From high-resolution observations and models of the Sun towards cool stars

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Recent advances in high-resolution ground-based and space-borne observations of the Sun enriched our physical understanding of our host star. **Detailed comparisons of these observations with numerical models** provide important tests, which nourish the development of numerical simulations with unprecedented levels of complexity and realism. Spatially resolved observations are unfortunately not possible for other dwarf stars. However, the numerical simulation codes, which are developed for the solar case, can also be applied to other stars because much of the modelled physics is valid there, too.

Dwarf stars of spectral type M ("**M-dwarfs**") constitute about 75% of all stars in our galaxy *(Bochanski et al. 2010)*, which makes them highly relevant for stars in general, incl. stellar magnetism and stellar activity, and for a multitude of fundamental questions in modern astrophysics like, e.g., the chemical evolution of the universe. Observations of these stars provide statistically significant samples that span large parameter ranges, which are not accessible from solar observations alone.
The combination of solar and stellar studies yields therefore large potential for a better understanding of our Sun and stars in general.

The general strategy is outlined in Fig. 1 at the bottom. Both solar and stellar applications make to a large extent use of the same tools but serve as complementary feedback loops. The comparison of observations with synthetic diagnostics is of central importance. A disagreement indicates the need for further improvements and/or extensions at the individual stages of the loop, while an agreement signals that certain aspects are already modelled sufficiently realistic and can therefore be investigated in more detail by using the thus validated numerical models.

The Sun serves as fundamental reference case. Our detailed understanding of the Sun allows now for exploiting the qualitative similarities concerning certain aspects of stellar atmospheres in the context of other stellar types. The right column gives a few examples for which 3D models of the Sun are compared to 3D models of a M-dwarf, incl. the small-scale magnetic field structure of the atmosphere, the granulation pattern in the low photosphere, and dynamic processes (e.g., so-called "magnetic tornadoes"), which exist both on the Sun and M-dwarfs.

References, code descriptions and further reading

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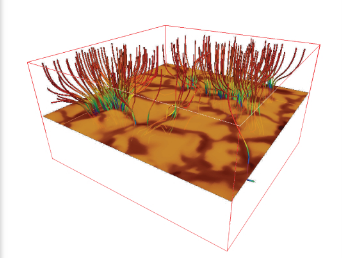
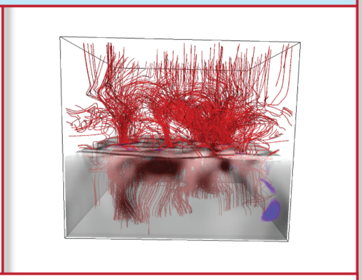
The Sun (Teff= 5770 K, logg=4.4)	**M-dwarf (AD Leo)** (Teff= 3240 K, logg=4.5)

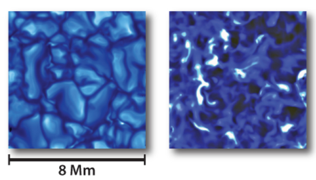
Three-dimensional magnetic field structure

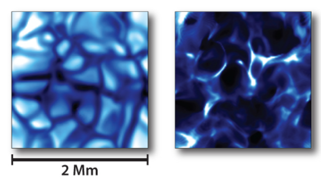




The 3D models extend from the upper convection zone into the chromosphere. In both cases, the convective flows result in a concentration of magnetic flux in the intergranular lanes in form of sheets and knots ("bright points"), whereas the magnetic field expands in the chromosphere above.

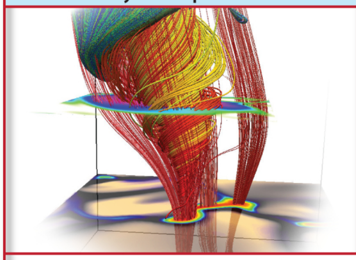
Small-scale atmospheric pattern - Granulation and mid-chromosphere

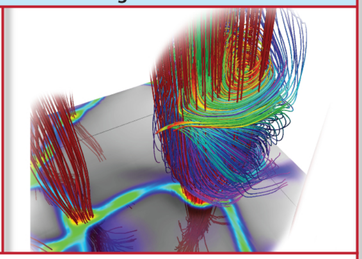




Both the solar and the AD Leo model exhibit surface convection and a similar granulation pattern, although the spatial scales differ significantly. Also the chromospheres are characterized by a combination of magnetic fields and interacting shock waves as structuring agents.

Dynamic processes on small spatial scales - magnetic tornadoes





Magnetic tornadoes are the result of magnetic field structures, which are rotated as a result of vortex flows at the interface between the upper convection zone and the photosphere. Vortex flows and magnetic fields and consequently 'tornadoes' are present in both models.

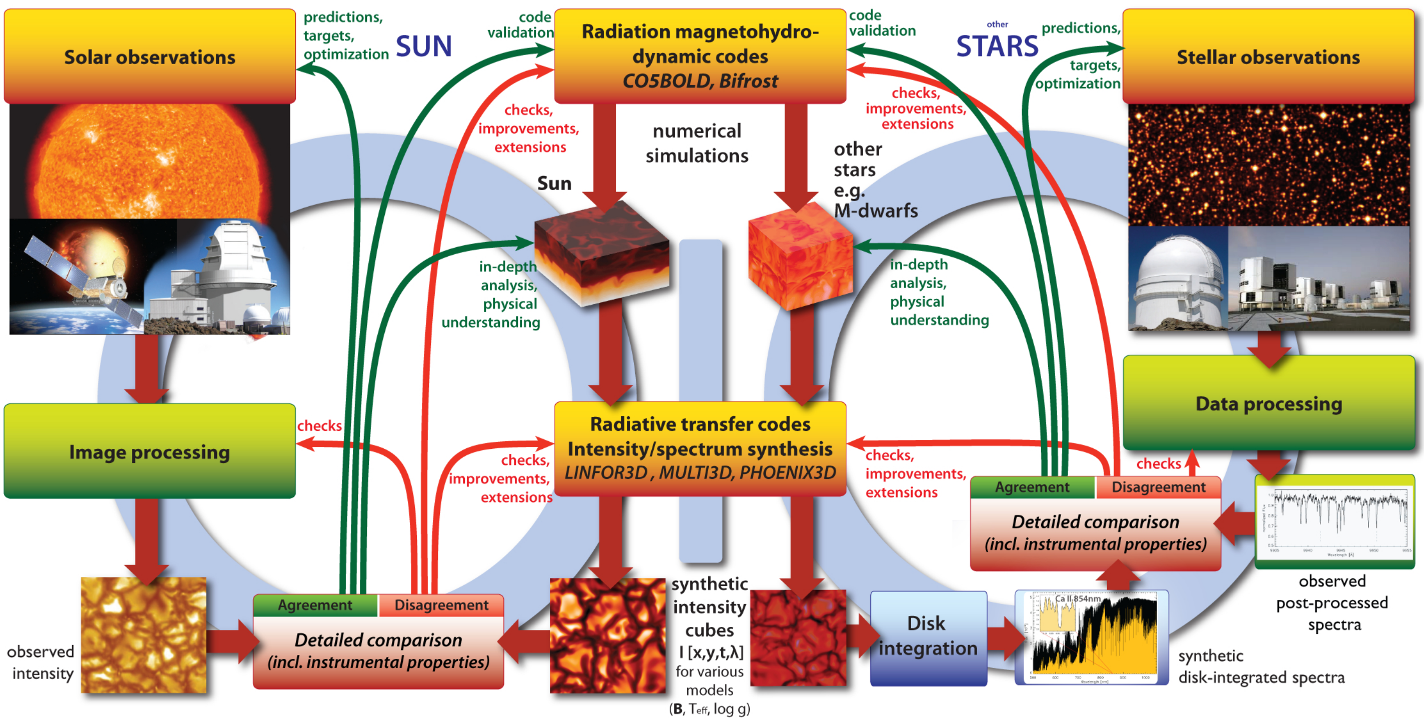


Fig. 1: The same numerical codes can be used for numerical time-dependent simulations of stellar atmospheres (middle). Detailed comparisons with solar observations (left) enable us to validate and improve these codes, which then can be applied to other stellar types, too (right).