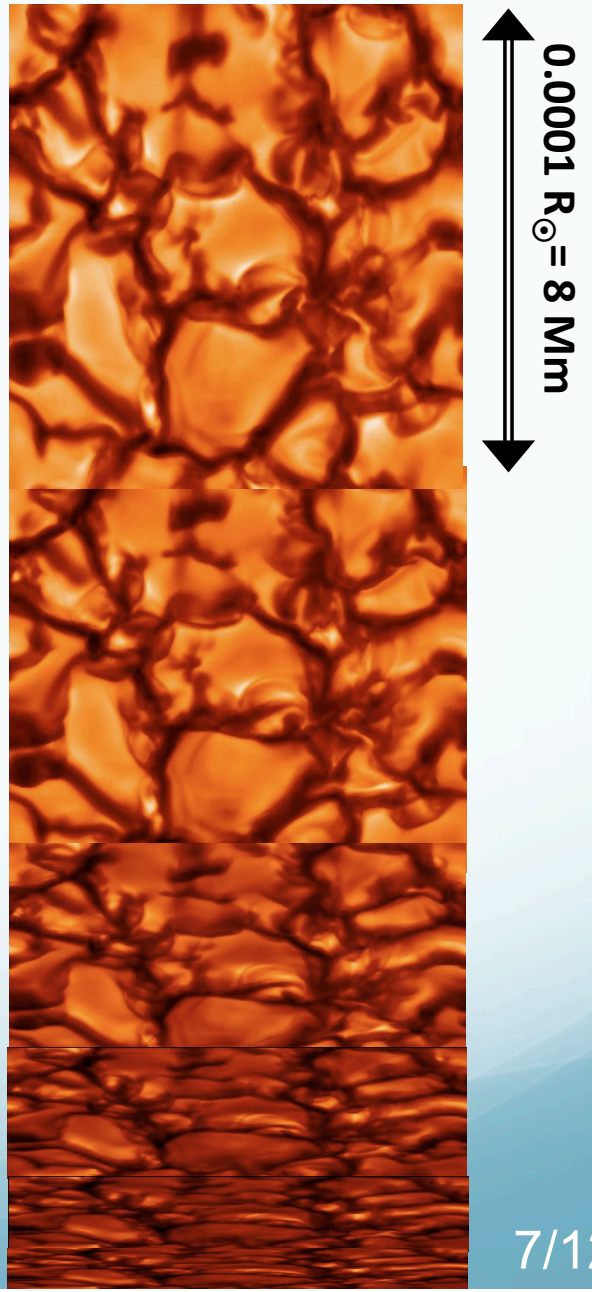


Computing spherical tiled images

Center to limb granulation computed with OPTIM3D
RANDOM SNAPSHOTS WITHIN THE SIMULATIONS RUN

No correlated granulation appearance





Chiavassa et al. 2010, A&A, 521, A93
Chiavassa et al. 2012, A&A, 540, A5
Chiavassa et al. 2014, A&A, 567, A115
Chiavassa et al. 2015, A&A, 576, A13

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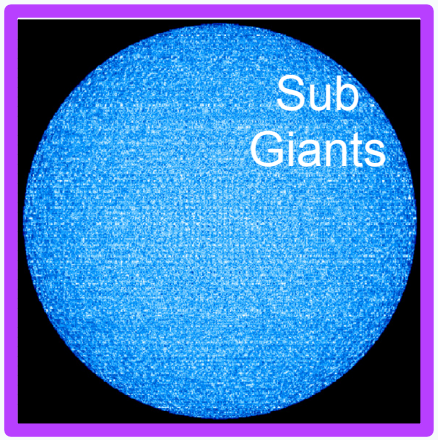
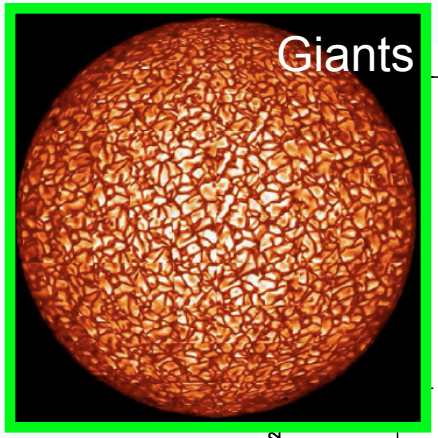
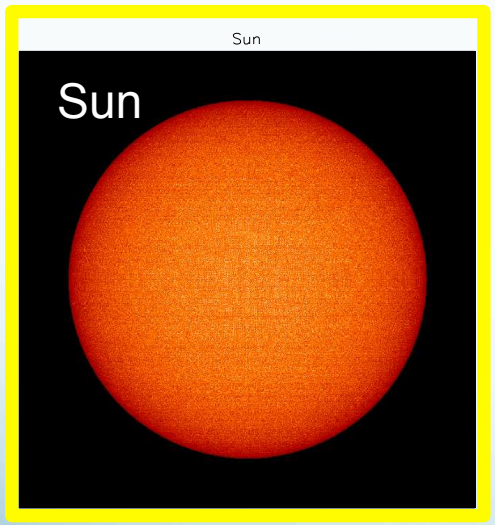
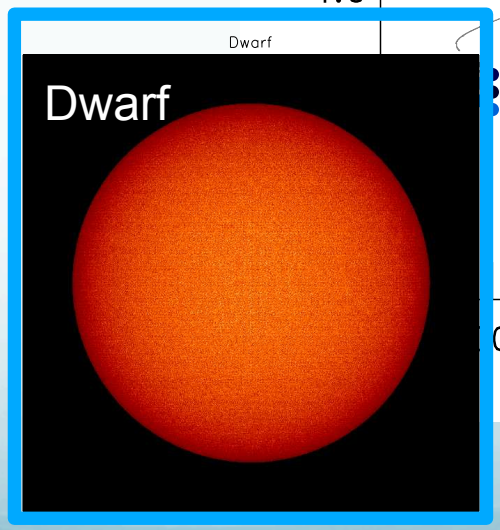
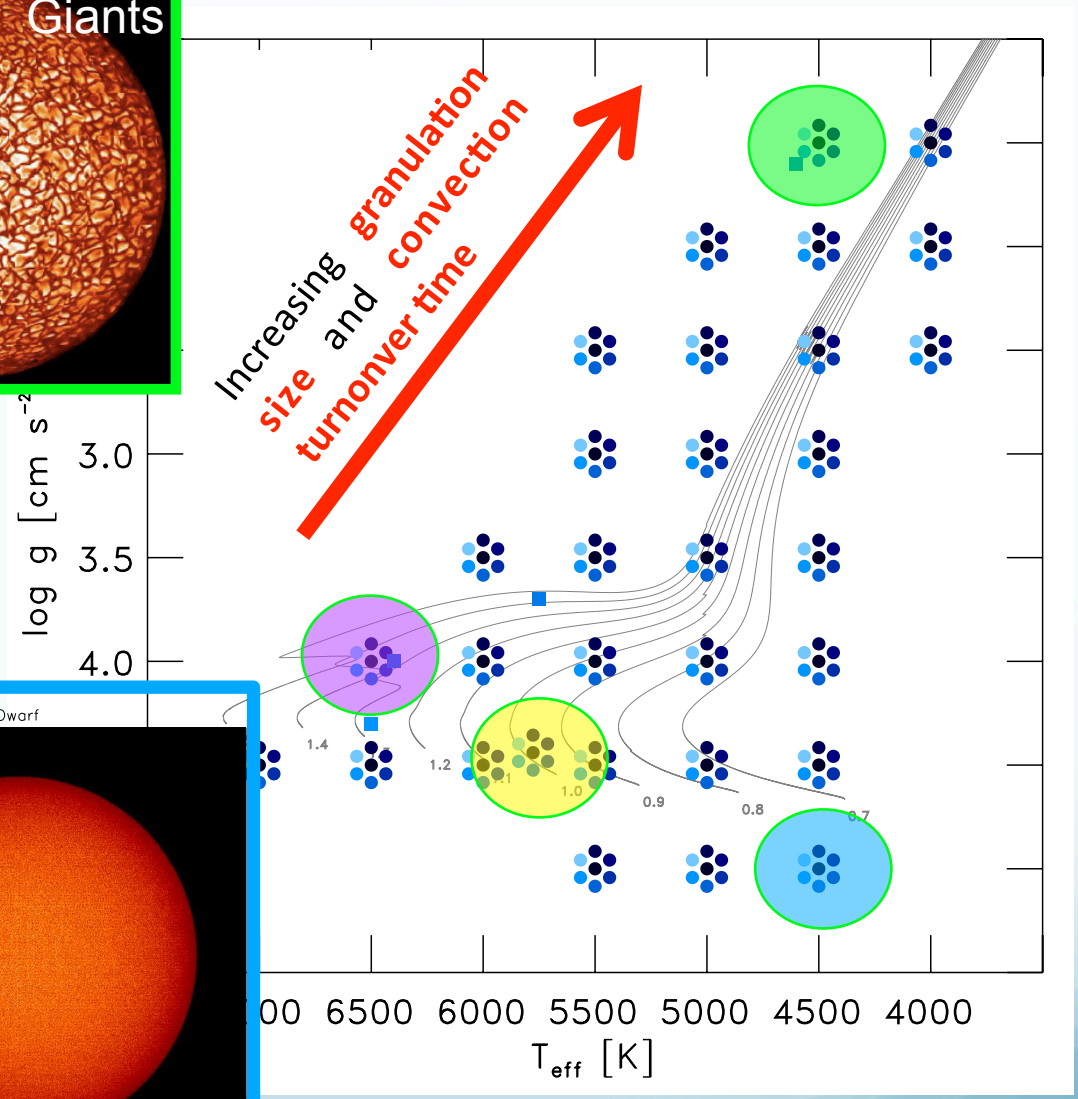






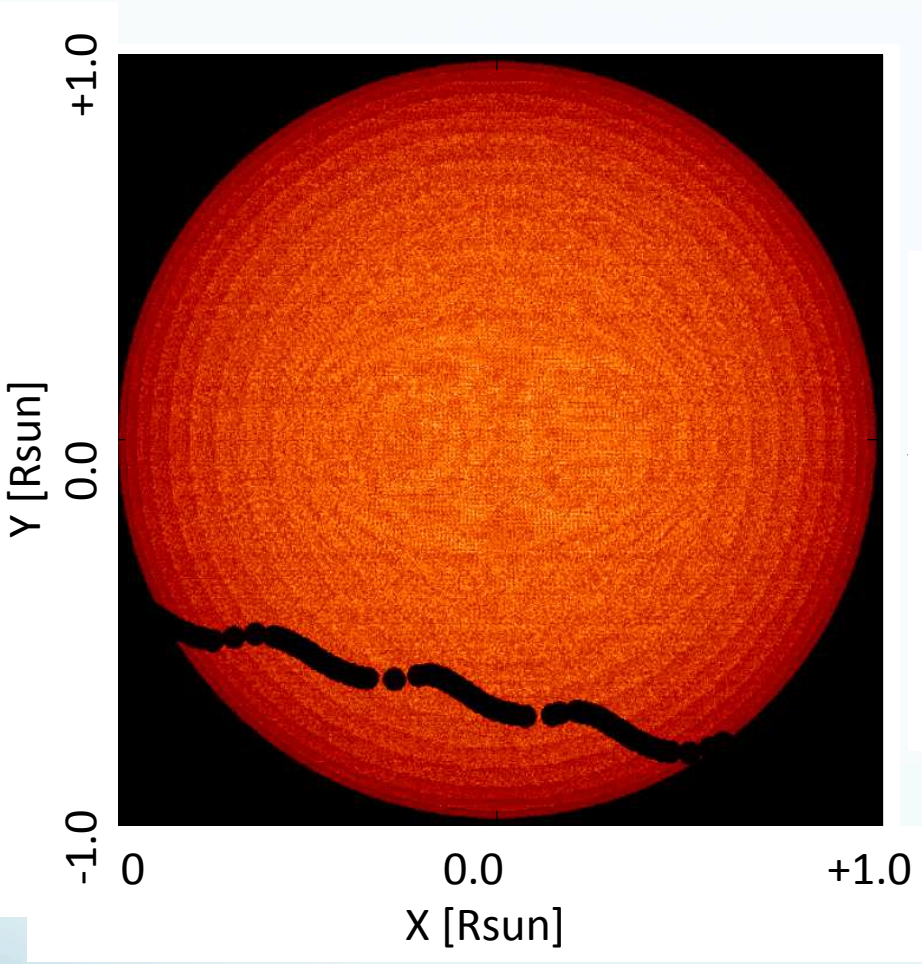


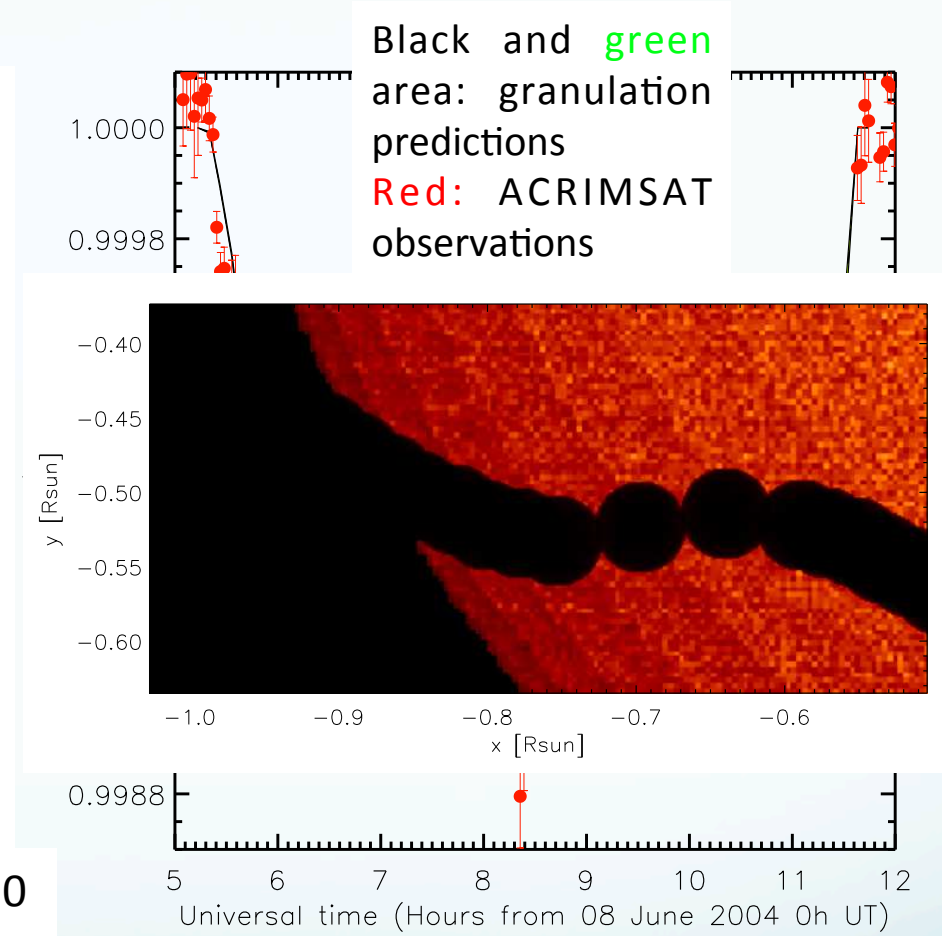


Transit of Venus

Chiavassa, Pere, Faurobert, Ricort, Tanga, Magic, Collet, Asplund, A&A 576, A13

Transit of Venus





Black and green area: granulation predictions
Red: ACRIMSAT observations

Transit of Venus in June 8th 2004 as seen from ACRIMSAT

The overall agreement is very good either in term depth and Ingress/Egress slopes. Venus transit fit is the important benchmark test for 3D simulations

Chiavassa, Pere, Faurobert, Ricort, Tanga, Magic, Collet, Asplund, A&A 576, A13

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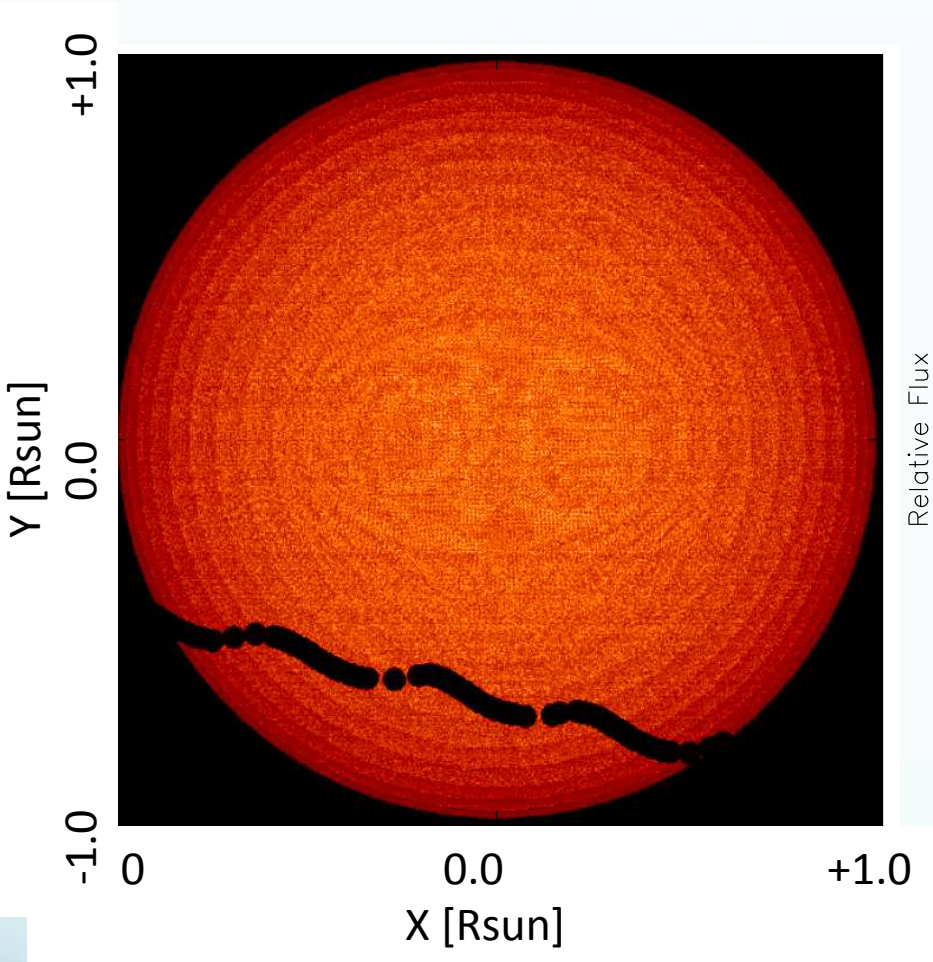

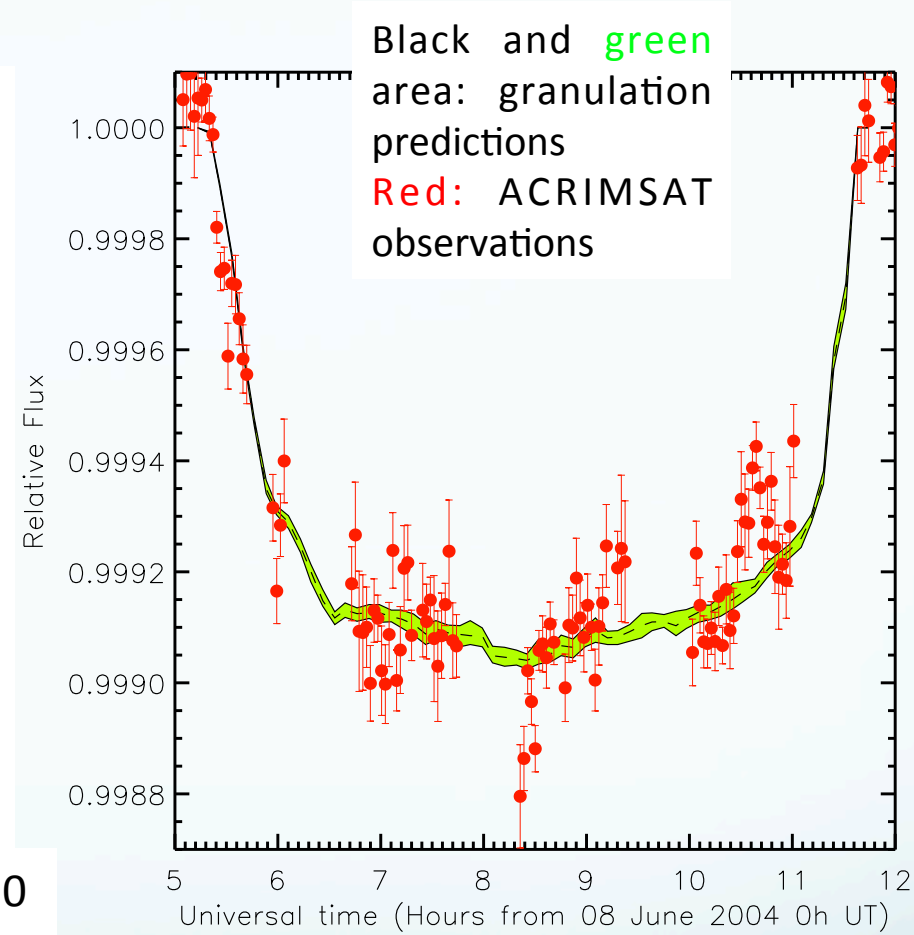

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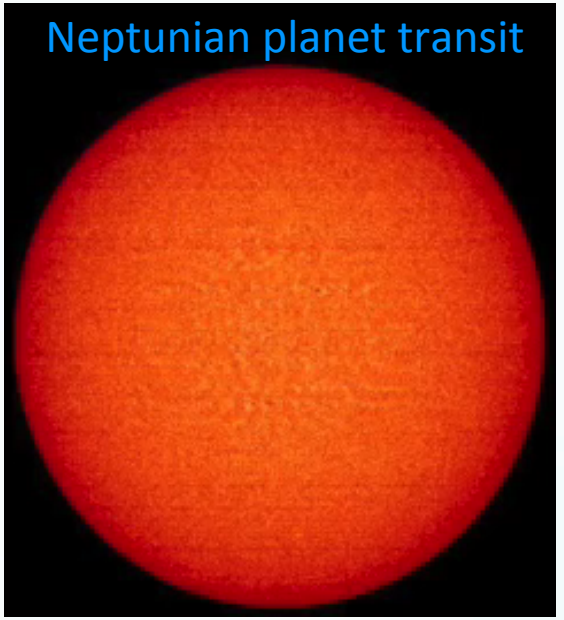
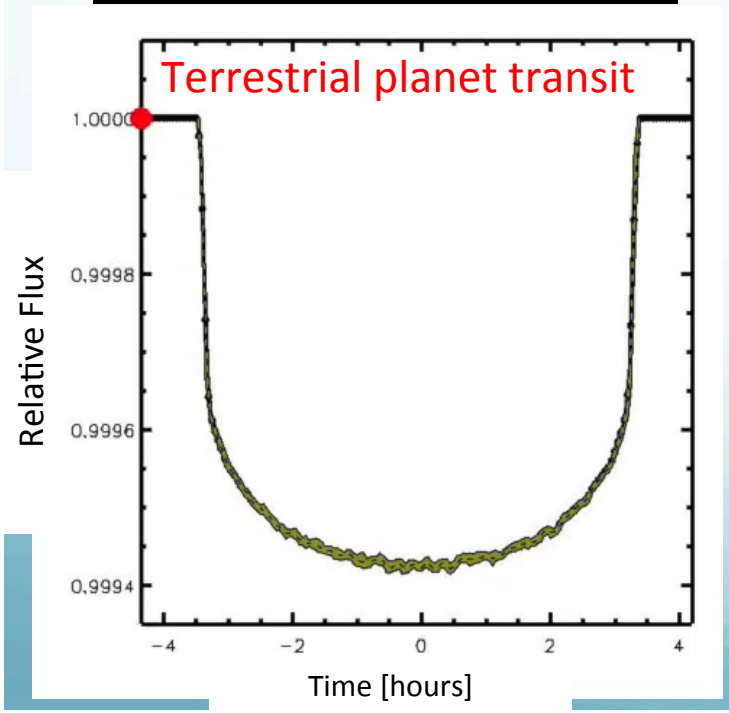
Chiavassa, Pere, Faurobert, Ricort, Tanga, Magic, Collet, Asplund, A&A 576, A13

Synthetic Transits for different stellar and planet types

Terrestrial planet transit

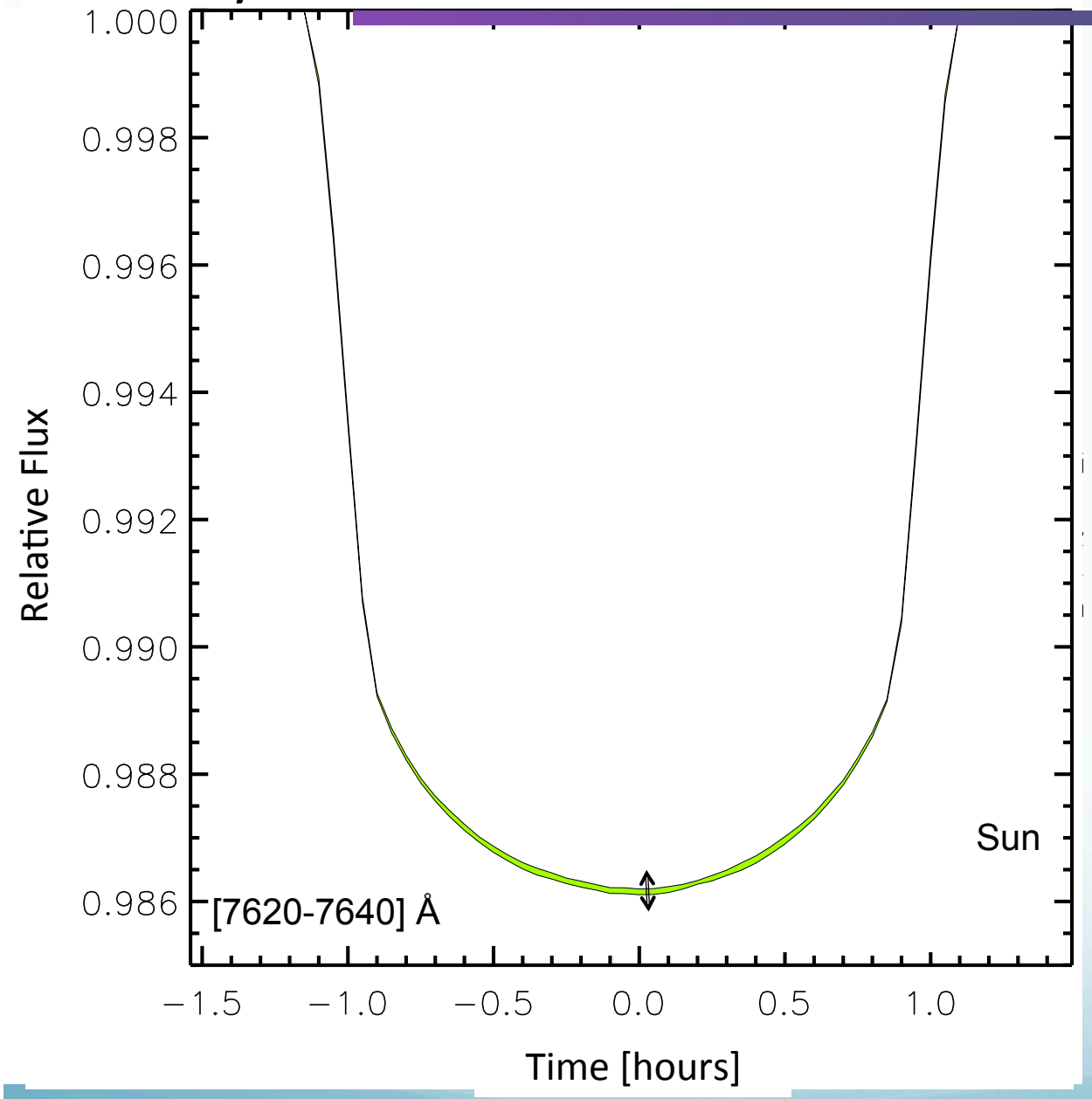
Photometric variability simulated with different uncorrelated stellar disk images with a timestep of about 10 minutes





Jupiter planet transit

Synthetic Transits for different stellar and planet types



Terrestrial planet
37 part per million

Neptunian planet
411 part per million

Jupiter planet
682 part per million

For comparison:

- Kepler accuracy 20-84 ppm (Koch et al. 2010)
- TESS ≈ 60 ppm (Ricker et al. 2015)
- Sun granulation variability: 10 to 50 ppm (Jenkins 2002, Frohlich et al. 1997)

Chiavassa, Selsis, Von Paris, Bordé, Magic, Collet, Asplund, A&A, to be submitted

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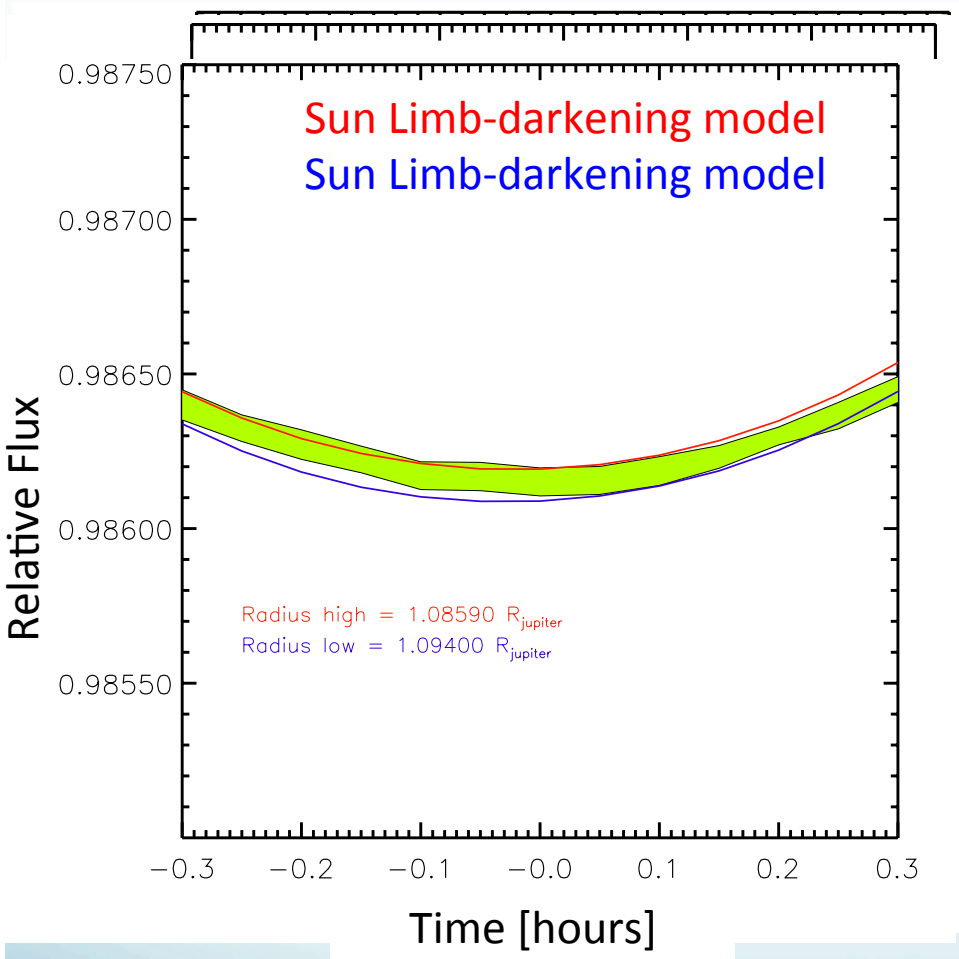

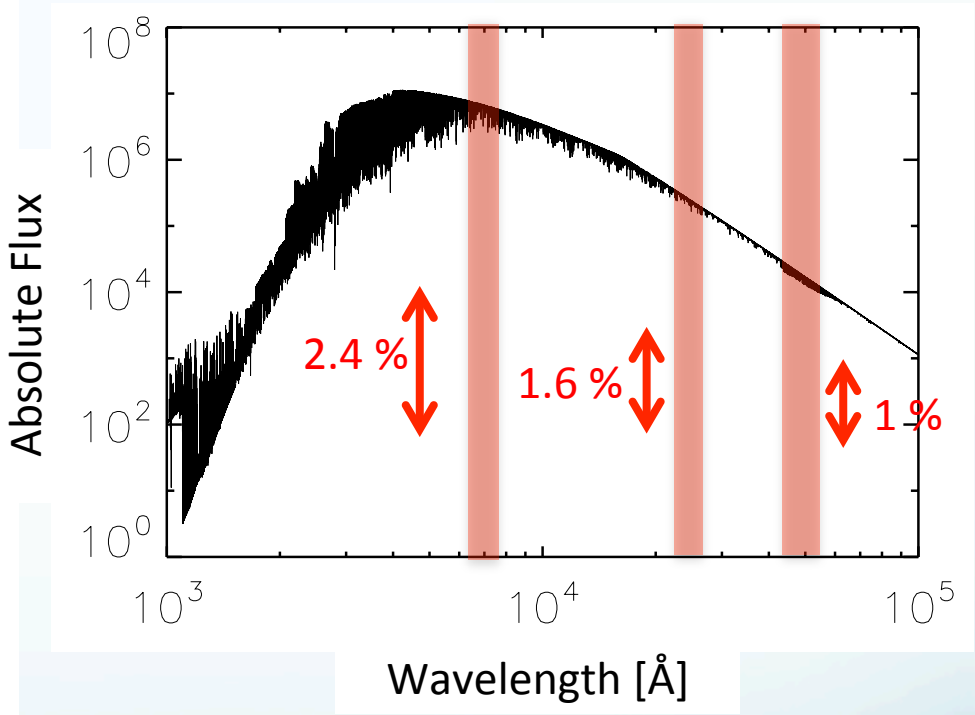

Terrestrial planet incertitude on planet radius

Jupiter plane
7500-7700 Å 0.4 %

Neptunian planet
7500-7700 Å 0.7 %

Chiavassa, Selsis, Von Paris, Bordé, Magic, Collet, Asplund, A&A, to be submitted

Conclusions

- Venus 2004 transit matching with 3D simulations of solar convection is very important benchmark test
- The granulation pattern signal pollute the detection of planets with impact on the planet radius (in particular for terrestrial planet).
- The comprehensive knowledge of the hosting star dynamics is crucial for quantifying the bias caused by the granulation