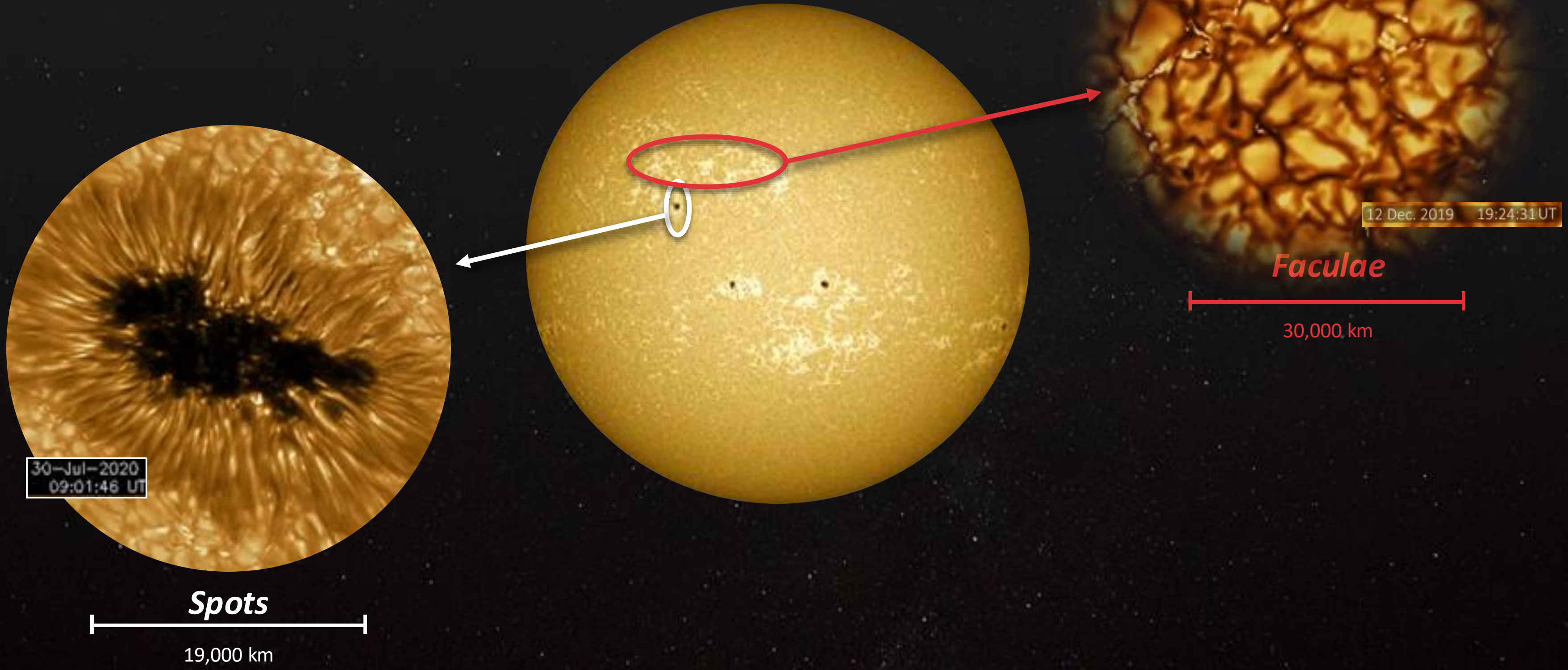
The Curious Case of Dark Faculae on M Dwarf Stars

Sara Seager (MIT), Sasha Shapiro (U. Graz) and the REVEAL Team



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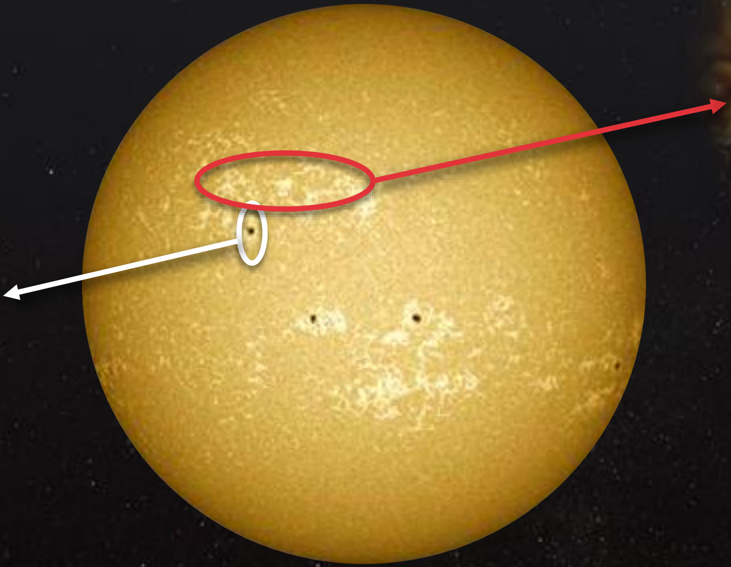

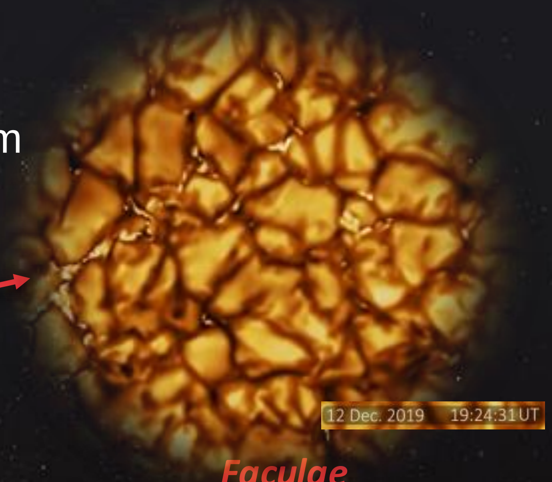

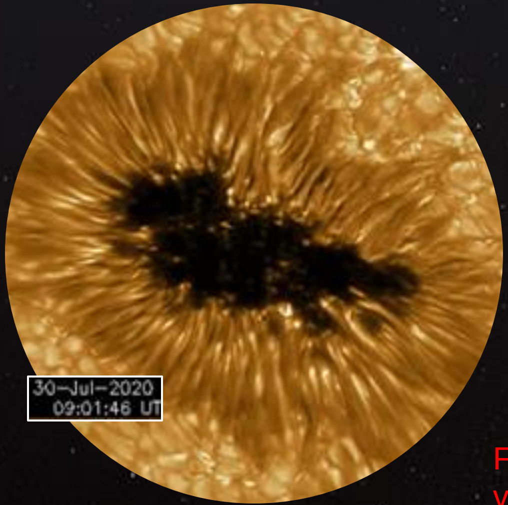

Faculae

30,000 km

Spots

19,000 km

Faculae are small-scale concentrations of roughly vertical magnetic fields, located between convective granules. These patches are often referred to as flux tubes (Solanki 1993).

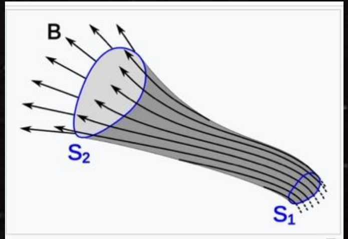

Diagram of a flux tube showing the magnetic field lines B in the tube walls. The same amount of magnetic flux enters the tube through surface S_1 as leaves the tube through surface S_2

Credit: GREGOR and DKIST

REVEAL

Prof. Dr. Andrew Collier Cameron

Discovering Earth "twins" with extreme precision RV ground-based spectroscopy and new methodology for its analysis.

University of St Andrews

Prof. Dr. Sara Seager

Characterizing Earth "cousins" atmospheres with JWST via transmission spectroscopy and new atmospheric retrieval methodology.

Massachusetts Institute of Technology

Dr. Alexander (Sasha) Shapiro

Modelling stellar signals in RV and transmission spectrosocopy with frontier computer simulations.

UNI GRAZ

Dr. Jeff Valenti

Observational tests

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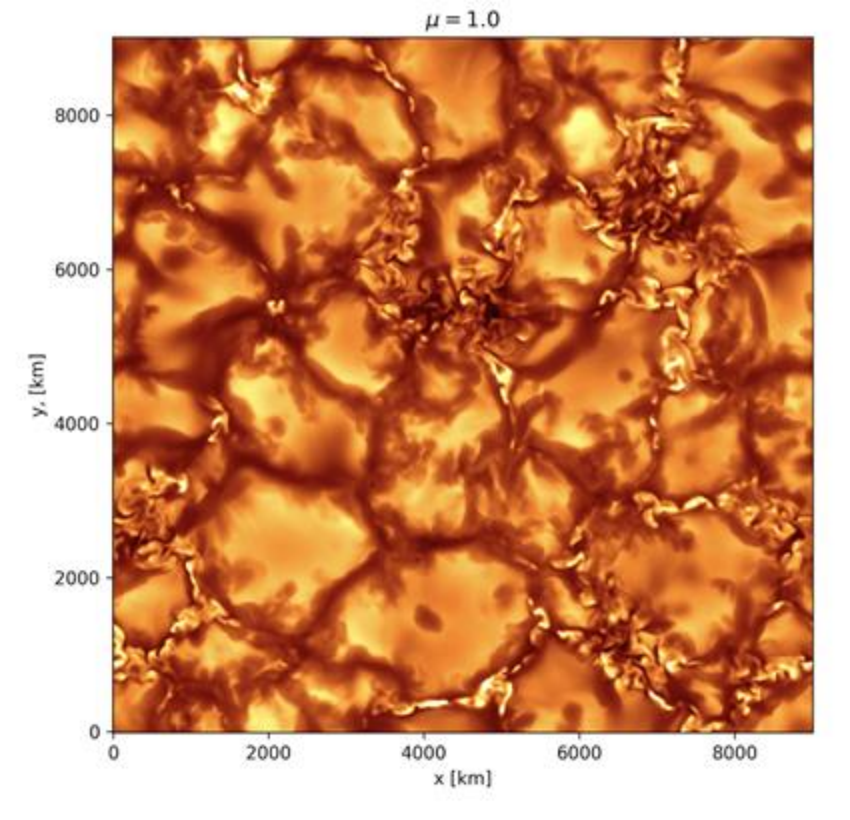
REVEALING SIGNATURES OF HABITABLE WORLDS HIDDEN BY STELLAR ACTIVITY

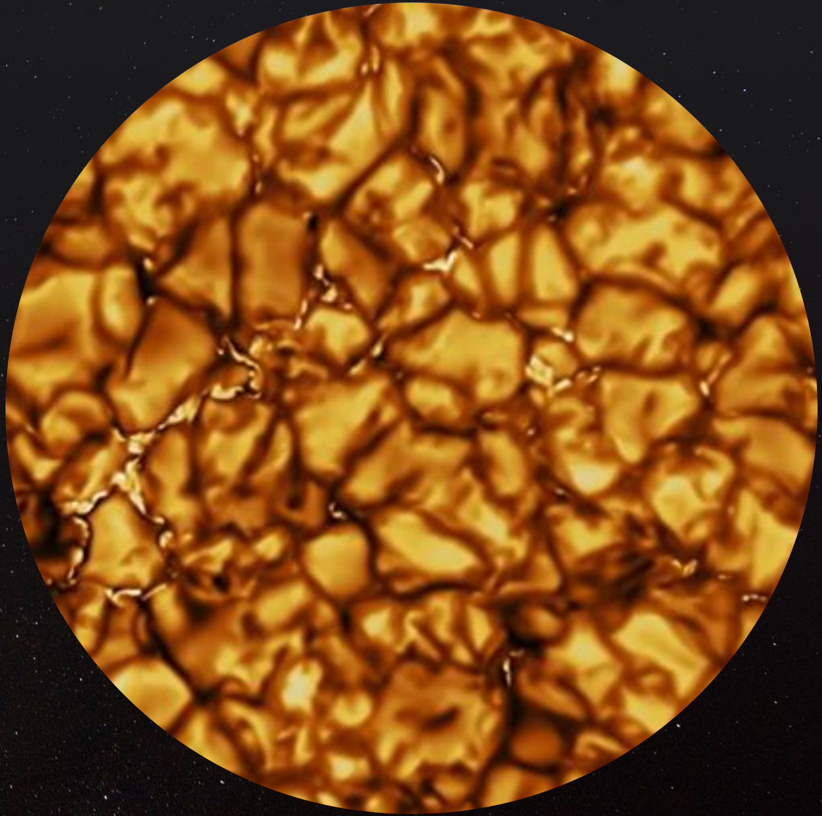
The Sun

3D MHD Simulations

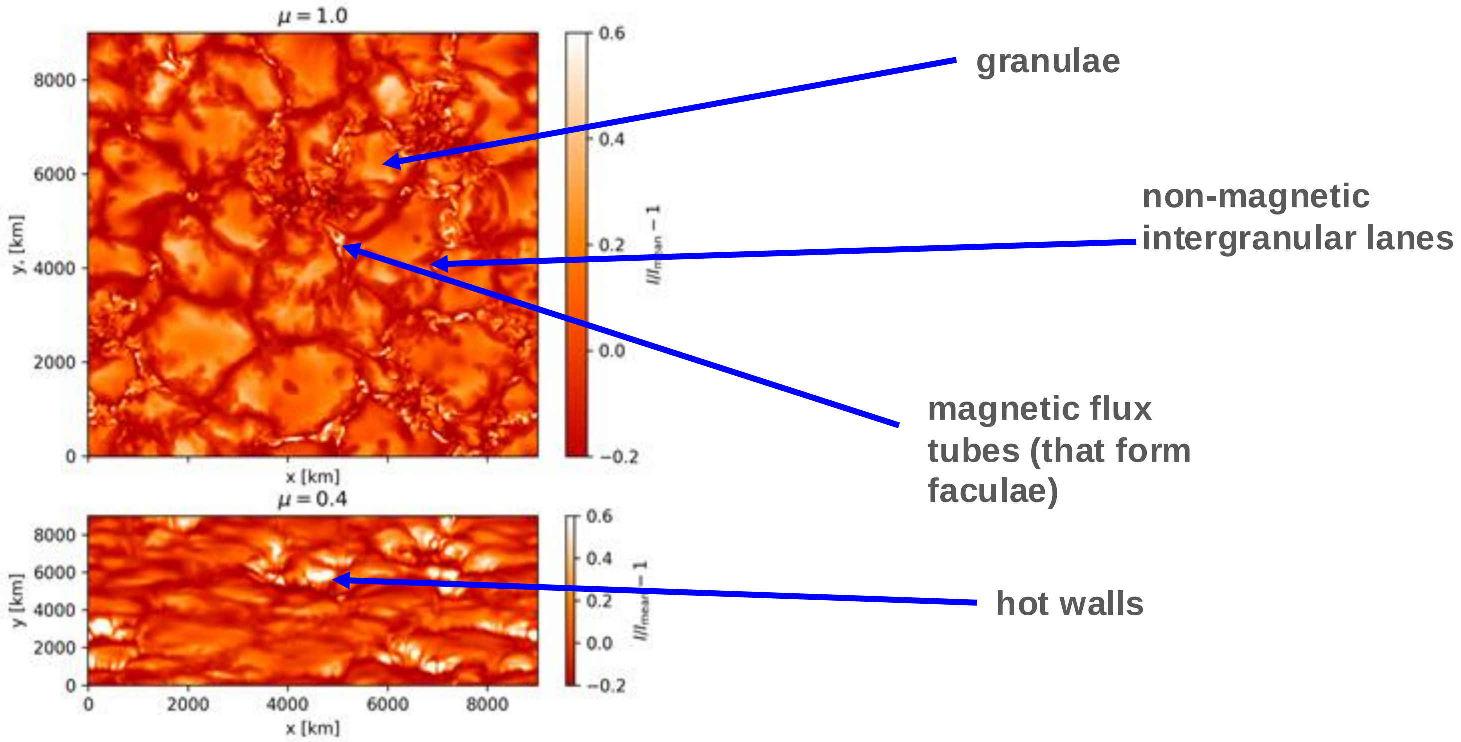


3D MHD Simulations from REVEAL: MURaM + MPS Atlas

Observations

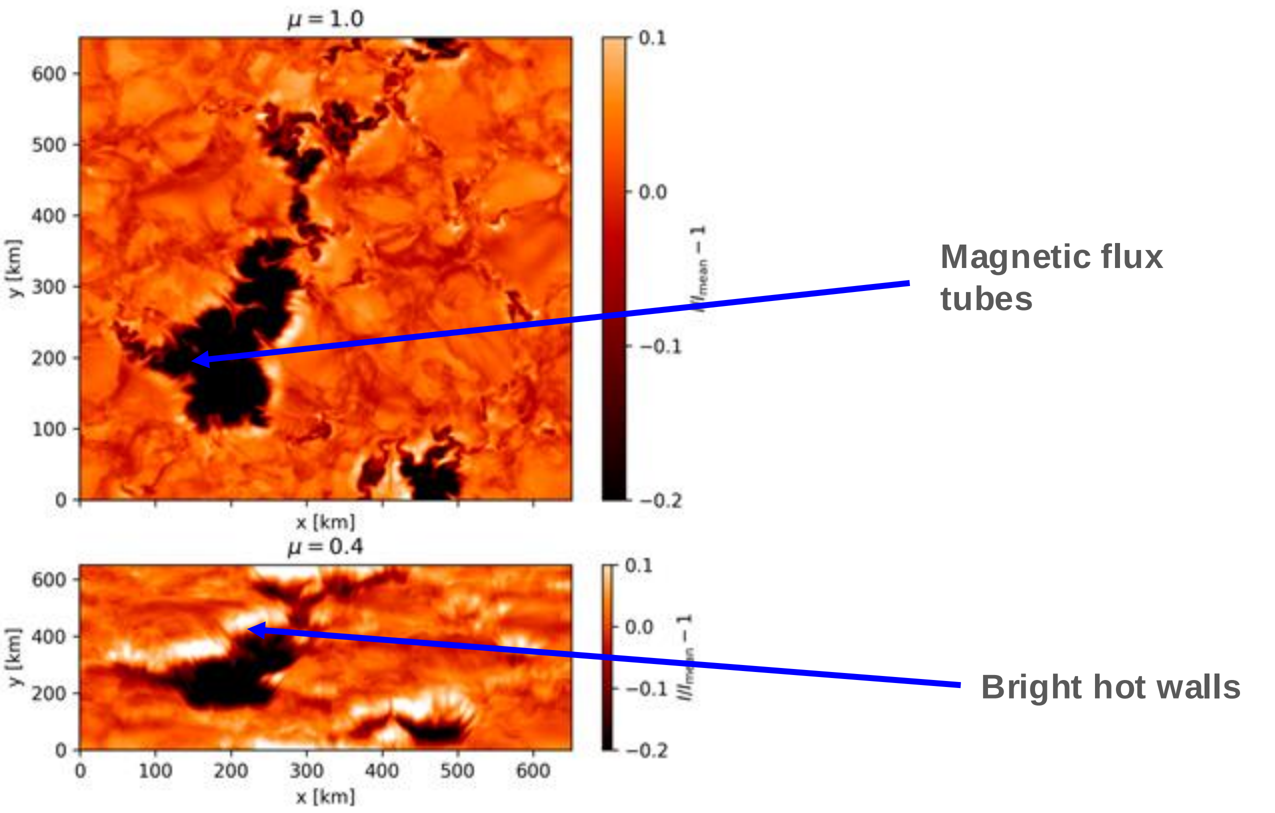


G2 Dwarf Simulated Image Computed at 0.6 micron.

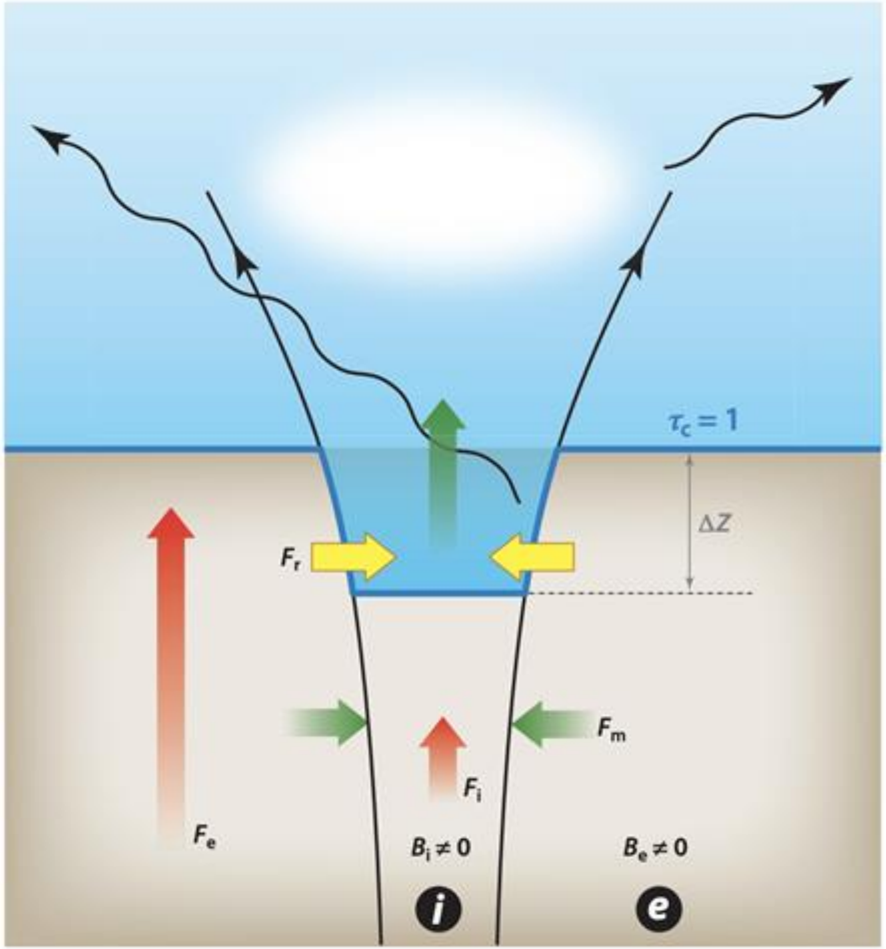


3D MHD Simulations from REVEAL: MURaM + MPS Atlas
Credit: Veronika Witzke and Nadiia Kostogryz

M4 Dwarf Simulated Image Computed at 0.6 micron.



3D MHD Simulations from REVEAL: MURaM + MPS Atlas
Credit: Nadiia Kostogryz, Veronika Witzke, and Tanayveer Bhatia



Red arrows: vertical convective and radiative energy. Yellow: radiation influx. Green: mechanical energy flux. Credit: Solanki et al. 2013

Schematic of a Narrow Flux Tube

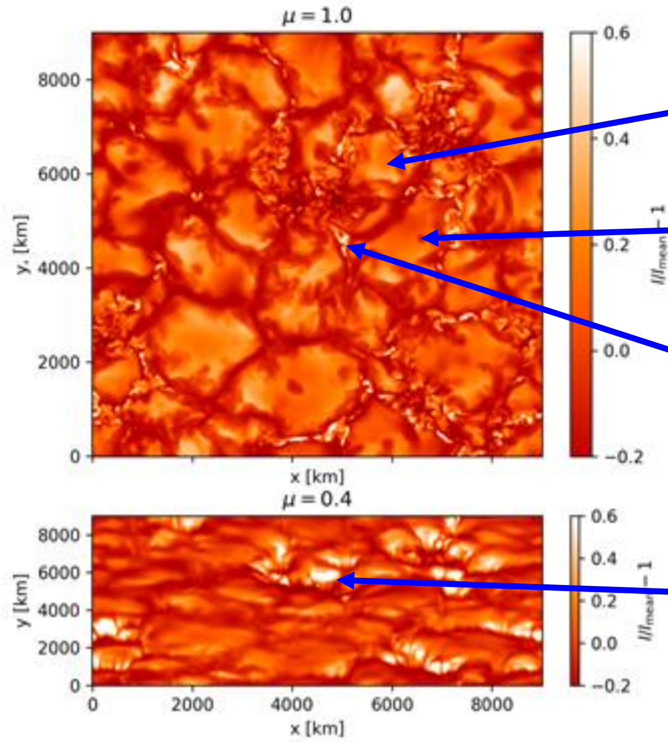
The optical surface is depressed because of magnetic pressure. Total pressure of each layer is equal, so gas becomes evacuated.

The "optical surface", optical depth= 1, is illustrated by the blue line.

The tenuous gas is heated from the hot walls and the hot walls are themselves bright.

Note: without the hot walls and heating, the flux tube interior would appear dark.

G2 Dwarf Simulated Image Computed at 0.6 micron.

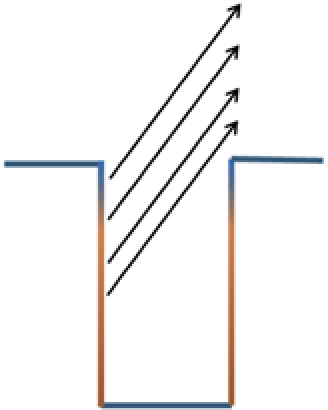


granulae

non-magnetic intergranular lanes

magnetic flux tubes (that form faculae)

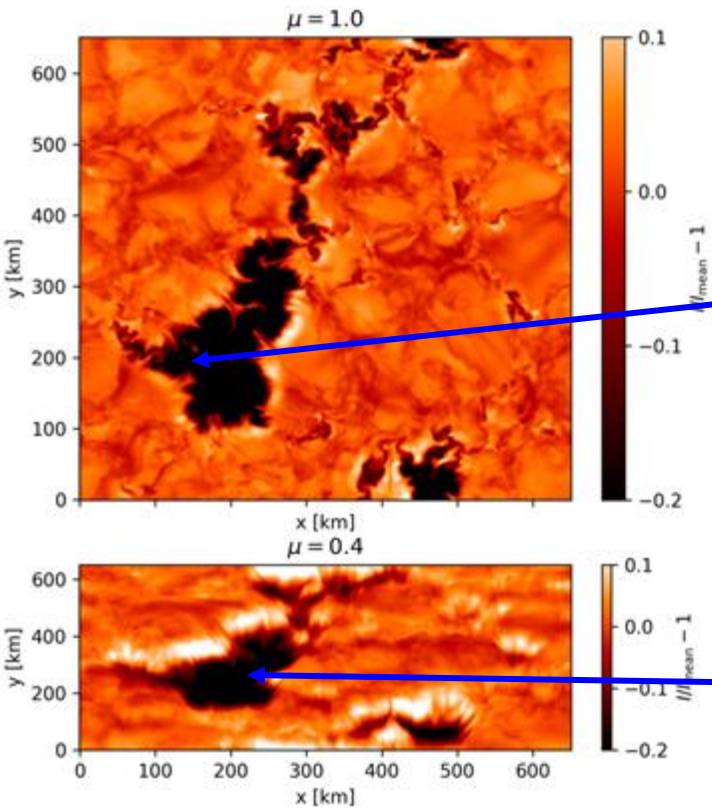
hot walls



3D MHD Simulations from REVEAL:
MURaM + MPS Atlas
Credit: V. Witzke, N. Kostogryz

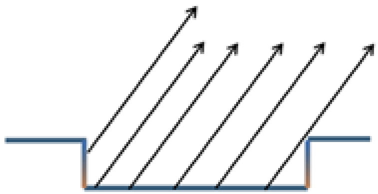
G2 Dwarf: Narrow flux tube interior is heated by the hot walls. Additionally, because the tubes are narrow, most viewing geometry is dominated by the hot walls.

M4 Dwarf Simulated Image Computed at 0.6 micron.



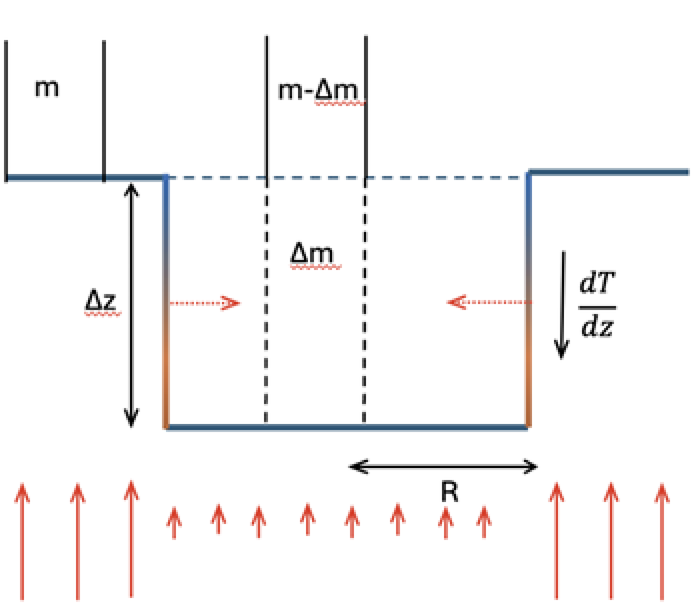
Magnetic flux tubes

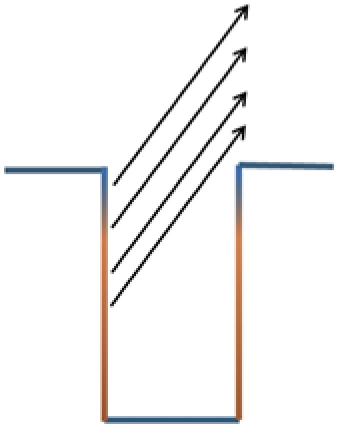
Bright hot walls

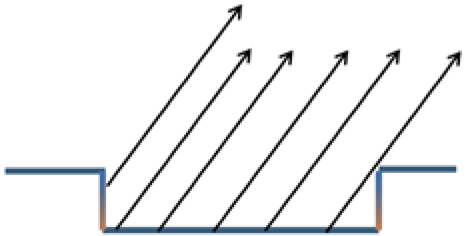


3D MHD Simulations from REVEAL:
MURaM + MPS Atlas
Credit: N. Kostogryz, V. Witzke, T. Bhatia

M4 Dwarf: Wide shallow flux tubes instead of deep narrow tubes. The interior cannot be heated by the hot walls (too much volume per surface area). Because the tubes are wide and shallow, most viewing geometries are not dominated by the walls.







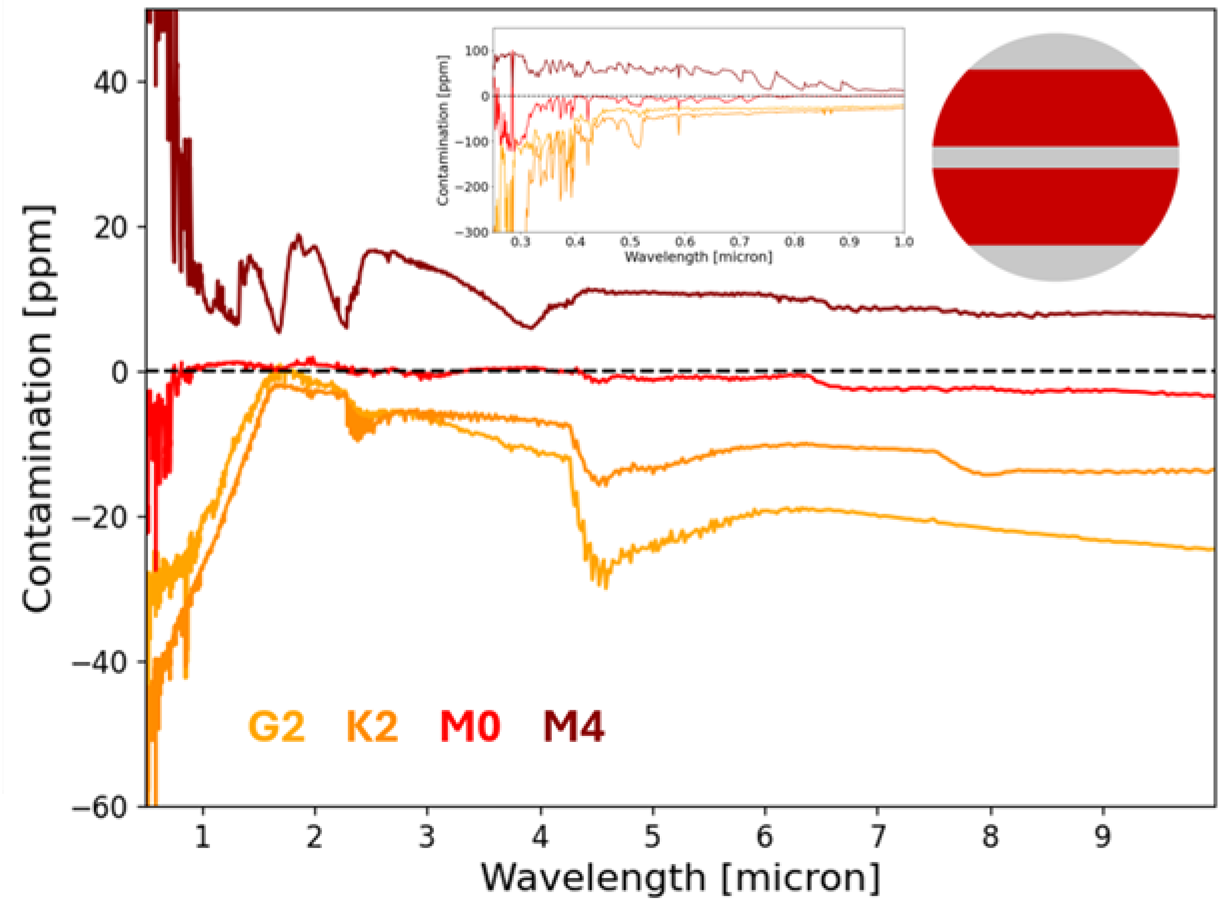
How large are hot walls

How bright are hot walls

$$\mathcal{HW} \equiv \left(\frac{\Delta z}{R}\right) \cdot \left(\frac{dT}{dz}\frac{\Delta z}{T_{\rm eff}}\right)$$

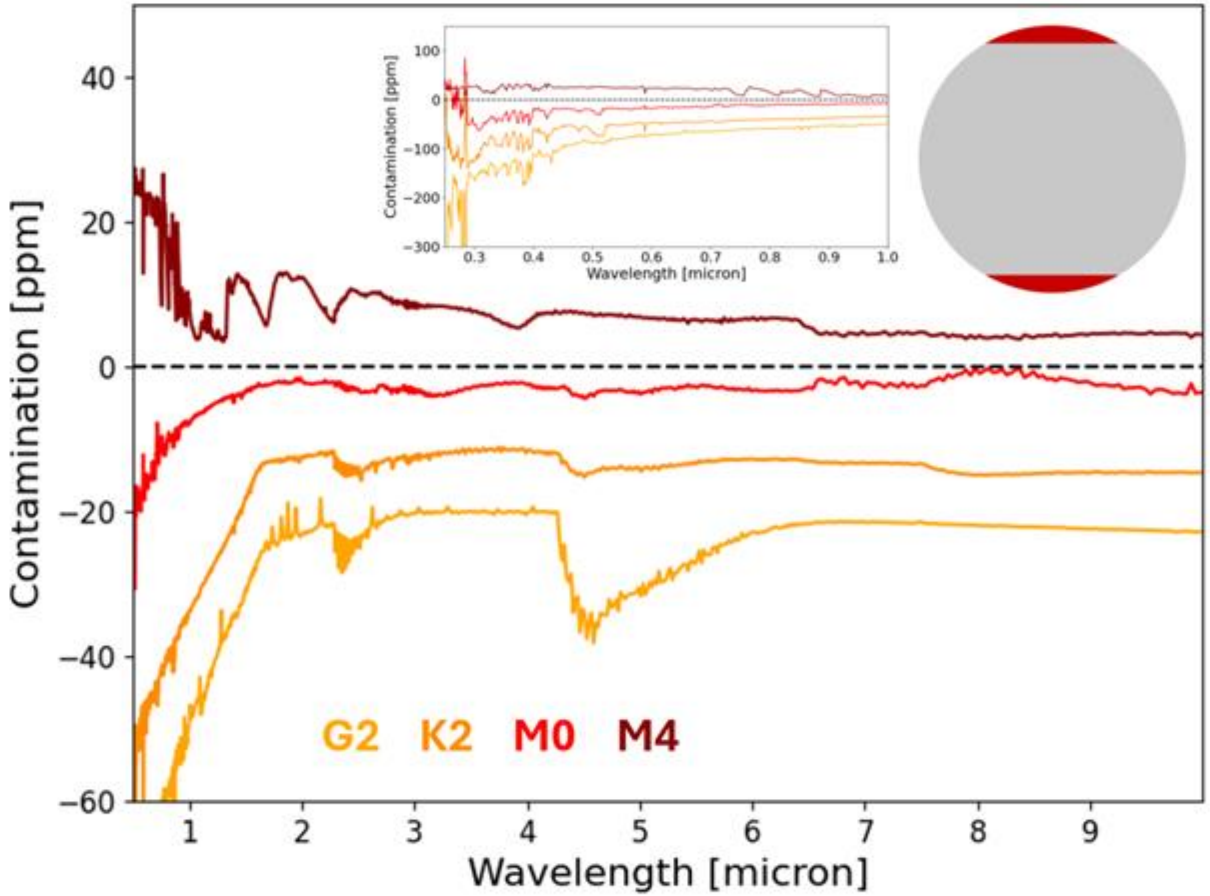
Simulations provide complex details, but the phenomena can also be approximated by simple math. See Shapiro, Seager, Solanki et al., in prep

Lower metallicity … confusing but makes G star faculae dark and not bright



Faculae are darker than the quiet star region on M4 stars.

10,000 ppm transit. 20% facular coverage. Equatorial belt distribution.



M Dwarf (dark faculae) only weakly depend on surface distribution, from comparison to the previous slide.

10,000 ppm transit. 20% facular coverage. Polar distribution.

Summary

MHD simulations show that faculae are dark and not bright on M dwarf stars, in contrast to G2 stars.

G2 dwarf flux tubes are narrow and deep. The hot flux tube walls not only heat the interior but also are seen directly from many viewing geometries.

M Dwarf stars have wide, shallow flux tubes. The flux tube wall area is small compared to the tube volume and thus ineffective at heating the interior. Also, the shallowness means the flux tube walls are not seen by most viewing geometries.

For details and equations see Shapiro, Seager et al. in prep.