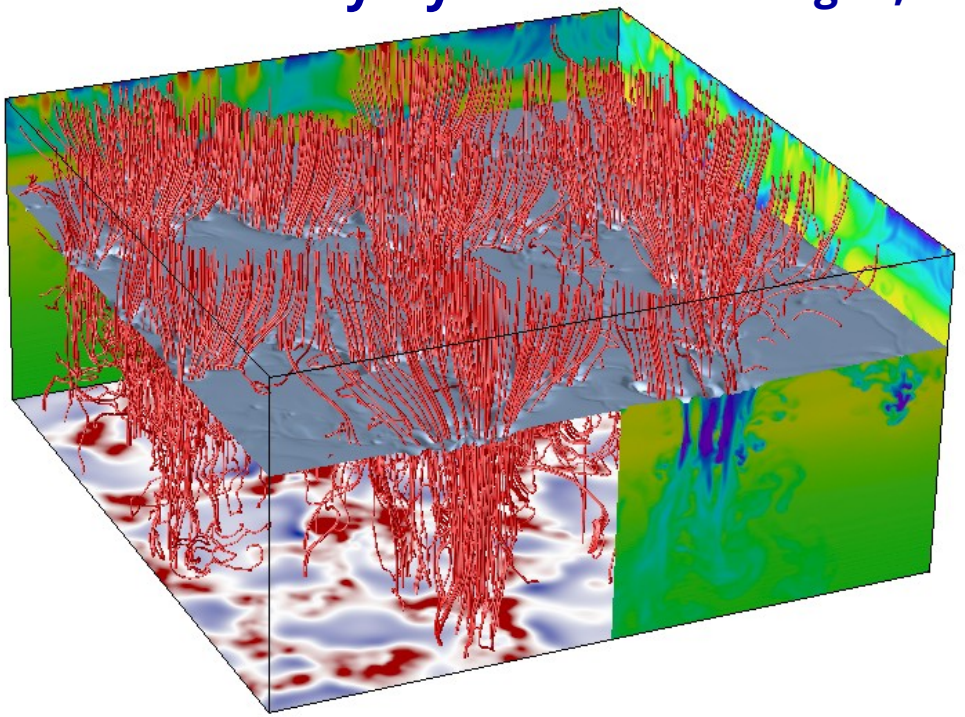
CRC 963 workshop on

Stellar and Planetary Dynamos – Göttingen, Germany



The importance of the local structure of stellar magnetic fields for observations

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Robert Cameron (MPS)

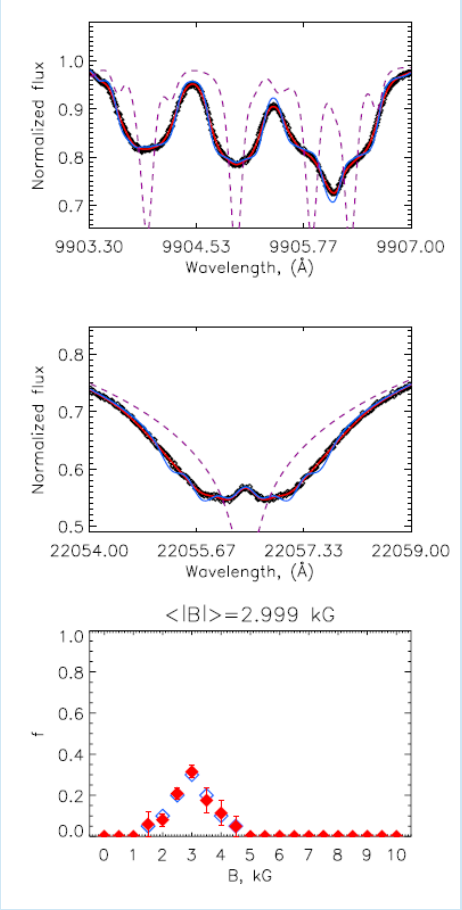
Ansgar Reiners (IAG)

Göttingen, 2015-05-26

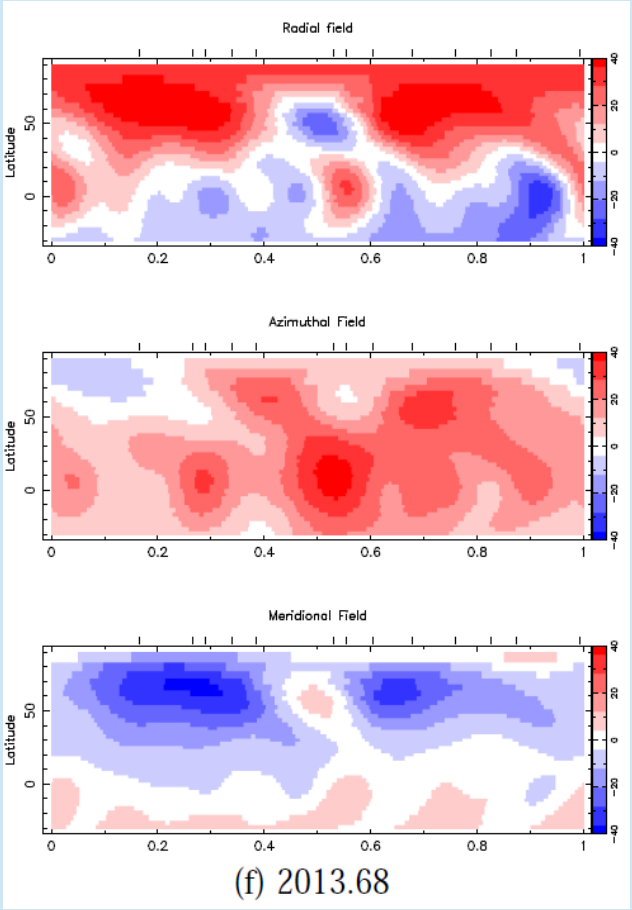
Global structure of magnetic fields

Spectroscopy + Spectropolarimetry → global structure of magnetic field

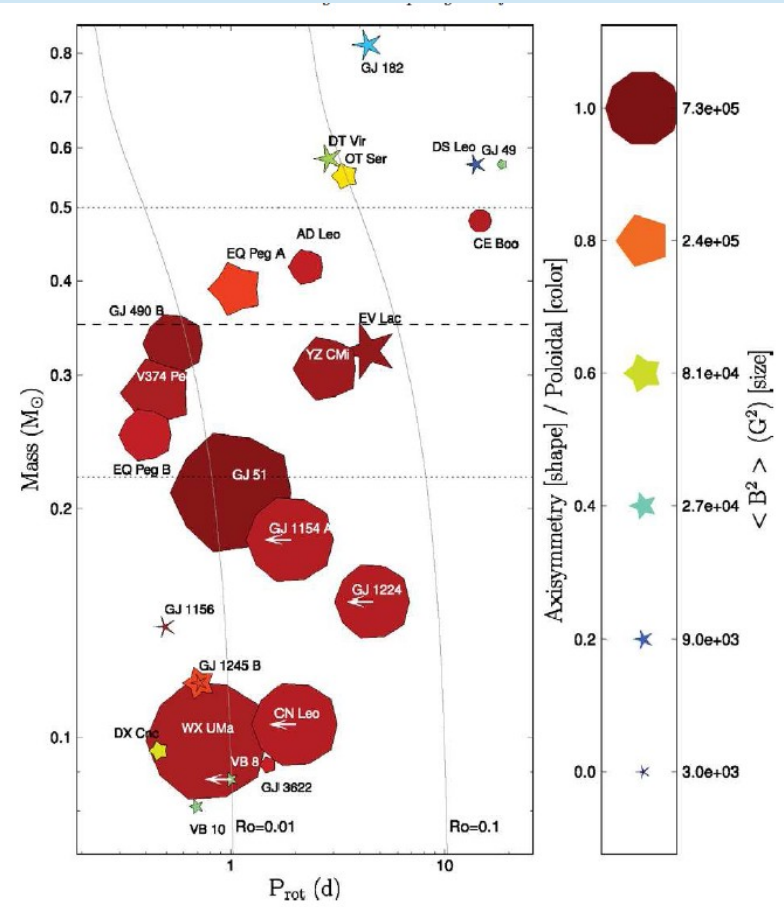
→ Constraints on Stellar Dynamos



Shulyak et al. (2014)

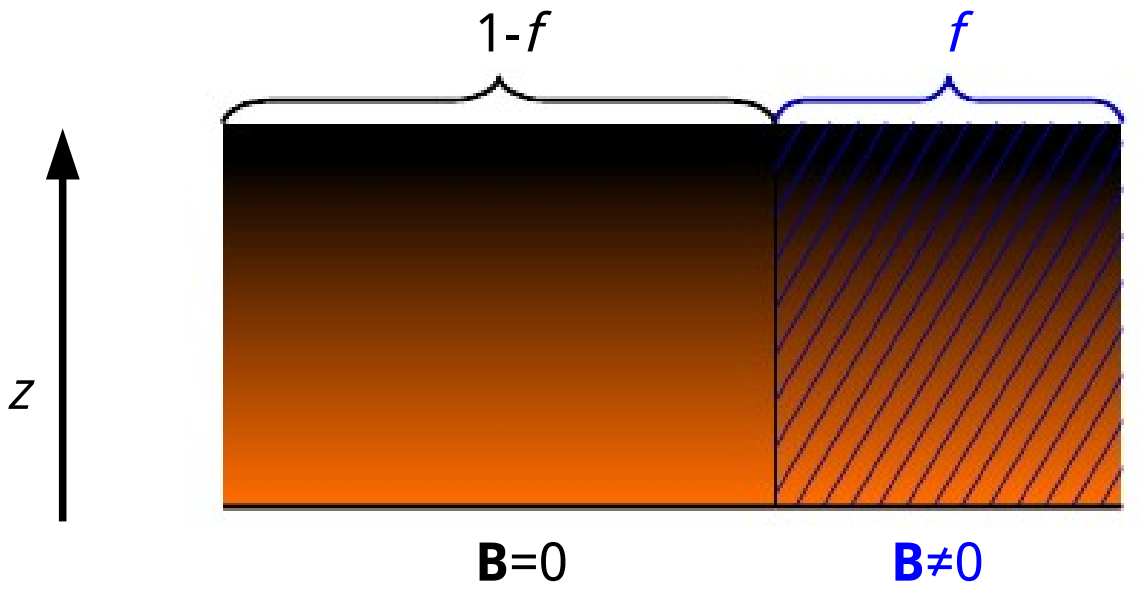


Boro Saikia et al. (2015)



Morin et al. (2011)

Local structure ?

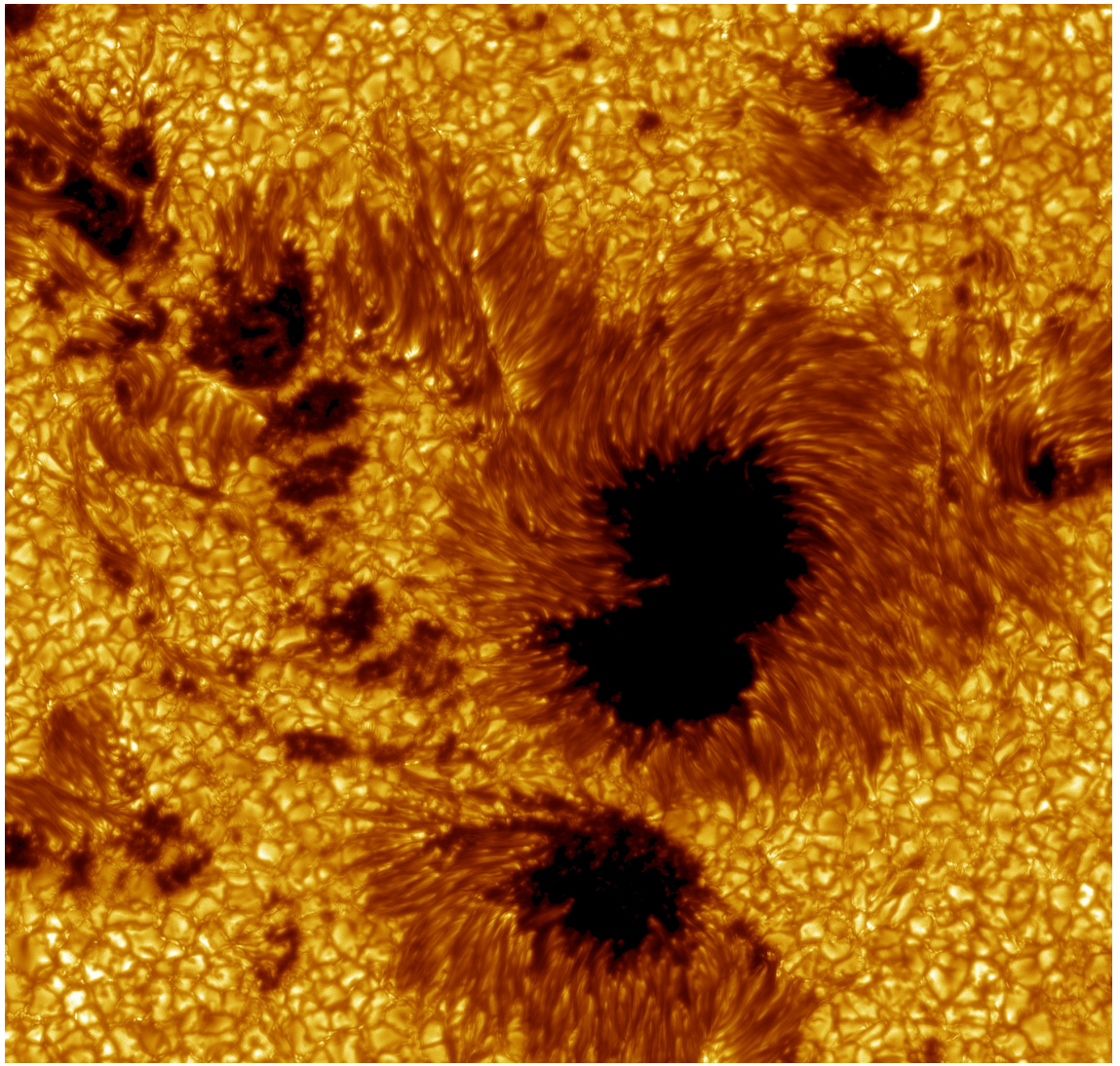


1D simplifications / assumptions

- static plane-parallel atmosphere in radiative equilibrium:
  - $T = T(z)$
  - $p = p(z)$
  - $\rho = \rho(z)$

  } independent of local magnetic field
- $v_{\rm turb}$ and B uncorrelated and often height-independent
- only effect of the magnetic field:
  - broadening/splitting/polarisation of spectral lines (Zeeman effect)

Observed solar magnetic field



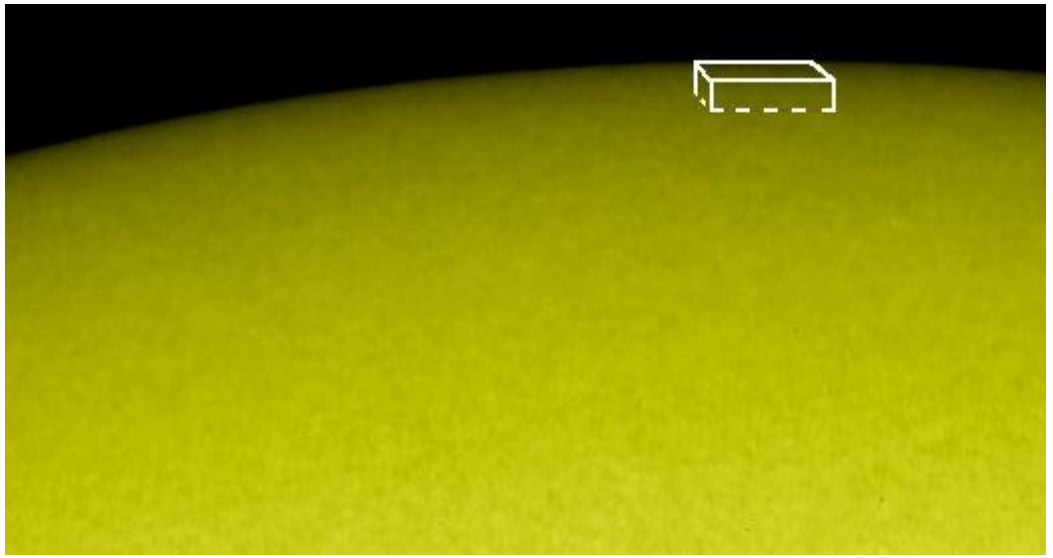
Credit: G. Scharmer, Institute for Solar Physics, Royal Swedish Academy of Sciences

- The solar magnetic field is locally highly structured
- Convective flows and magnetic field interact with each other (hence they are correlated)
- Modulation of intensity/atmosphere structure (sunspots, faculae, etc.)
- ***How about the local structure of stars?***
  → simulations

The MURaM code

MURaM = MPS/UofC Radiation MHD code
Developed by the **MPS MHD Group**
in cooperation with the **University of Chicago**

Vögler (2003), **Vögler et al. (2005)**, **Rempel et al. (2009)**, and references therein



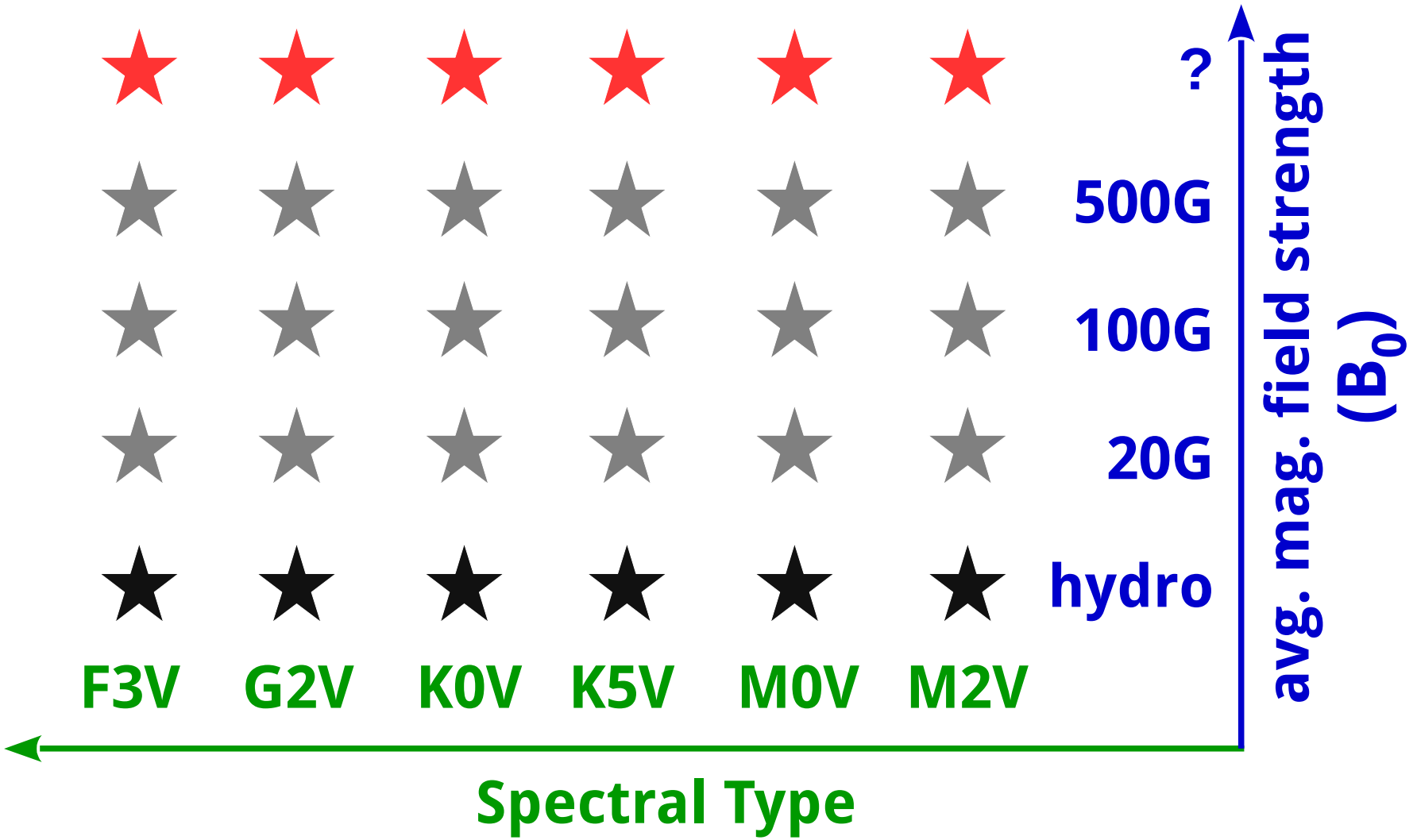
- Local-box code
- Solves compressible MHD on a three-dimensional cartesian grid
  - 4th order centred spatial difference scheme
  - explicit time stepping: 4th order Runge-Kutta
- radiative transport
  - short characteristics
  - opacity binning (here: four bins; τ-sorting)
  - LTE
- realistic OPAL EoS (including partial ionisation of the most relevant species)

Grid of simulations

$\log g$ [cgs]	4.30	4.44	4.61	4.70	4.83	4.83
$T_{\rm eff}$	6900 K	5800 K	4900 K	4400 K	3900 K	3700 K
	F3V	G2V	K0V	K5V	M0V	M2V

Spectral Type

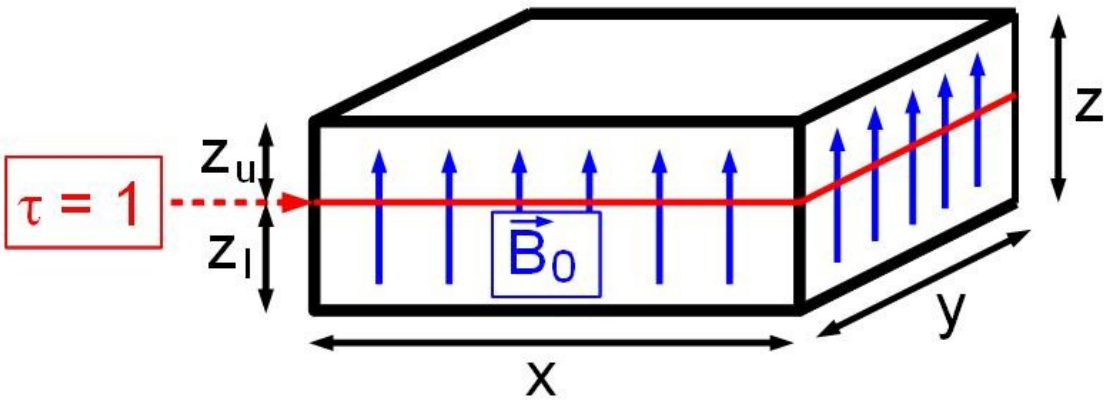
Grid of simulations



- **published:** **Beeck et al. (2013a), Beeck et al. (2013b)**
- **finished:** **Beeck et al. (2015a), Beeck et al. (2015b),** *both accepted for publication in A&A*
- **work in progress**

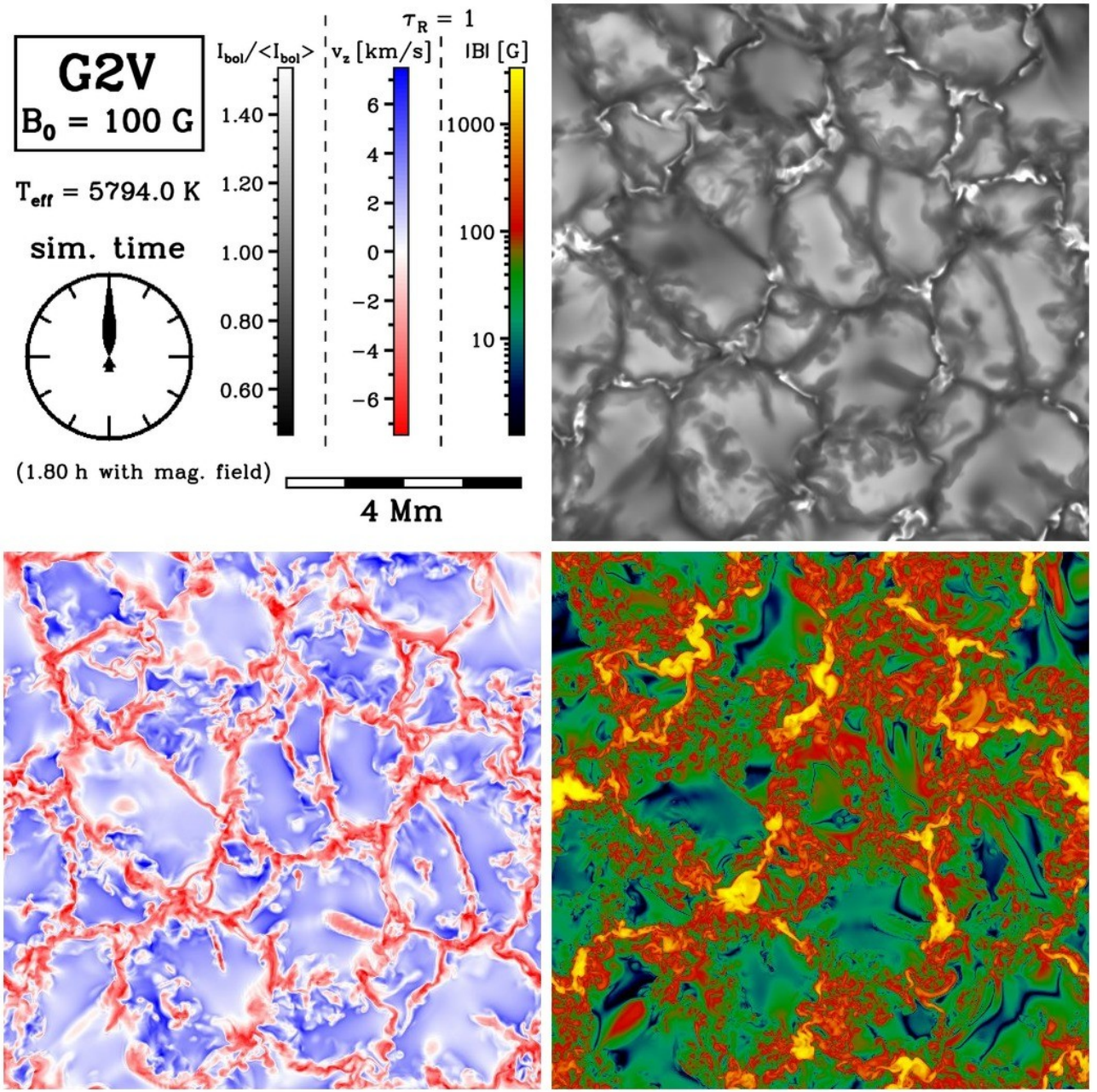
Simulation setup

- Box dimensions:
  - x=y, area of 20-30 granules. (Sun: 9 Mm)
  - z, at least 5 H_p each below and above τ=1 (Sun: 3 Mm)
- Abundances: solar **(Anders & Grevesse, 1989)**
- Top boundary:
  - closed for flows
  - vertical magnetic field
- Bottom boundary:
  - entropy density of inflows fixed (distinct value for each stellar type)
- Initial conditions:
  - *T*, *p*, **v**: from non-magnetic run
  - **B**: uniform, vertical

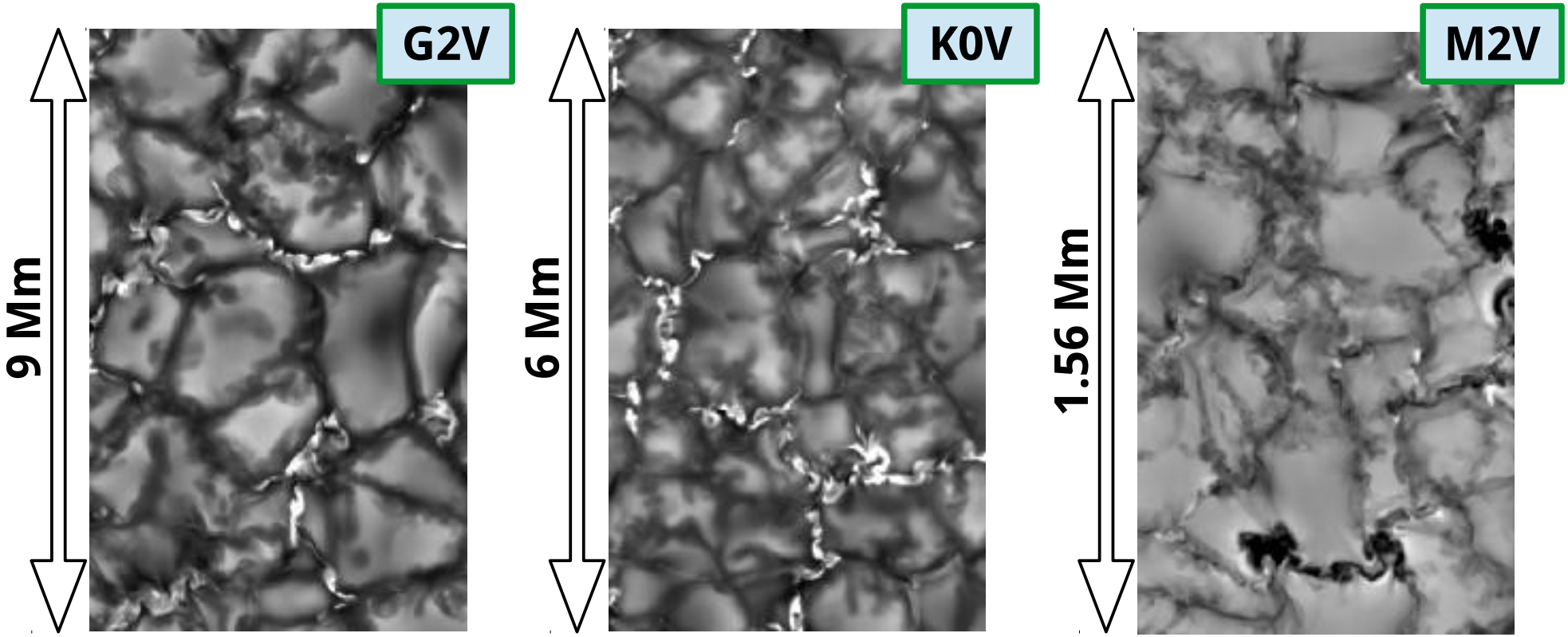


Note: The sun-/starspot simulations have a different setup

Movie: G2V, 100G

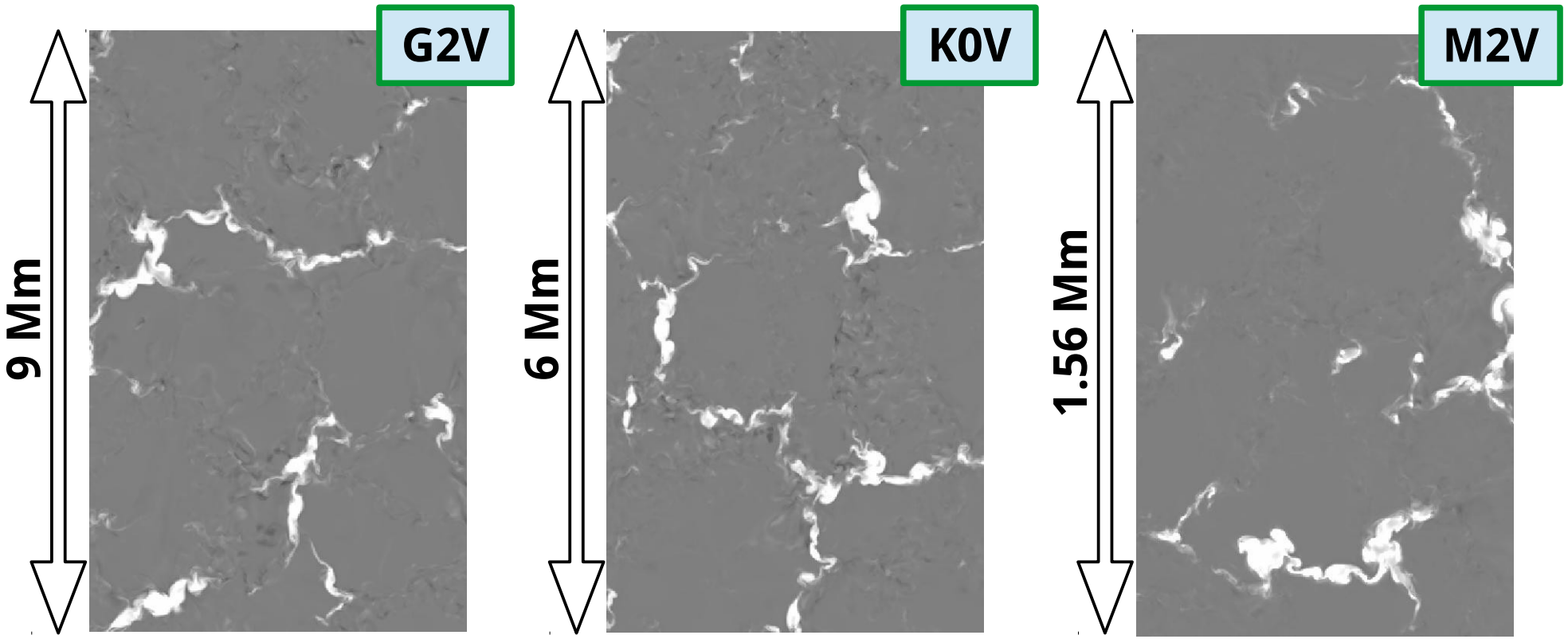


Small-scale magnetic flux concentrations (I_{bol})



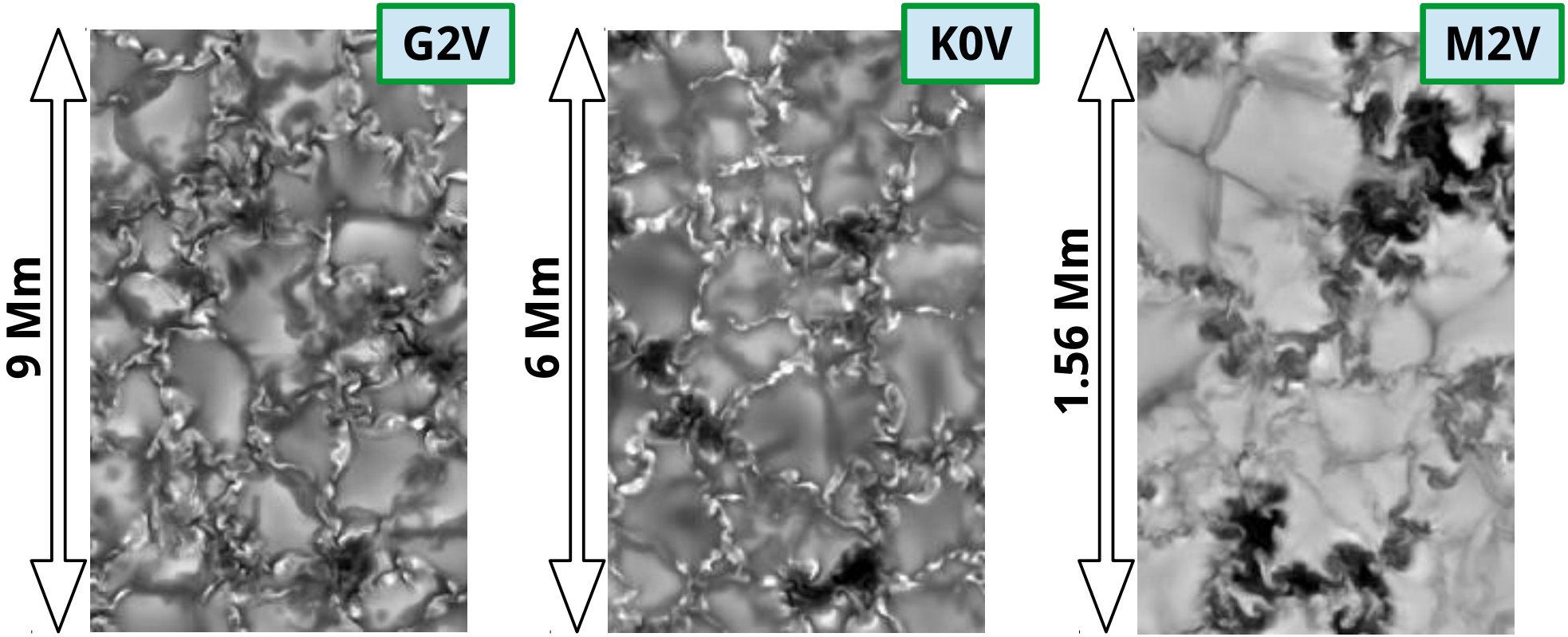
B_0 = 100G

Small-scale magnetic flux concentrations (B_z)



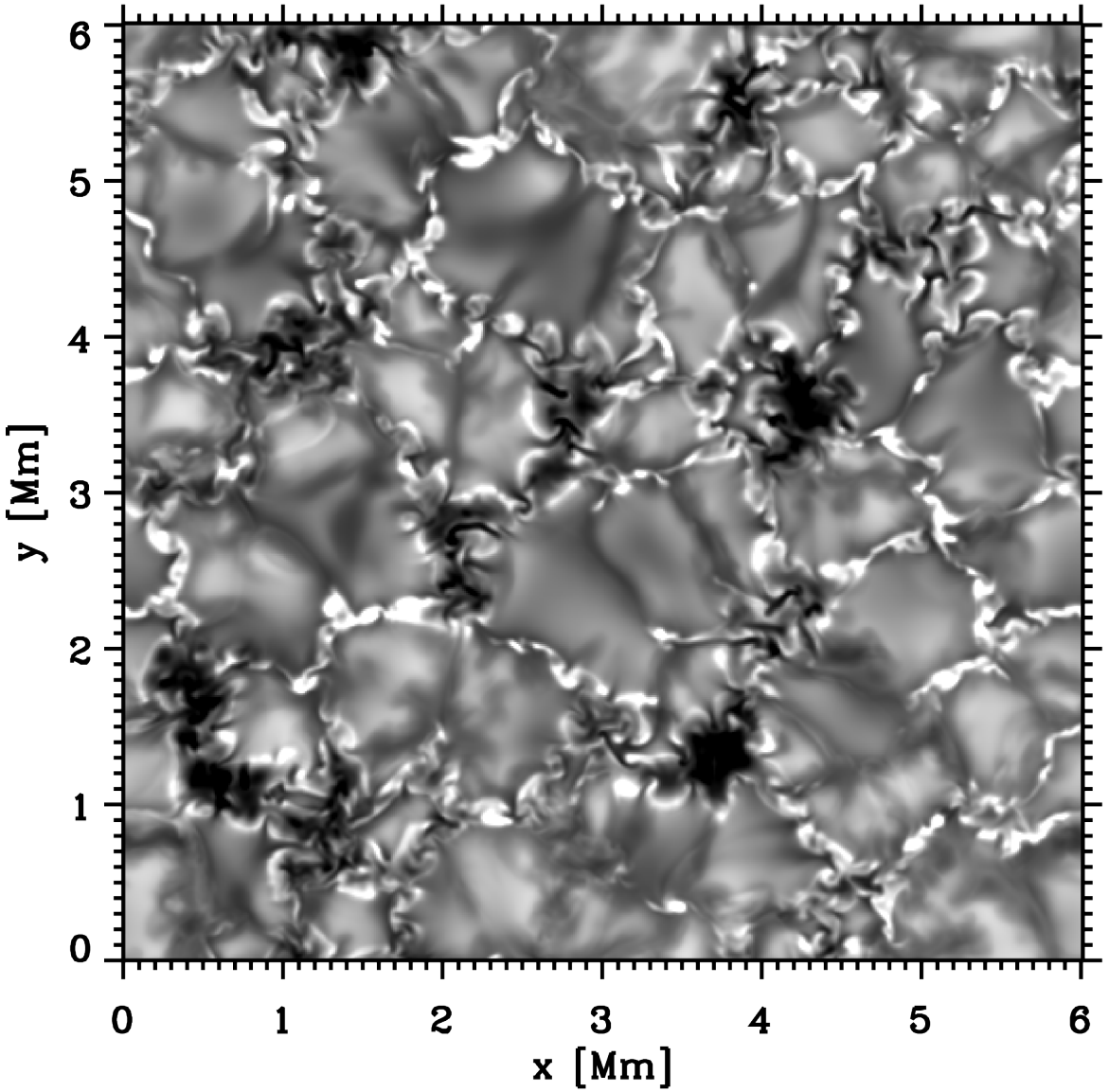
B_0 = 100G

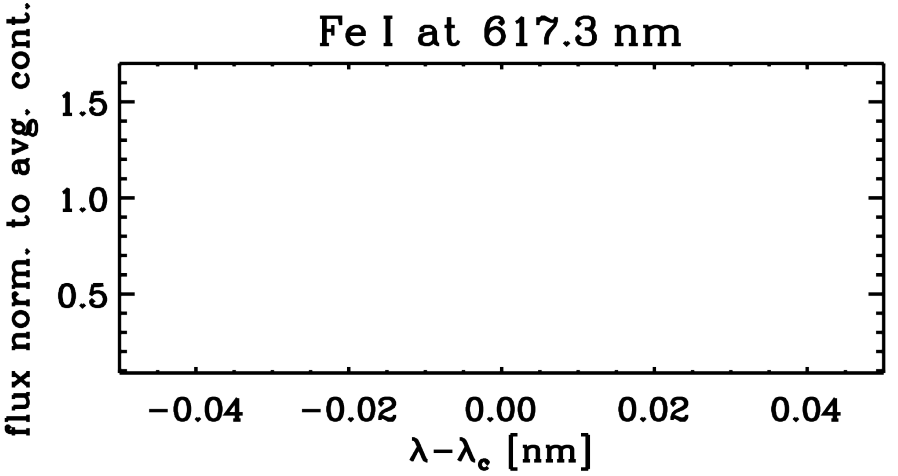
Small-scale magnetic flux concentrations (I_{bol})



B_0 = 500G

Impact on spectral lines (here: K0V, B_0=500G)





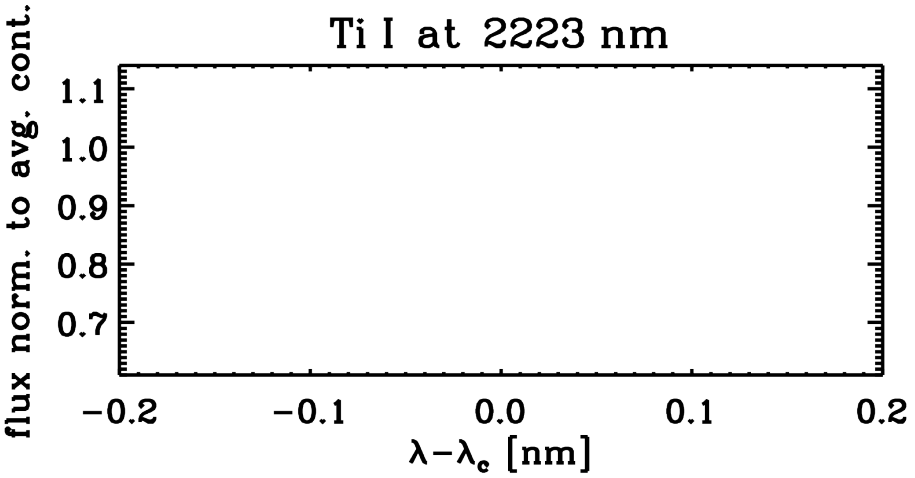
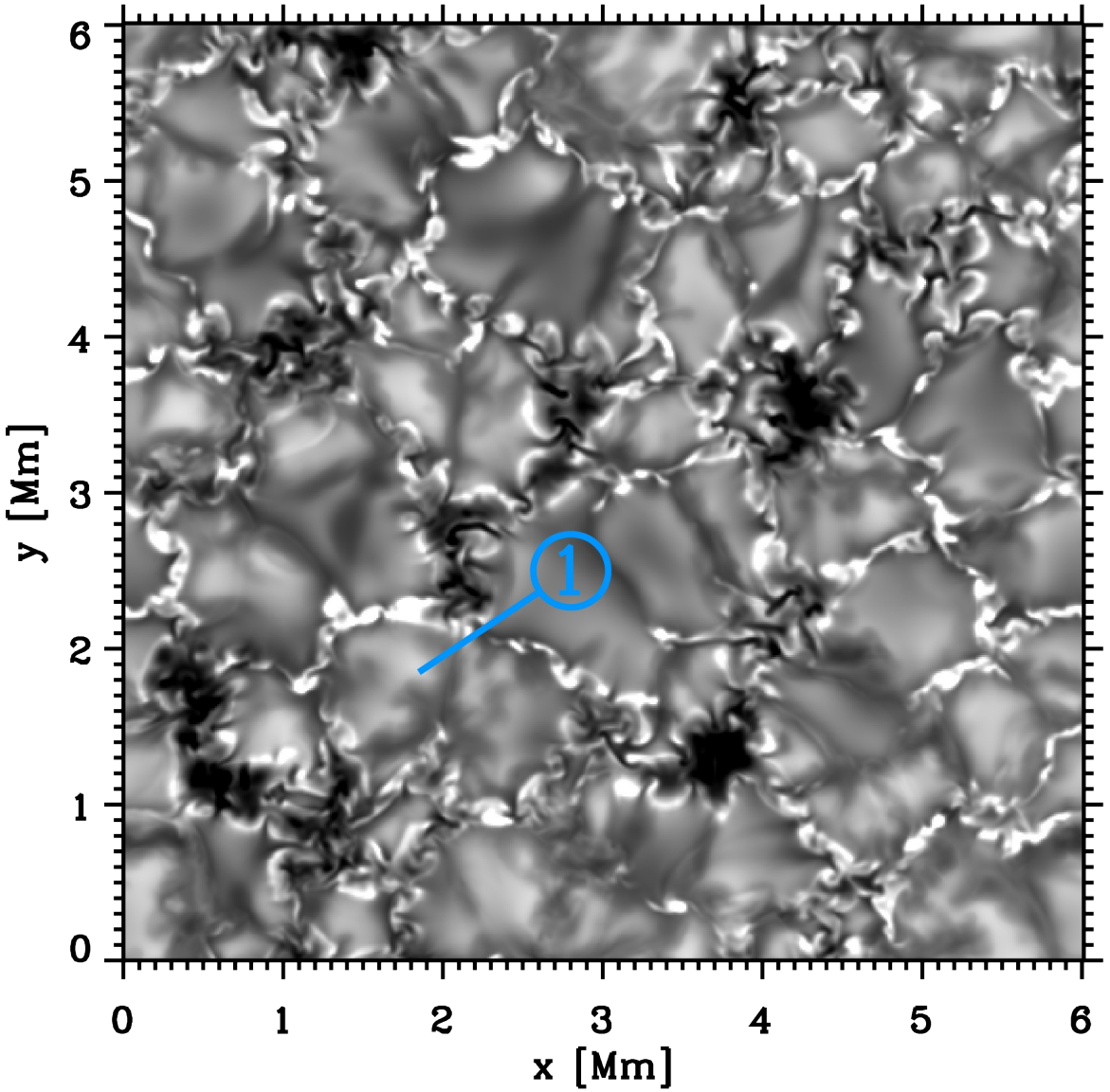
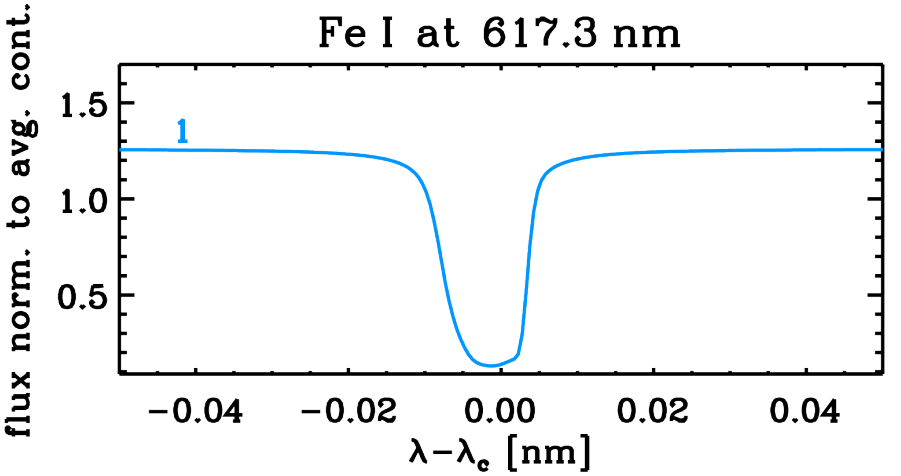


Figure from: **Beeck et al. (2015b)**

Impact on spectral lines (here: K0V, B_0=500G)





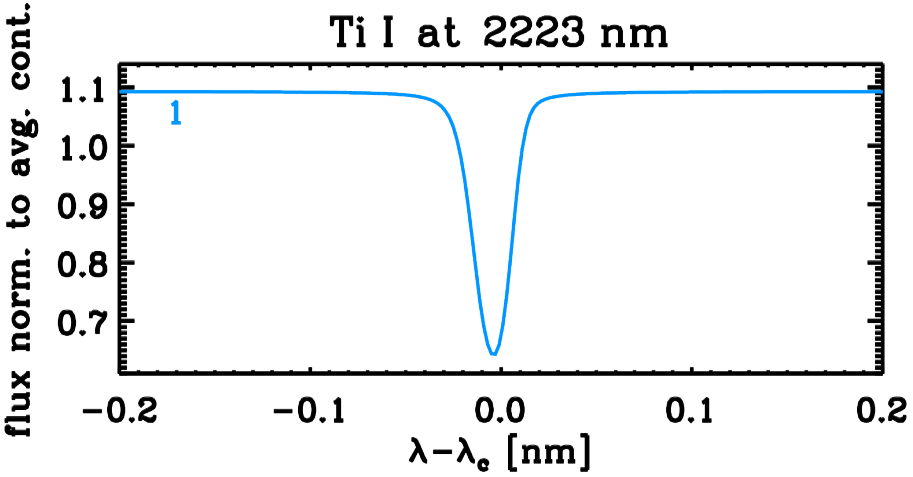
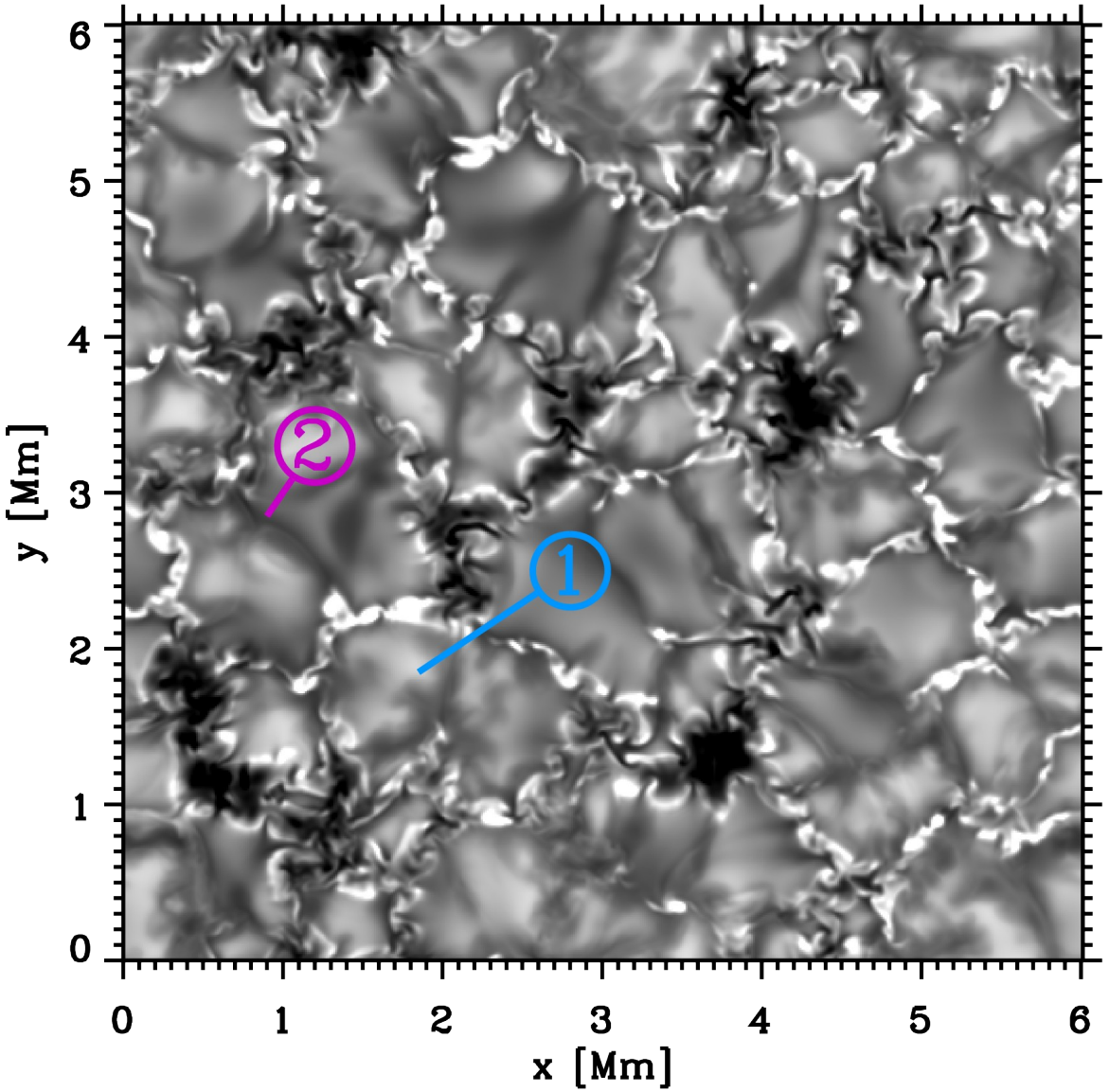
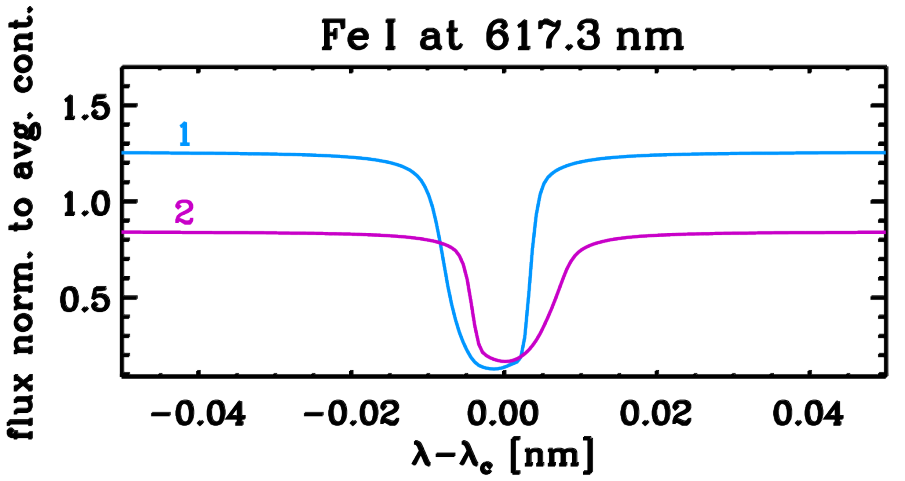


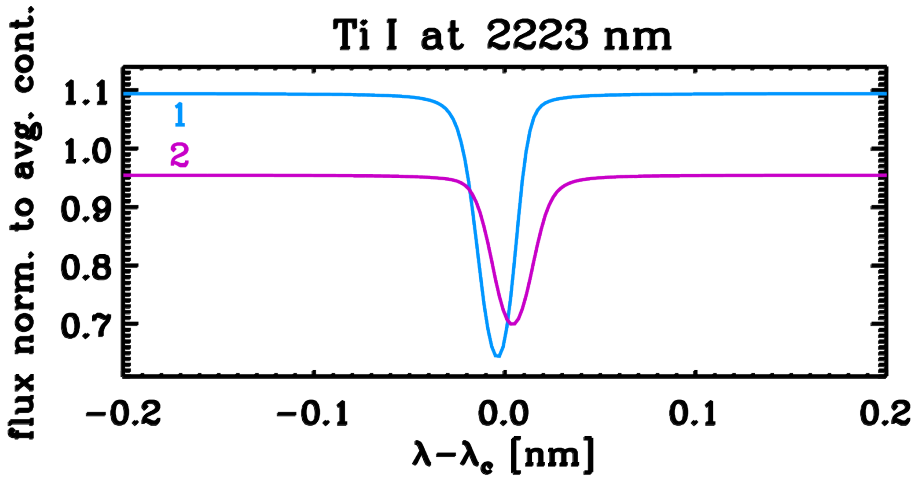
Figure from: **Beeck et al. (2015b)**

Spectral line synthesis code: **SPINOR**
Frutiger (2000), Frutiger et al. (2000)

Impact on spectral lines (here: K0V, B_0=500G)







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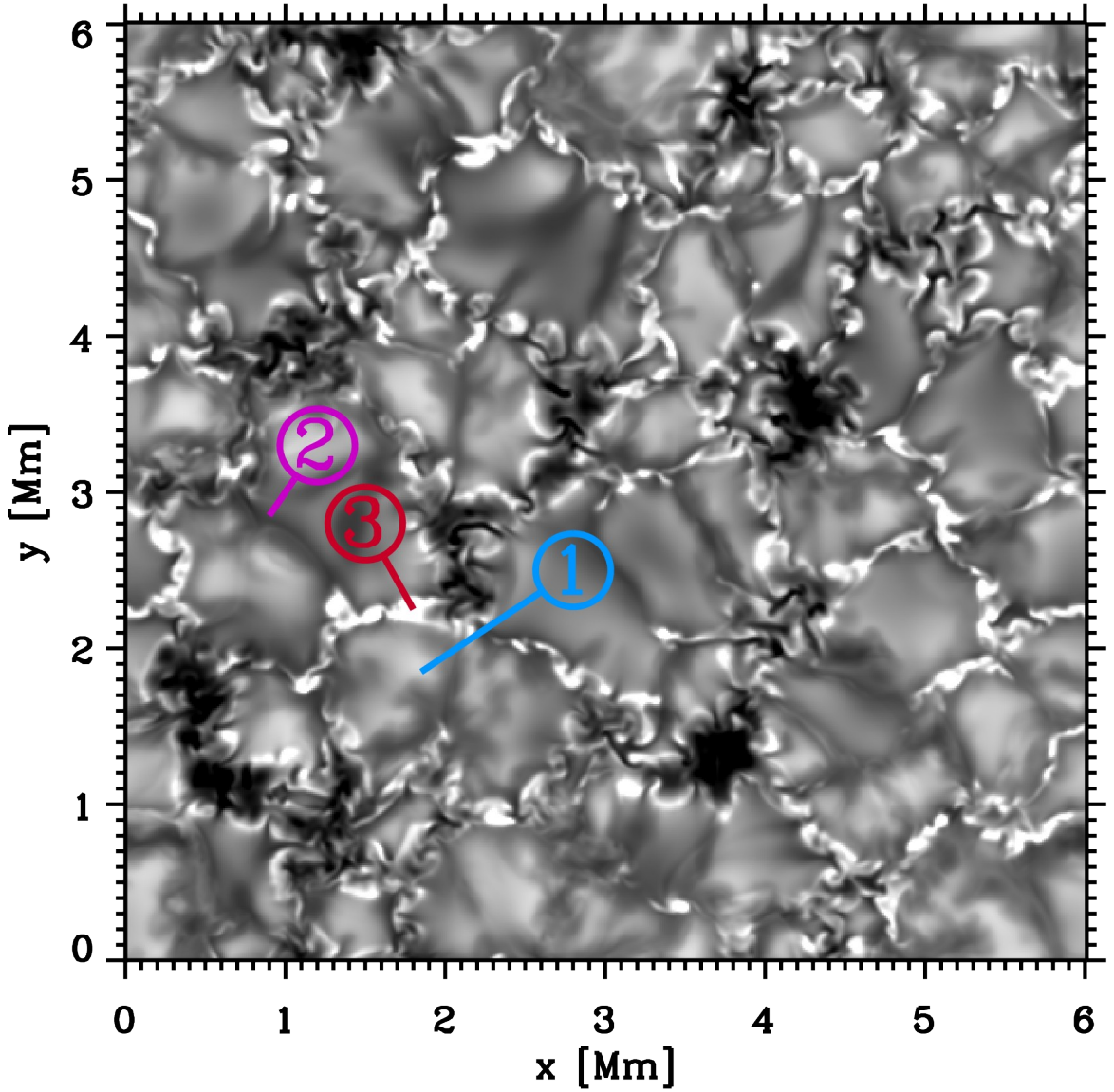

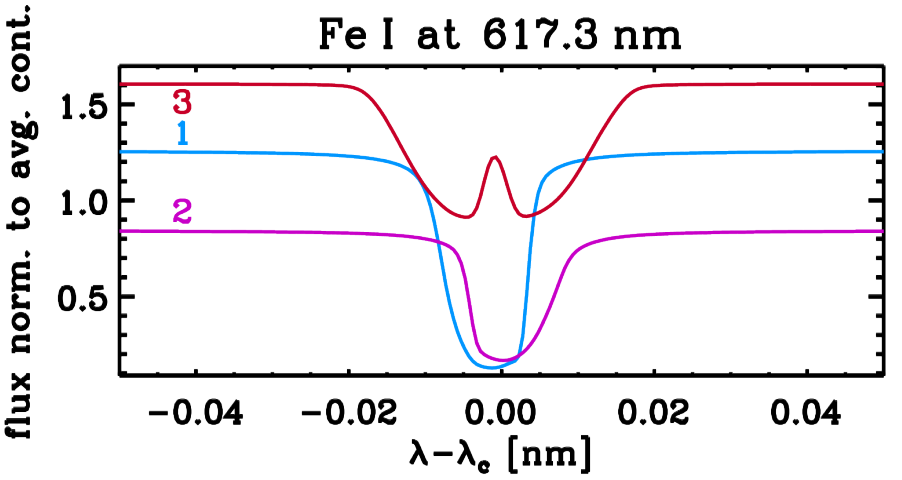

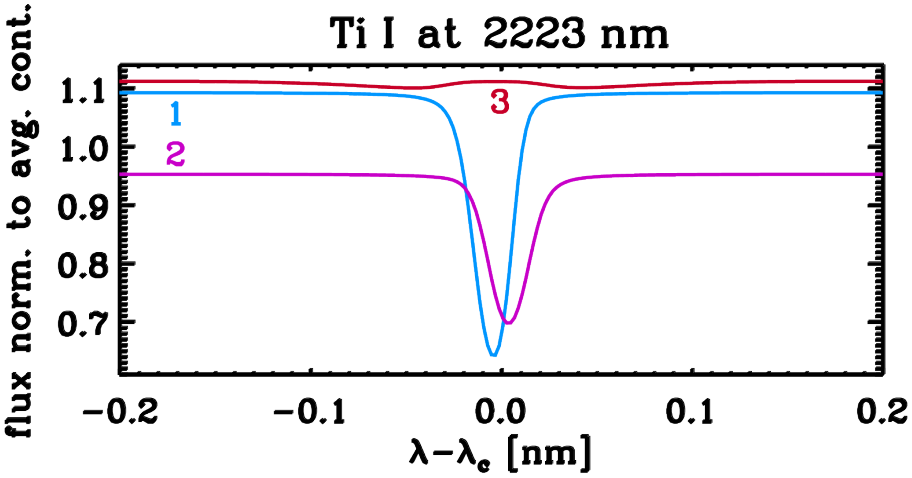

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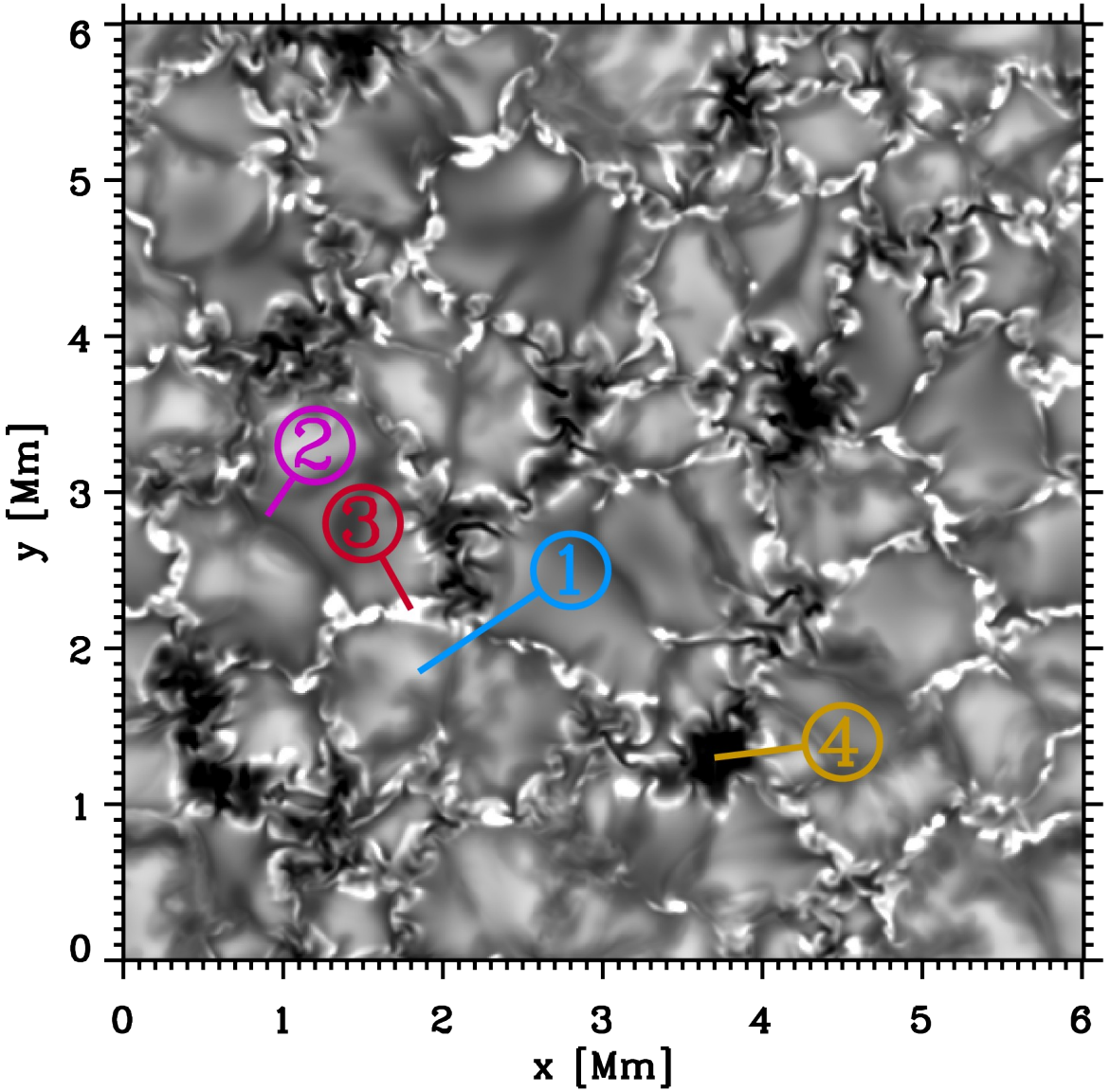

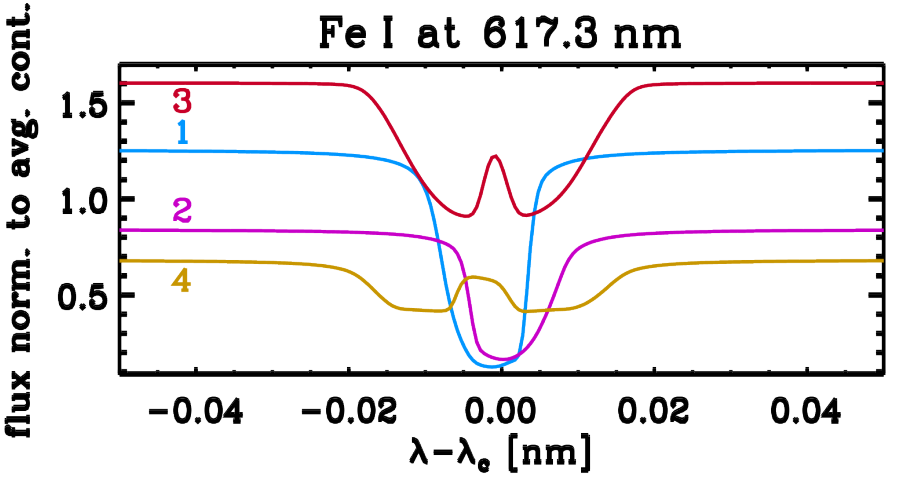

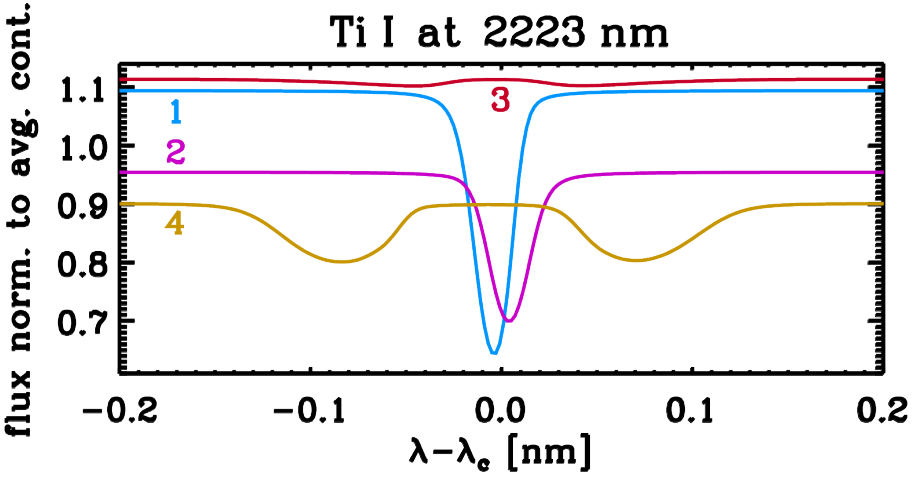

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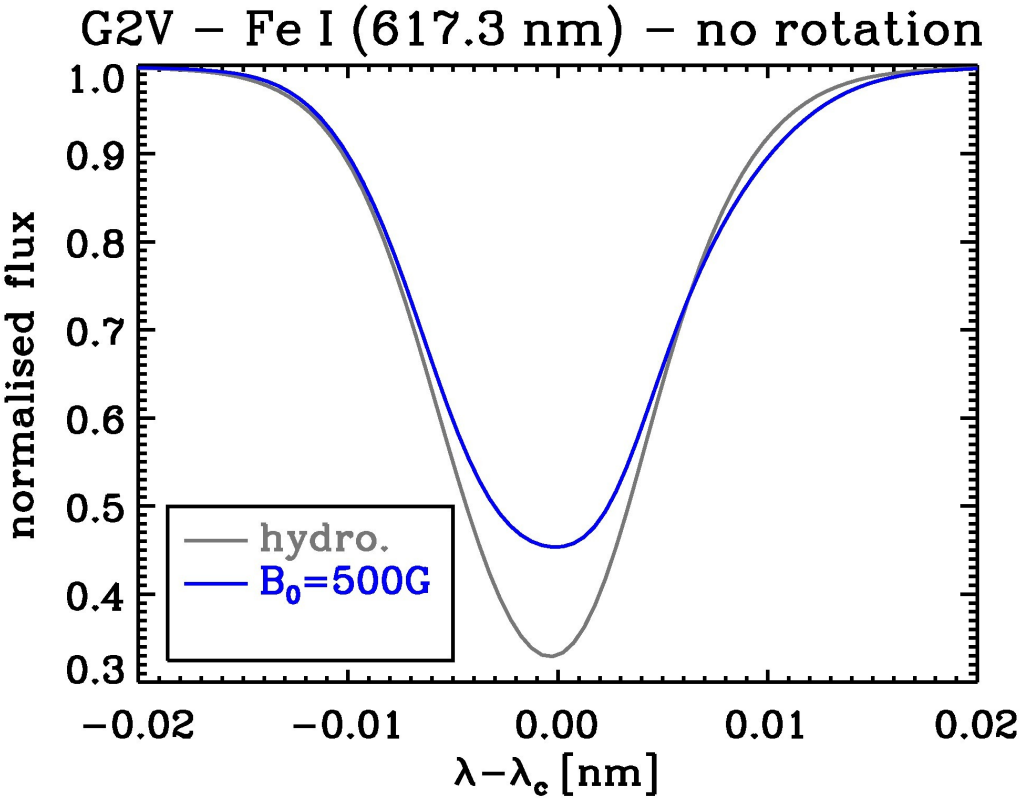
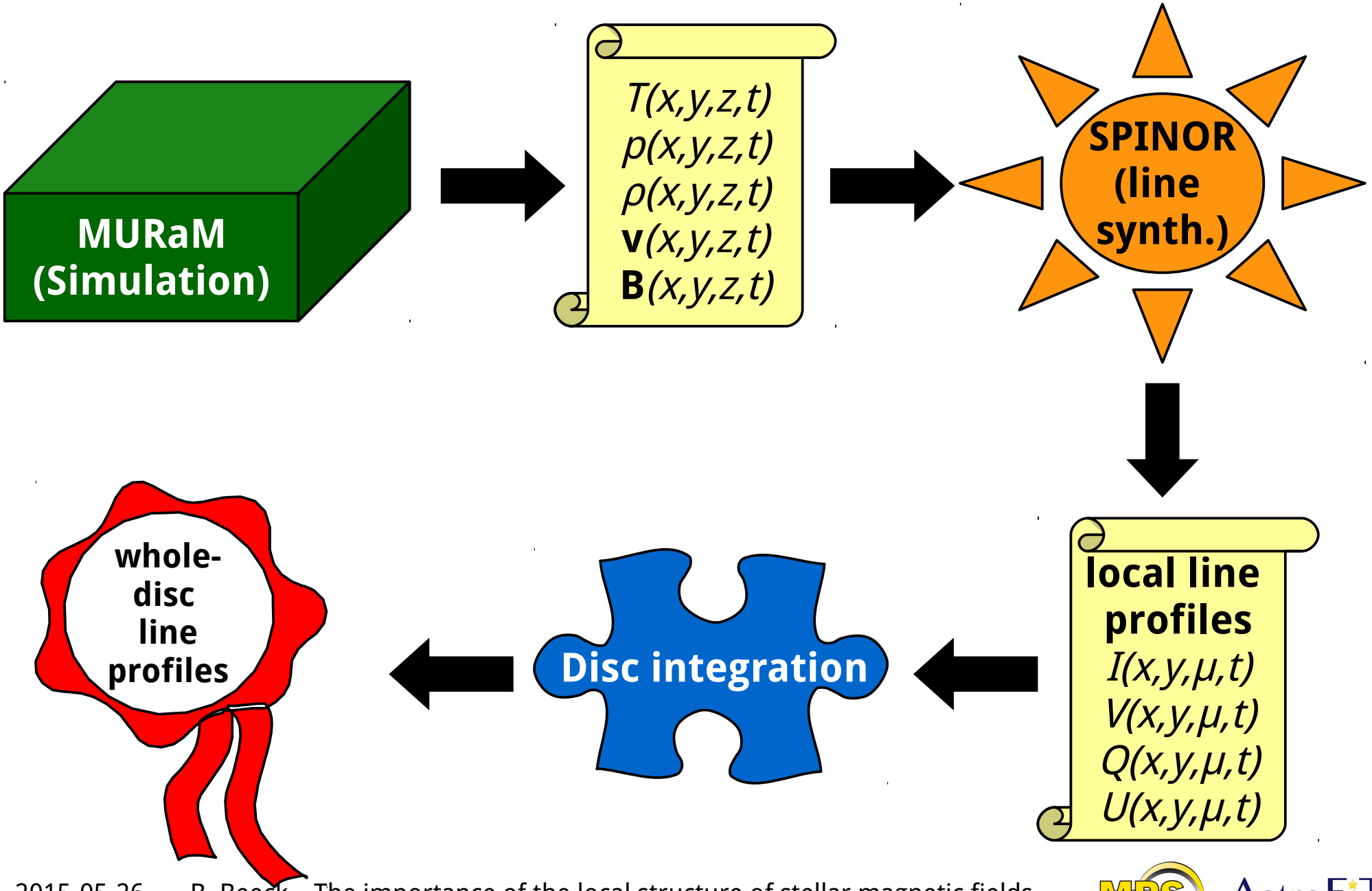
Spectral line synthesis code: **SPINOR**
Frutiger (2000), Frutiger et al. (2000)

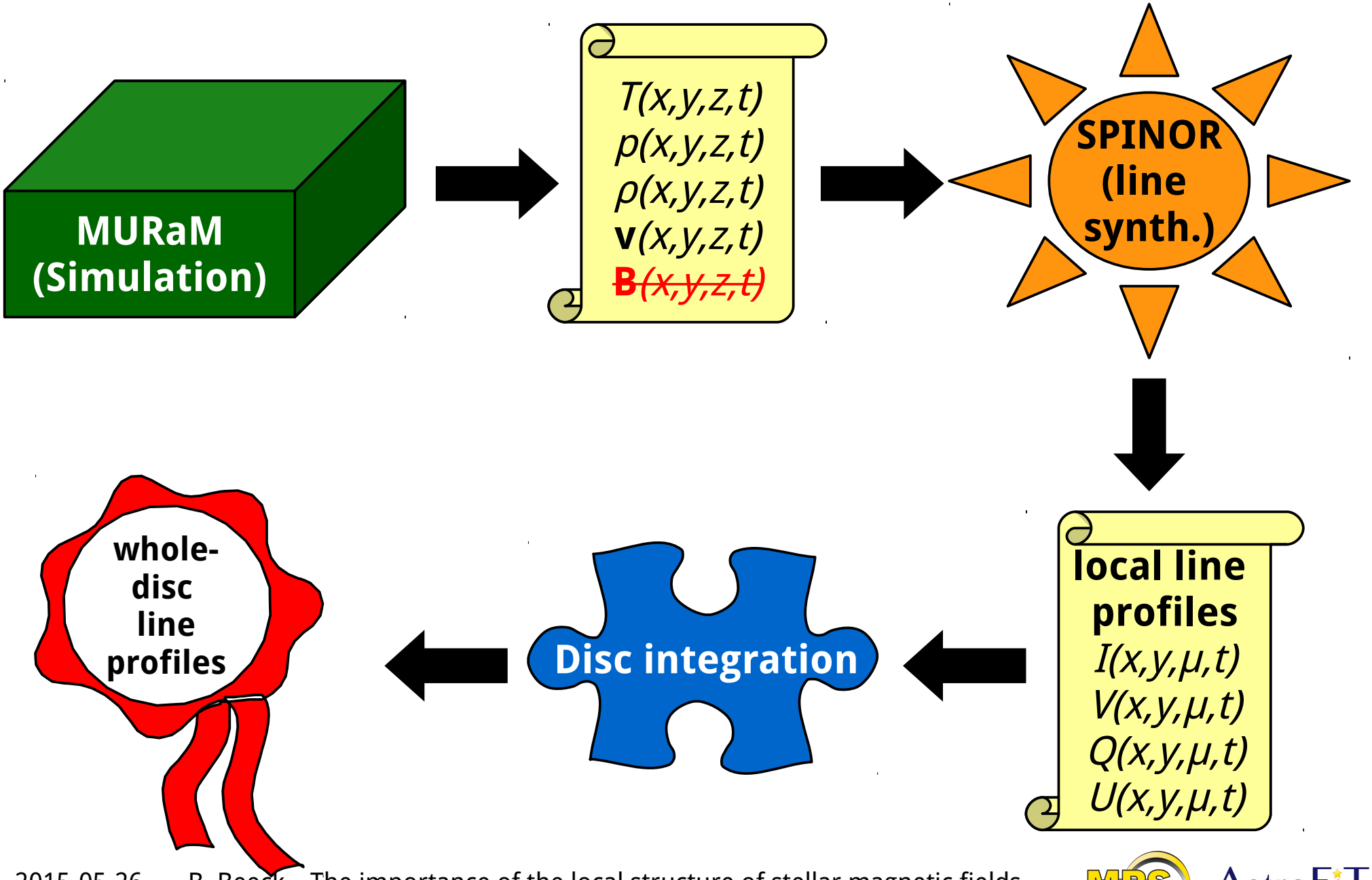
Effect on disc-integrated spectral line profiles



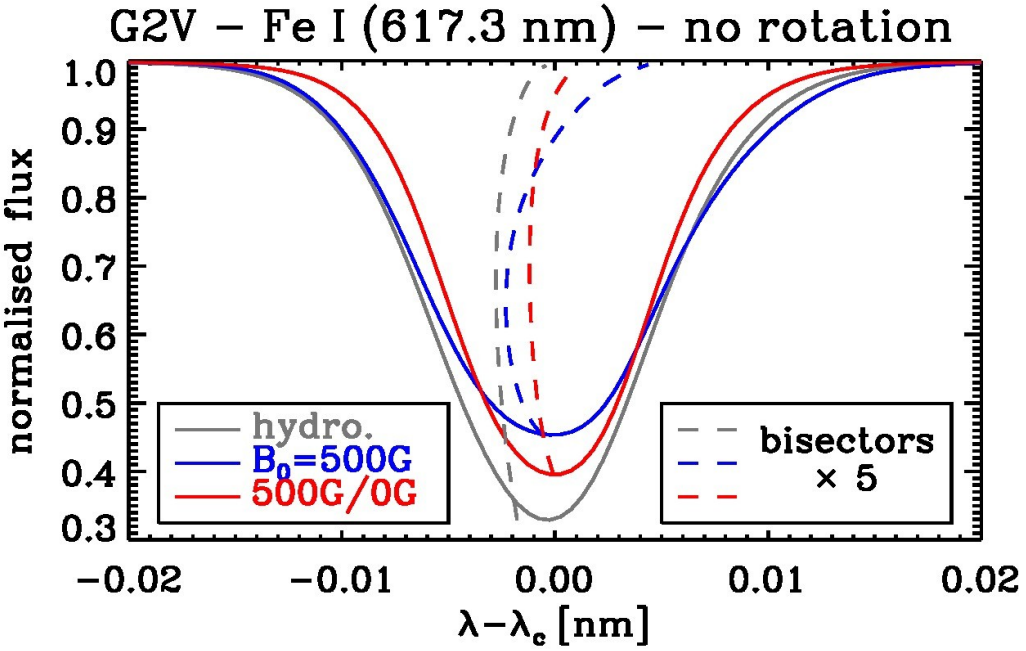
Spectral line synthesis

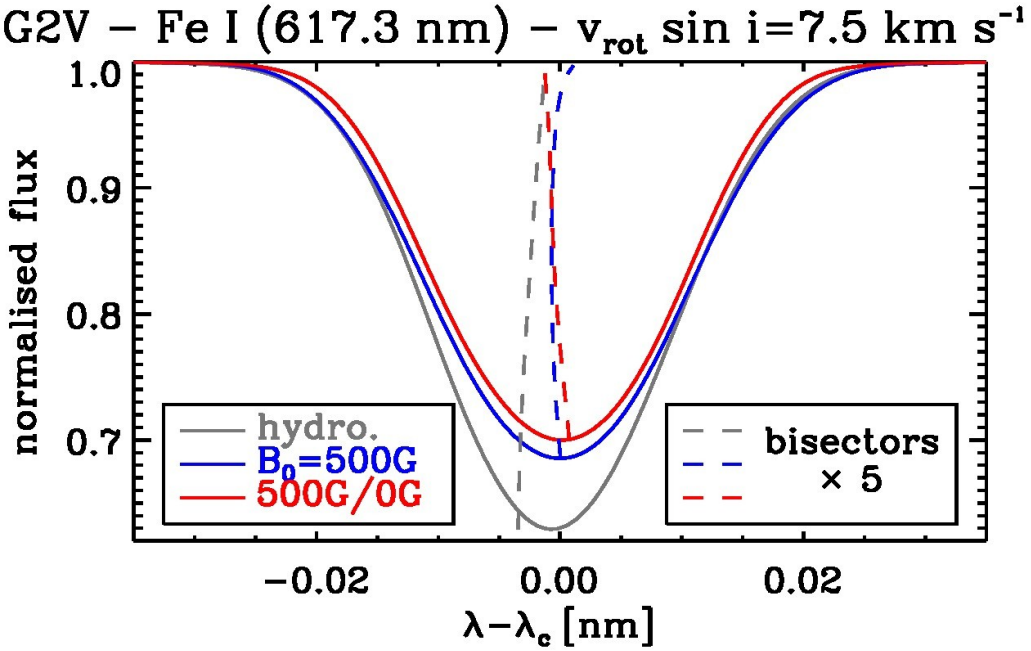


Spectral line synthesis



Zeeman effect vs. thermodynamics





Beeck et al. (2015b)

Conclusion

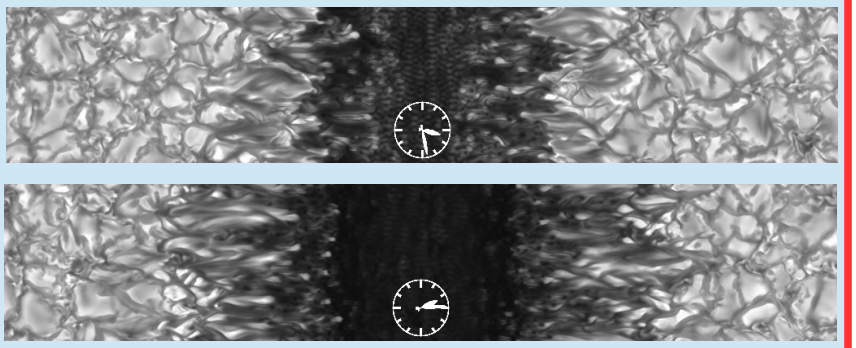
The local structure of stellar magnetic fields and its impact on the atmosphere **is of crucial importance** for correctly interpreting stellar spectra

- **Small-scale magnetic field concentrations** have different properties in different stars. E.g., **in M stars**, they **are dark** (owing to their small depth compared to their width)
- Some **spectral lines** (used for magnetic field diagnostics) **are** substantially **weakened** in magnetic bright points / faculae
- The **correlation between the velocity and magnetic fields** can induce line asymmetries which are enhanced by the Zeeman effect.
- ...

Outlook

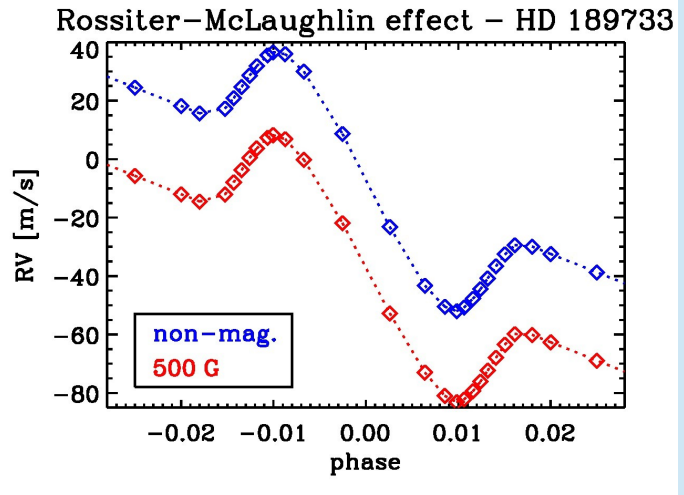
Sunspots/starspots

- obtain properties of starspots: B, T, I(μ), …



work in progress

Exoplanet transits



More simulations

- different mag. field geometries
- improved opacities

near future

Further comparison to observations

- spectroscopy
- spectropolarimetry (ZDI)

⇒ *better understanding of stellar magnetohydrodynamic dynamos*

References

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