Stellar Convection and Oscillations and their Relationship

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Intensity contrast and distribution on the solar surface: old wisdom with a surprising twist.

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1. Intensity rms contrast as a function of spatial resolution

We define here the *rms continuum intensity contrast* at a given wavelength λ as

$$c_{\mathrm{rms}} = \sqrt{\left\langle \left(\frac{I_{c,\lambda} - \langle I_{c,\lambda} \rangle}{\langle I_{c,\lambda} \rangle} \right)^2 \right\rangle}$$

rms granular contrasts from *spaceborne instruments* (quiet Sun, disk center)

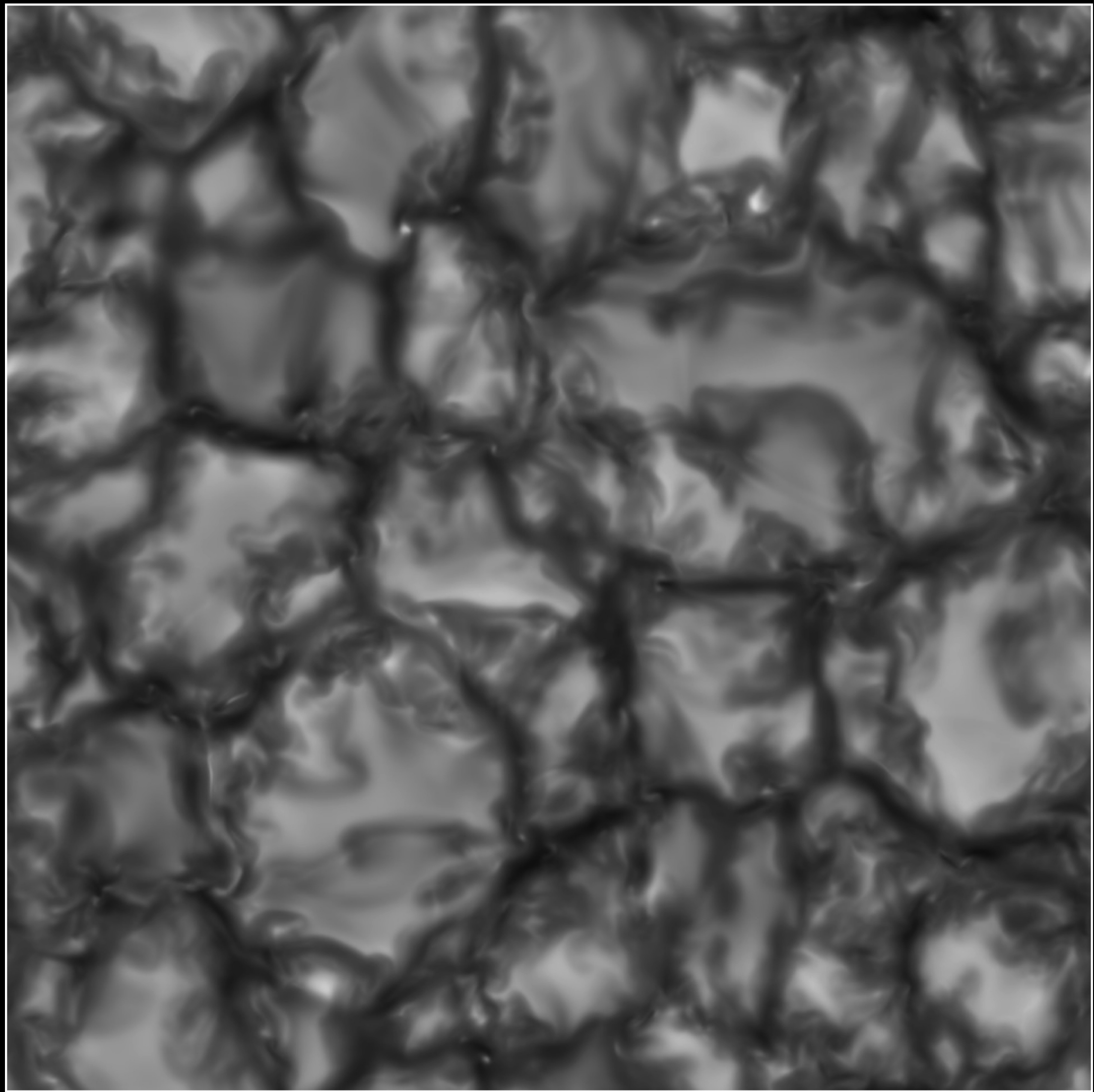
satellite	instrument	aperture	wavelength	c_{rms}	deconvolved	reference
SDO	HMI	14 cm	617.3 nm	4.0 %	12.2 %	Yeo et al. (2014)
Hinode	SOT/BFI	50 cm	555.0 nm	8.0 %		Afram et al. (2011)
Hinode	SOT/SP	50 cm	630.0 nm	7.0 %	14.4 %	Danilovic et al. (2008)

Old wisdom: With *increasing spatial resolution* (telescope aperture), the *granular contrast increases*.

1. Intensity rms contrast as a function of spatial resolution (cont.)

What about the simulations?

Computations: *Centro Svizzero di Calcolo Scientifico*



bolometric intensity

Courtesy, *F. Calvo, IRSOL*

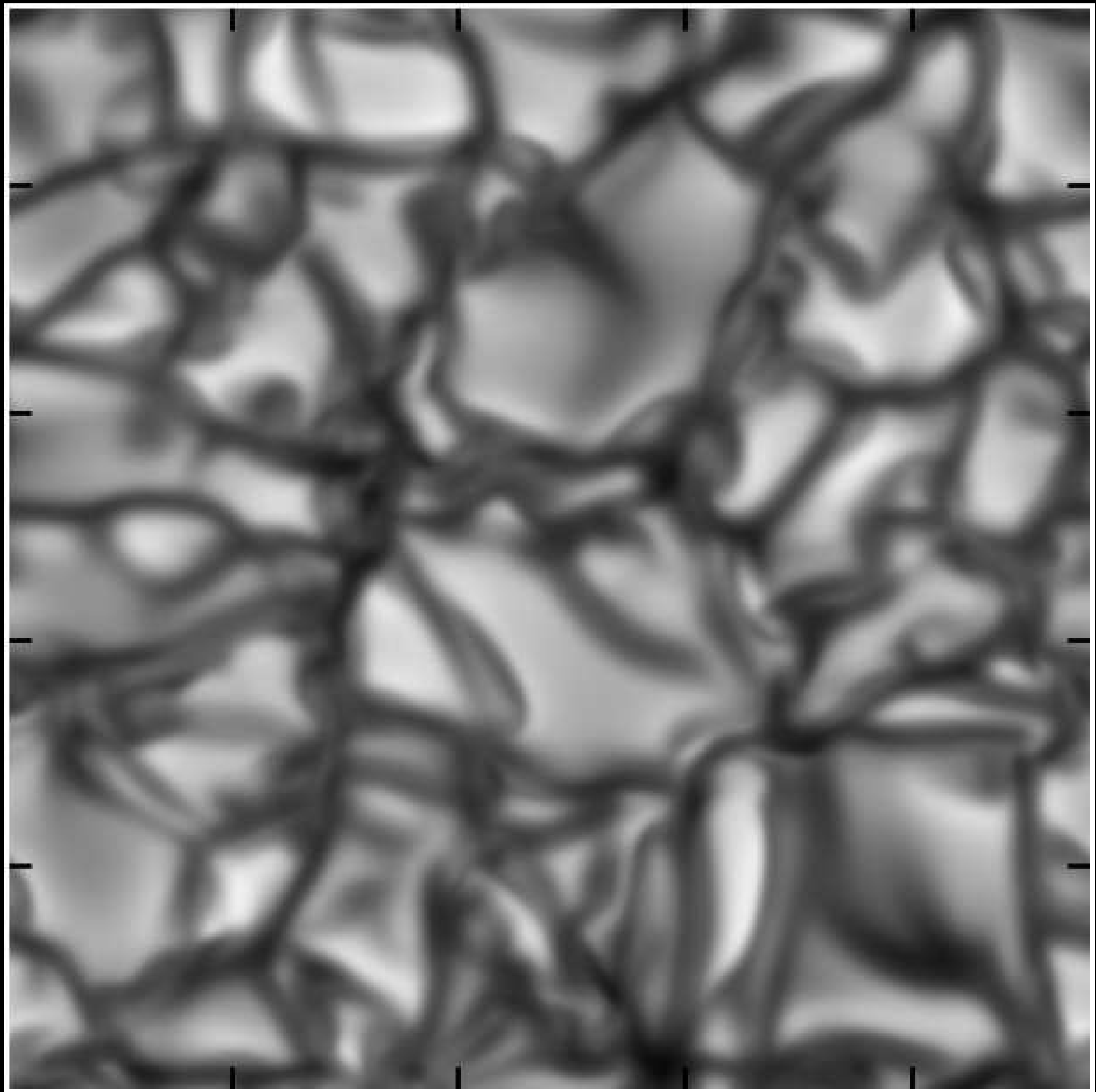
CO^{5}BOLD simulation with a *grid-cell size* of *10 km*.

No magnetic fields.

Field of view 9.6 x 9.6 Mm

λ [nm]	500	630	bolometric
rms	19.5 %	13.7 %	15.7 %

1. Intensity rms contrast as a function of spatial resolution (cont.)



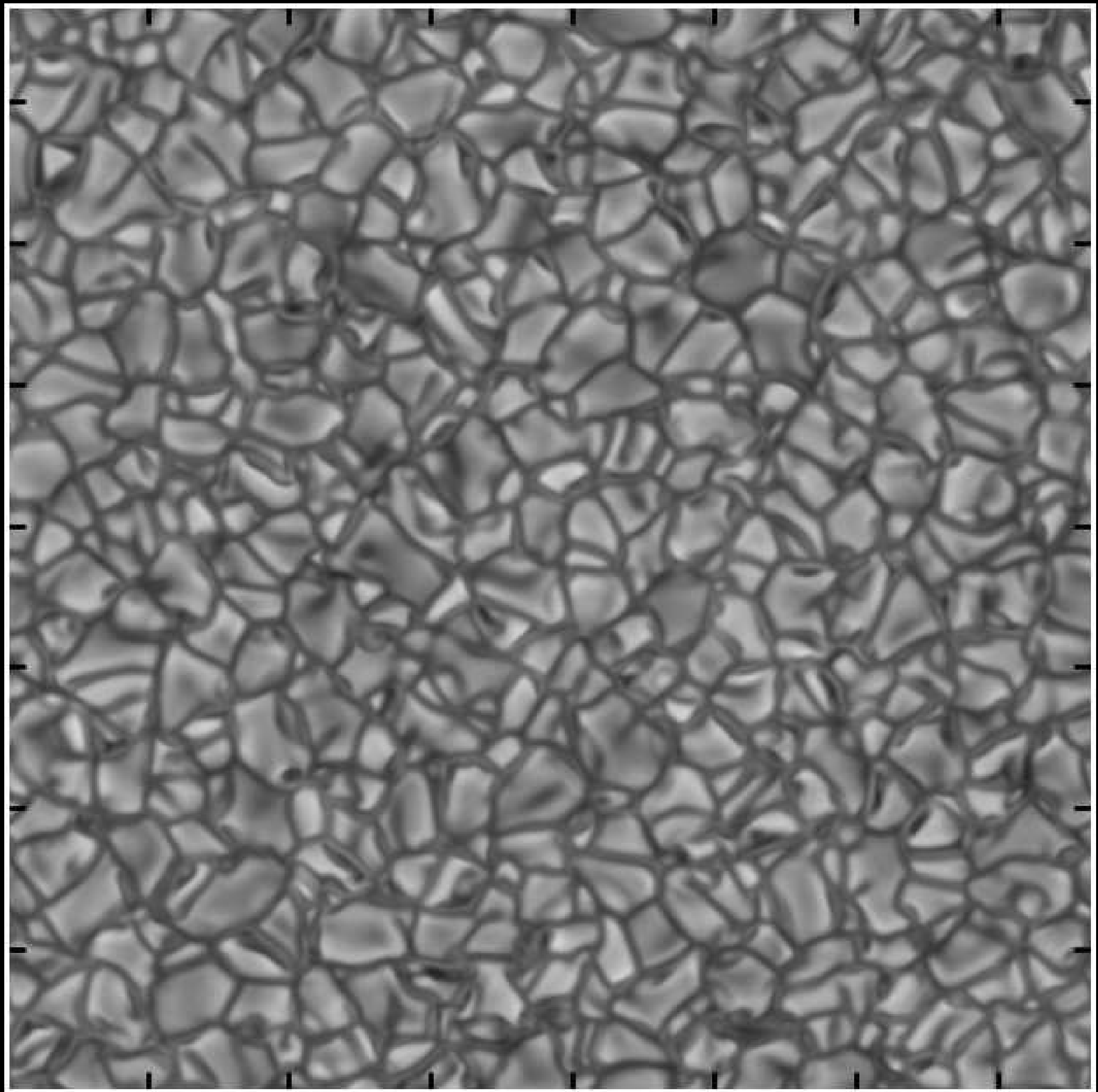
λ = 500 nm

CO[5]BOLD simulation with a *grid-cell size* of *40 km* (and more diffusive solver).

No magnetic fields.

Field of view 9.6 x 9.6 Mm

λ [nm]	500	630	bolometric
rms	19.1 %	13.6 %	15.9 %



bolometric intensity Courtesy, *G. Vigeesh, KIS*

CO^{5}BOLD simulation with a *grid-cell size* of *80 km*

No magnetic fields.

Field of view 38.4 x 38.4 Mm

λ [nm]	500	630	bolometric
rms	18.7 %	12.9 %	15.6 %

1. Intensity rms contrast as a function of spatial resolution (cont.)

rms granular contrast in % from simulations (quiet Sun, disk center)

		wavelength λ [nm]				
code	cell size [km]	500	600	630	bolometric	reference
CO^5BOLD/Roe	10	19.5		13.7	15.7	
CO^5BOLD/HLL	10	19.0		13.4	15.4	
CO^5BOLD/HLL	12	18.8		13.3	15.4	
CO^5BOLD/HLL	40	19.1		13.6	15.9	
CO^5BOLD/HLL	80	18.7		12.9	15.6	
MURaM	7.5			14.4		Danilovic et al. (2008)
CO^5BOLD	40	21.8			14.4	Beeck et al. (2012)
MURaM	17.6	21.8			15.4	Beeck et al. (2012)
Stagger	40	22.1			15.1	Beeck et al. (2012)
Nordlund	93.75	25-30	20-25			Nordlund (1984)

Surprising twist: The granular *rms contrast of simulations* stays fairly *constant as a function of spatial resolution*.

Corollary: A simulation of low spatial resolution is not equivalent to a low resolution observation.

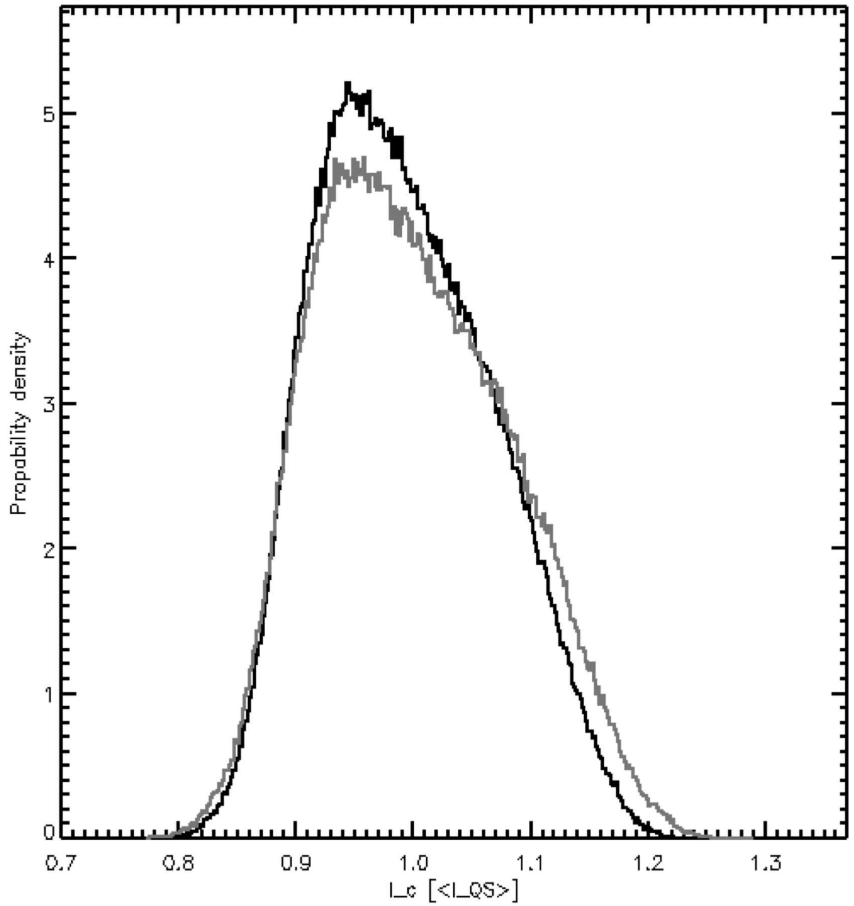
Physical reason: Limited convective velocities and given energy flux (T_{eff}) fixes the intensity contrast.

For the production of synthetic intensity maps one best starts from a simulation of highest possible spatial resolution and subsequently applies the modulation transfer function of the observational instruments.
See, e.g., *Danilovic et al.* (2008, A&A 484, L17),
Wedemeyer-Böhm & Rouppe van der Voort (2009, A&A 503, 225-239)

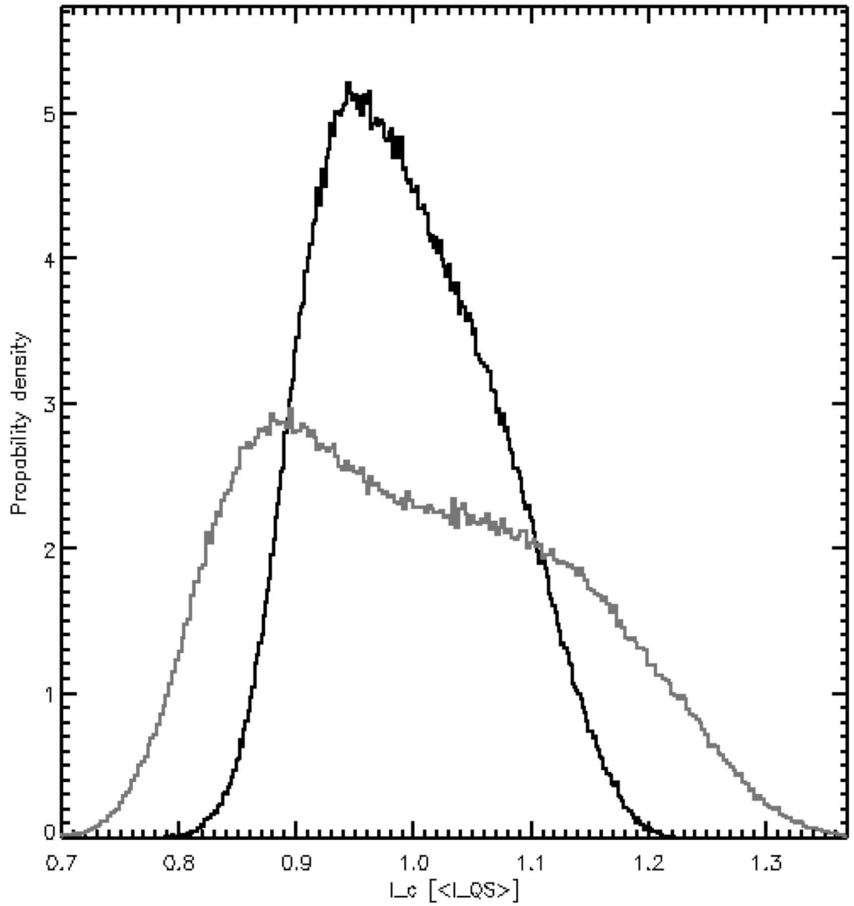
2. Intensity distribution as a function of spatial resolution

Disk-center radiative intensity distributions from observations.

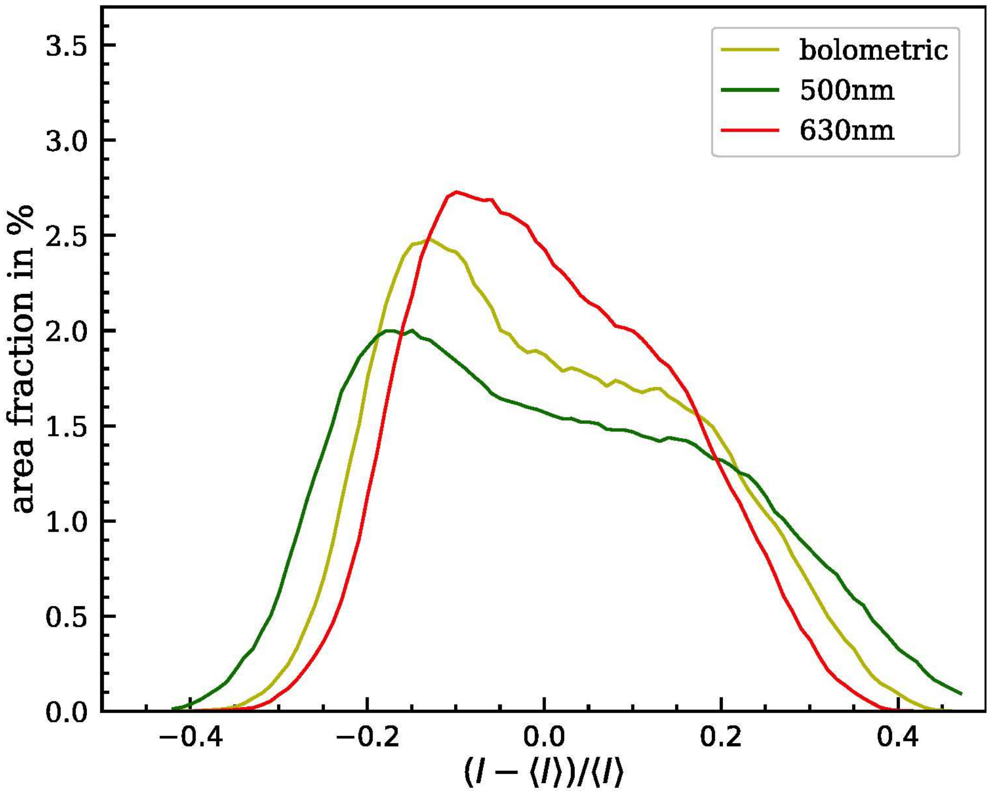
Hinode/SP (black) 630 nm vs.
Sunrise/IMaX (grey) 525 nm



Hinode/SP vs.
Sunrise/IMaX reconstructed



2. Intensity distribution as a function of spatial resolution (cont.)



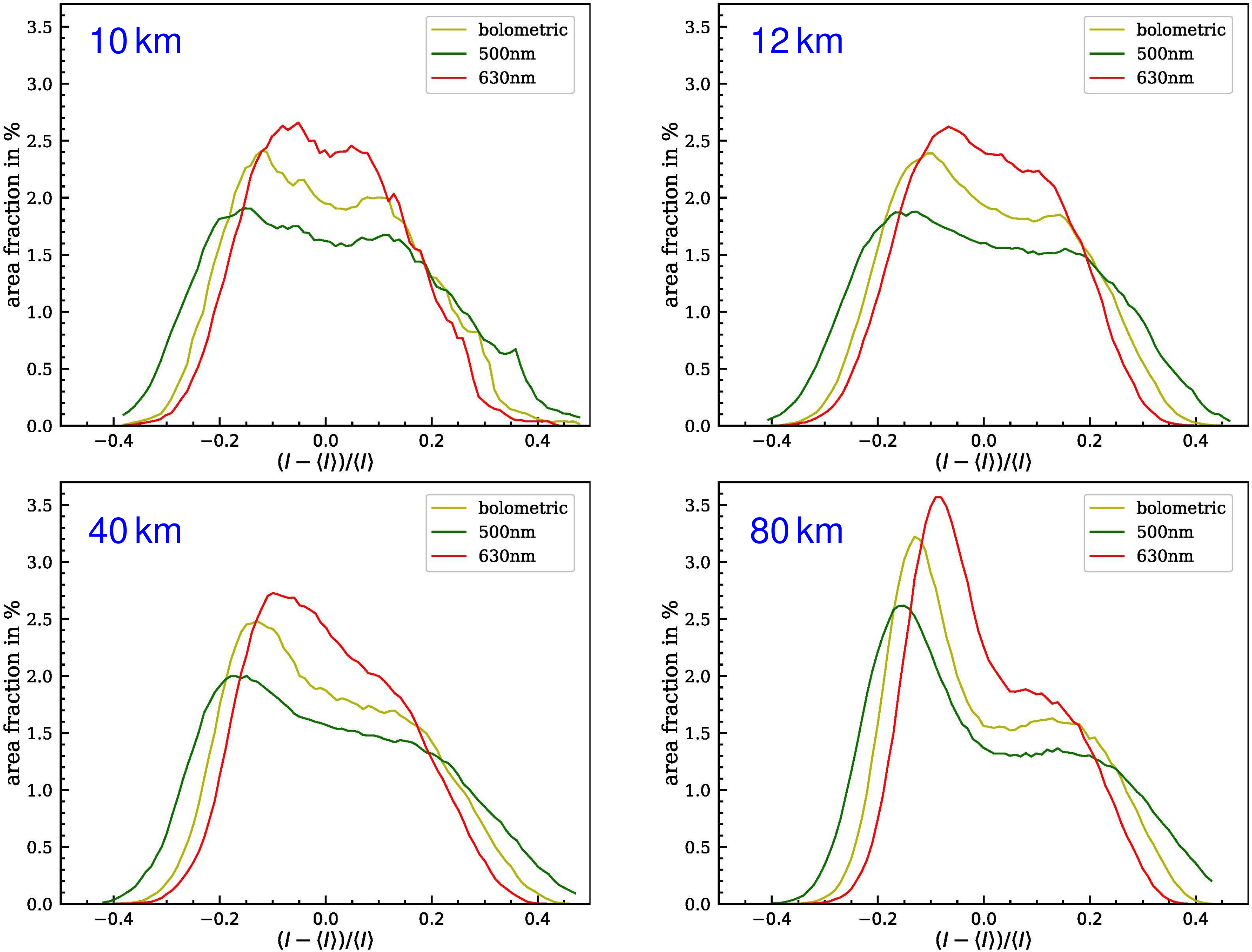
Distribution of the relative intensity of the vertically propagating radiation at λ = 500 nm, 630 nm, and bolometric of a CO^5BOLD simulation of *moderate spatial spatial resolution*. The grid-cell size is 40 km. The distribution is *bimodal*.

This bimodal distribution is also seen in simulations of stellar atmospheres others than the Sun. *Trampedach et al. (2013, ApJ 769, 18)* fit it with the double Gaussian

$$n(I) = I_1 \mathrm{e}^{((I-I_2)/I_3)^2} + I_4 \mathrm{e}^{((I-I_5)/I_6)^2}$$

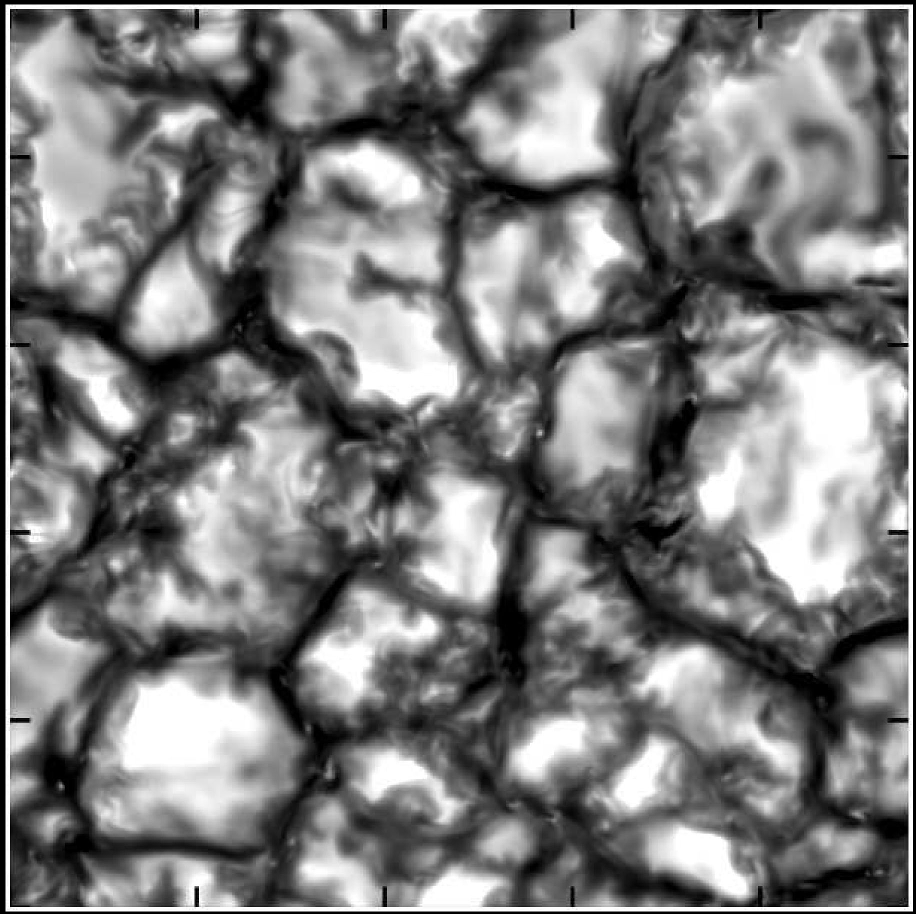
Tremblay et al. (2013, A&A 557) show distributions over a wide range of stellar types.

2. Intensity distribution as a function of spatial resolution (cont.)

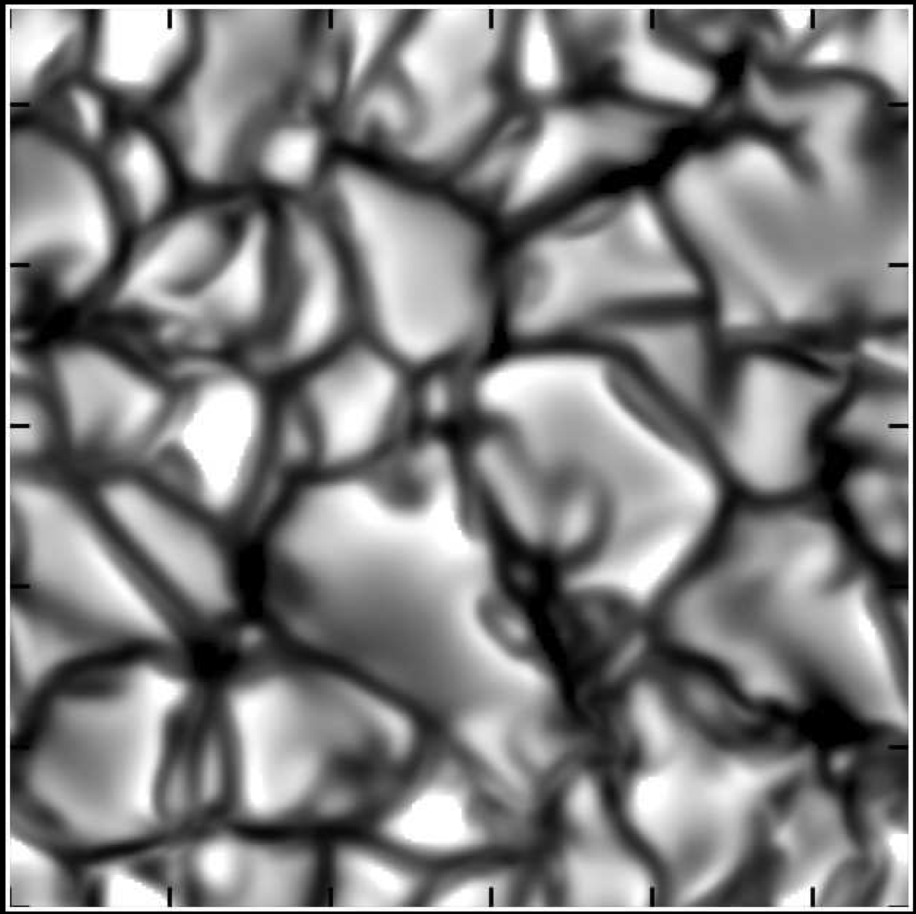


2. Intensity distribution as a function of spatial resolution (cont.)

λ = 500 nm



Cell size 10 km, high-res solver



Cell size 40 km, low-res solver

common gray scale: $0.65 \leq I/\langle I \rangle \leq 1.35$

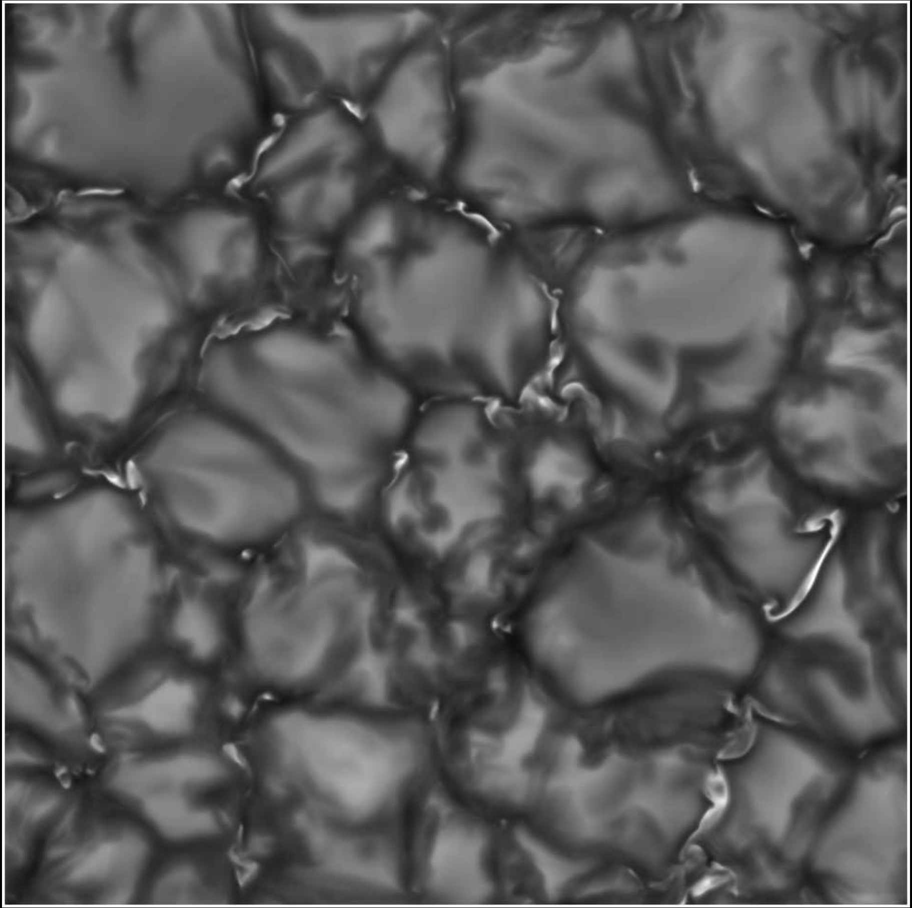
Surprising twist: The bimodality of the intensity distribution becomes less prominent with increasing spatial resolution.

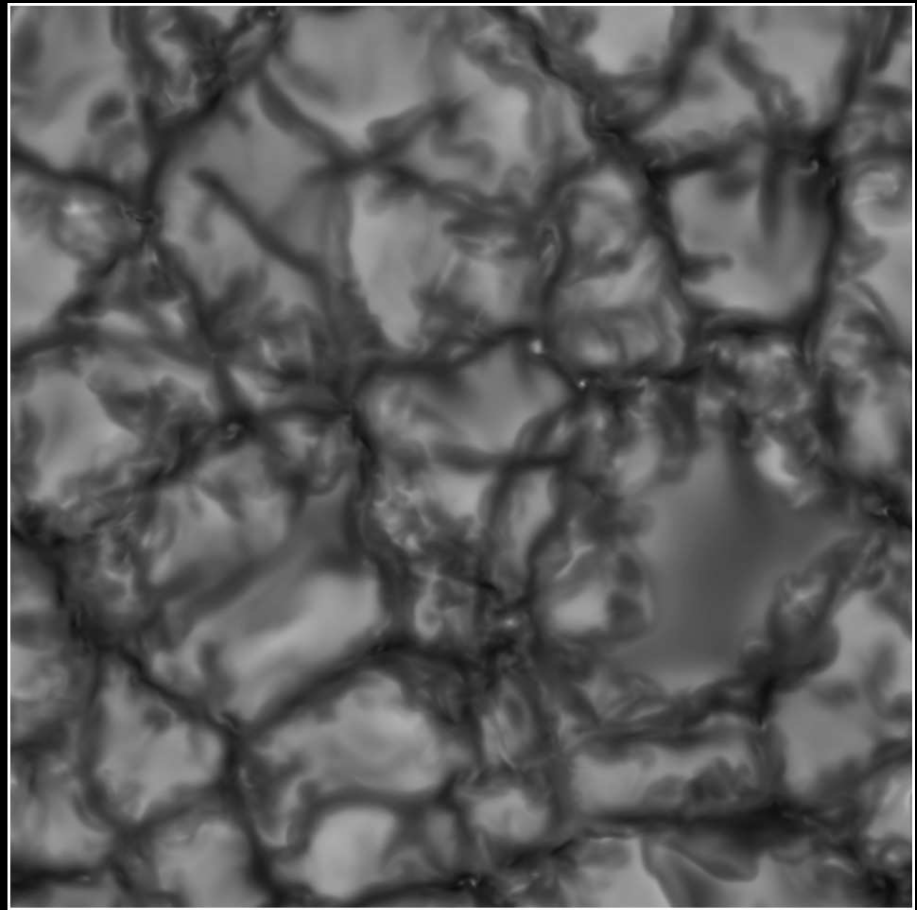
Different from the rms contrast, the intensity distribution *does* depend on the spatial resolution of the simulation.

3. Non-magnetic bright points

Bolometric intensity maps

Calvo, Steiner & Freytag (2016, A&A 596, A43)





Computations: *Centro Svizzero di Calcolo Scientifico*

With magnetic fields:
Magnetohydrodynamic simulation.

Without magnetic fields:
Hydrodynamic simulation

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