

30th NSO workshop, August 7–11, 2017  
Sacramento Peak National Solar Observatory  
High-resolution Solar Physics: Past, Present, Future

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

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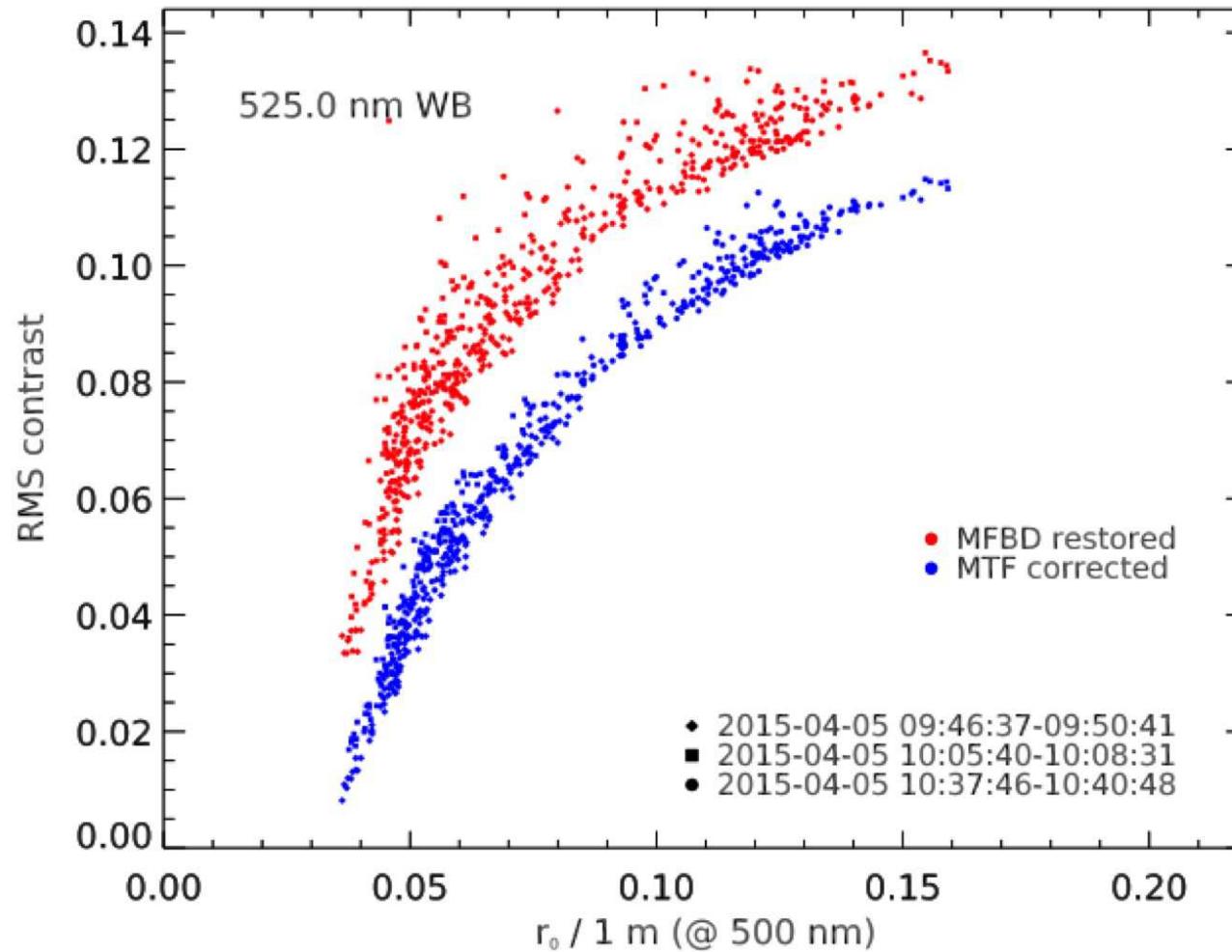
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# 1. Intensity rms contrast as a function of spatial resolution

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rms *granular contrast* in continuum intensity vs. Fried parameter,  $r_0$ , of the SST. The *rms contrast increases with increasing  $r_0$*  (better seeing).  
From a slide of *Göran Scharmer* (Hinode 9 meeting, 2015, Belfast).

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

We define here the *rms continuum intensity contrast* at a given wavelength  $\lambda$  as

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

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

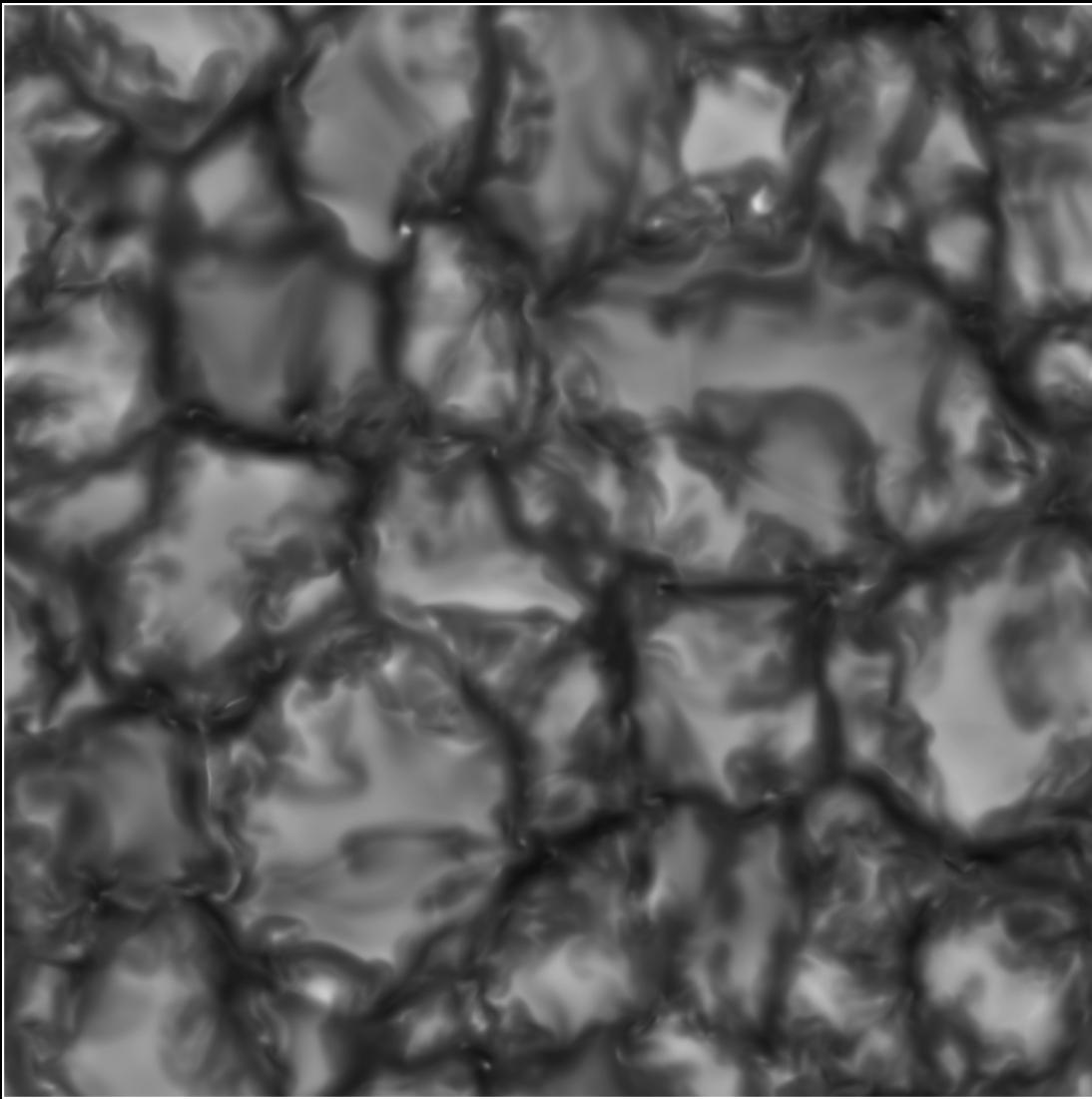
satellite	instrument	aperture	wavelength	$c_{\text{rms}}$	deconvolved	reference
SDO	HMI	14 cm	617.3 nm	4.0 %	12.2 %	Yeo et al. (2014)
Hinode	SOT/BFI	50 cm	555.0 nm	8.0 %		Afram et al. (2011)
Hinode	SOT/SP	50 cm	630.0 nm	7.0 %	14.4 %	Danilovic et al. (2008)

**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*

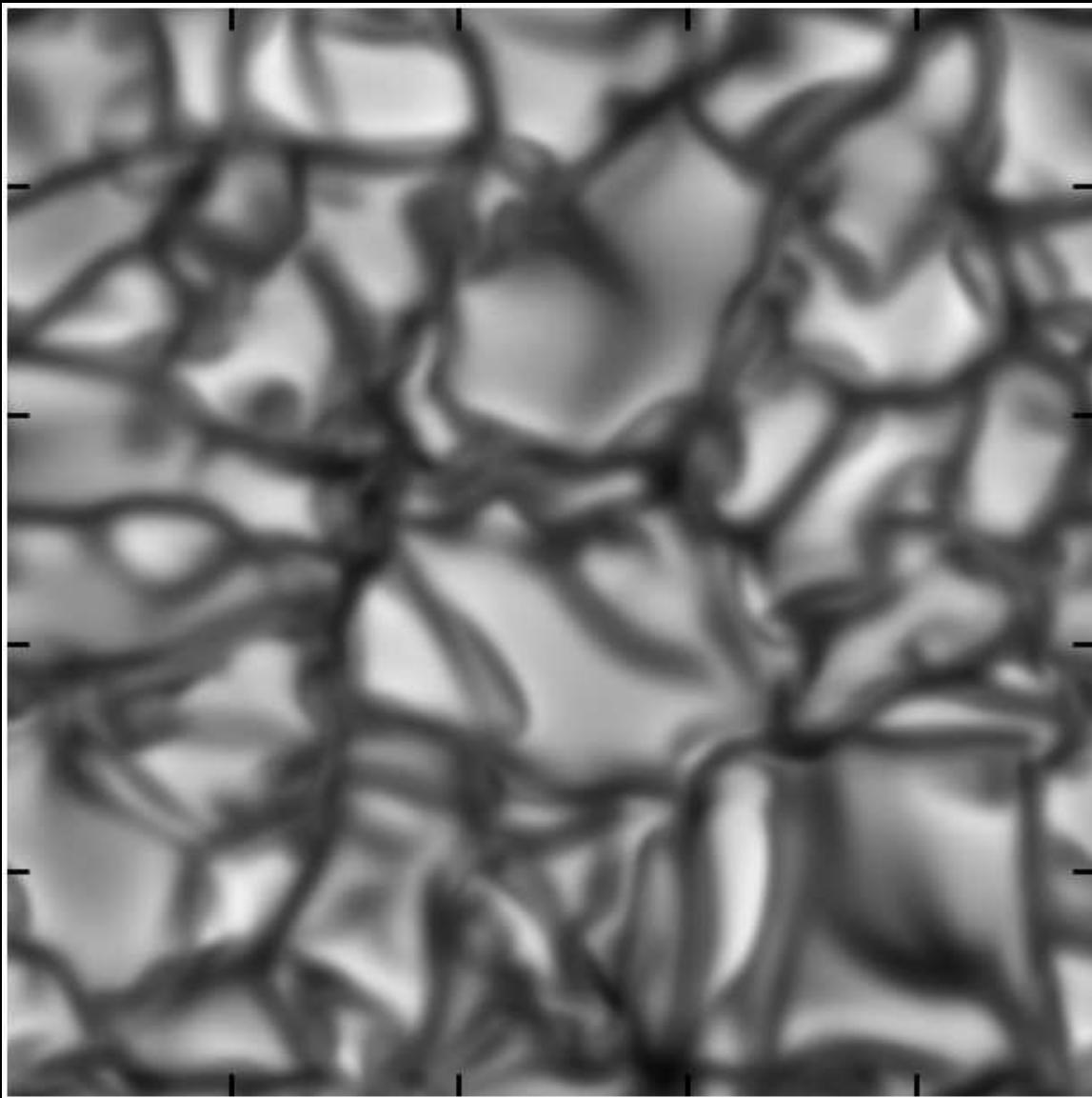
CO<sup>5</sup>BOLD simulation with a  
*grid-cell size* of *10 km*.

No magnetic fields.

Field of view 9.6 x 9.6 Mm

$\lambda$ [nm]	500	630	bolometric
rms	19.5 %	13.7 %	15.7 %

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



$\lambda = 500 \text{ nm}$

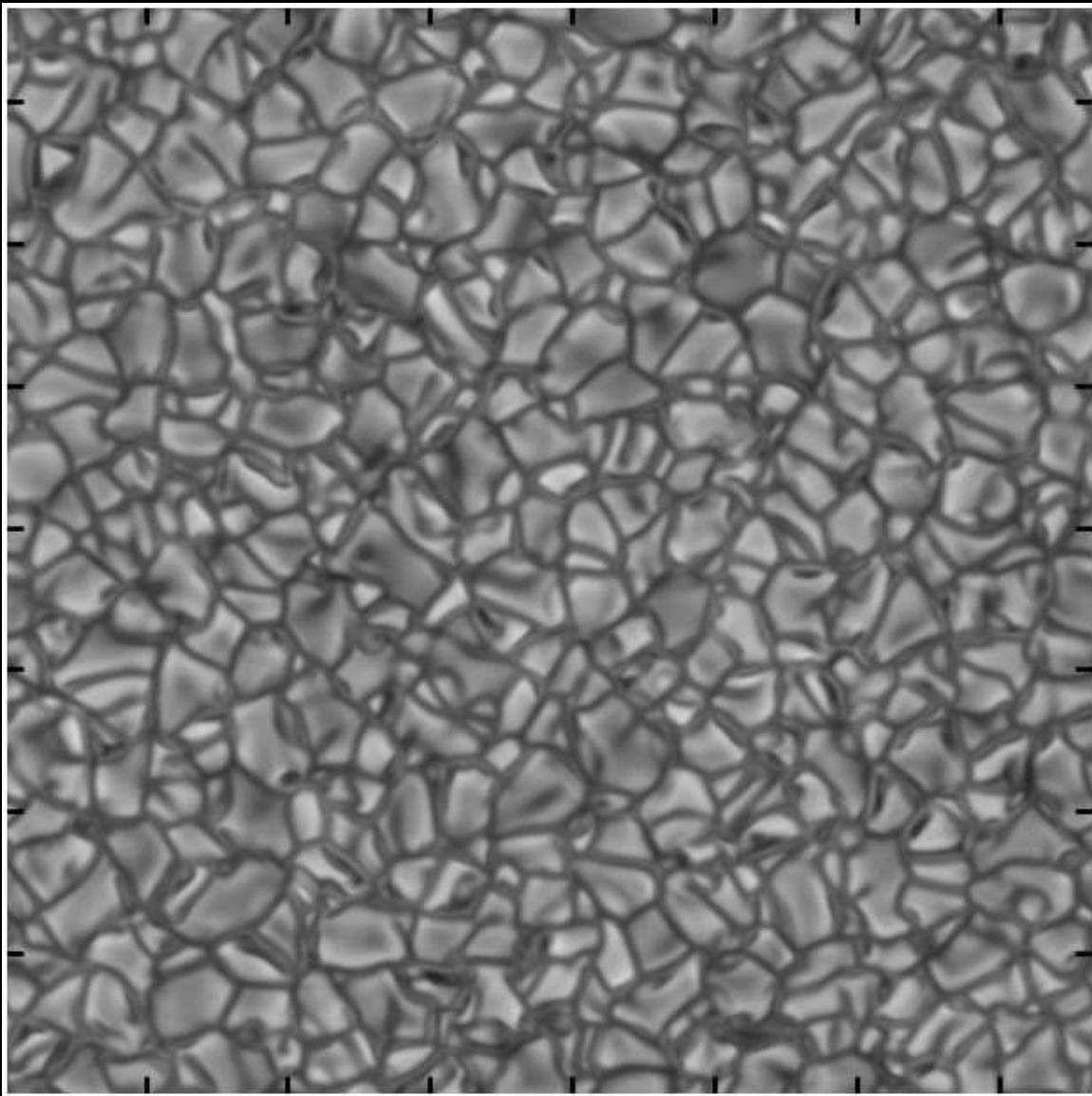
toc — ref

CO<sup>5</sup>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

$\lambda$ [nm]	500	630	bolometric
rms	19.1 %	13.6 %	15.9 %

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



bolometric intensity

Courtesy, *G. Vigeesh, KIS*

$\text{CO}^5\text{BOLD}$  simulation with a

*grid-cell size* of *80 km*

No magnetic fields.

Field of view  $38.4 \times 38.4 \text{ Mm}$

$\lambda [\text{nm}]$	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)

code	cell size [km]	wavelength $\lambda$ [nm]			bolometric	reference
		500	600	630		
CO <sup>5</sup> BOLD/Roe	10	19.5		13.7	15.7	
CO <sup>5</sup> BOLD/HLL	10	19.0		13.4	15.4	
CO <sup>5</sup> BOLD/HLL	12	18.8		13.3	15.4	
CO <sup>5</sup> BOLD/HLL	40	19.1		13.6	15.9	
CO <sup>5</sup> BOLD/HLL	80	18.7		12.9	15.6	
MURaM	7.5			14.4		Danilovic et al. (2008)
CO <sup>5</sup> BOLD	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)

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

**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 ( $T_{\text{eff}}$ ) fixes the intensity contrast.

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



Åke Nordlund during the discussion at a Sac Peak Workshop  
(approximate quote to my recollection):  
“I have this high contrast from the very beginning. In  
the course of time I have seen observers to report  
higher and higher values and I am confident that in  
near future they will converge to my value.”

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.

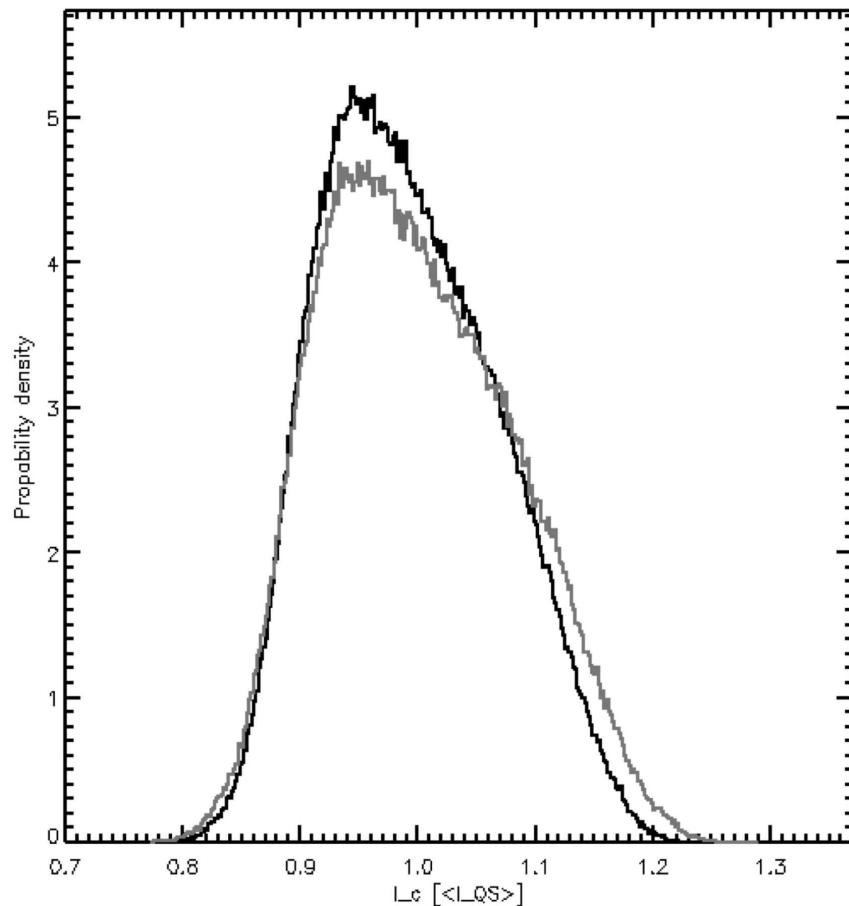
See, e.g., *Danilovic et al.* (2008, A&A 484, L17)

## 2. Intensity distribution as a function of spatial resolution

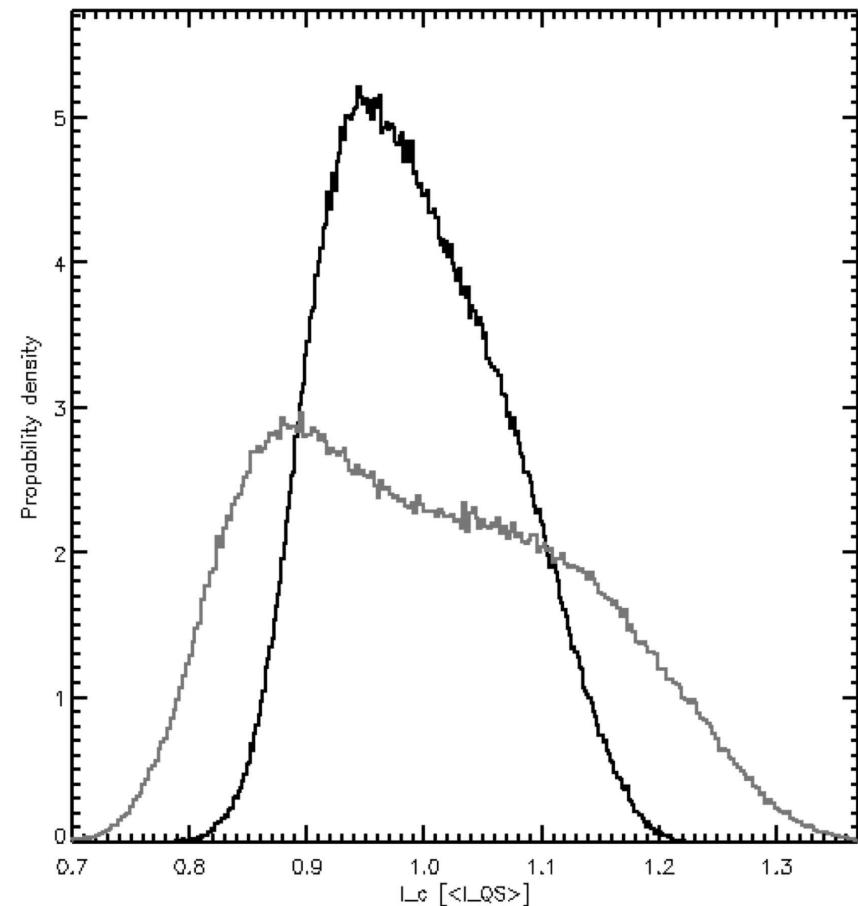
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Disk-center radiative intensity distributions from observations.

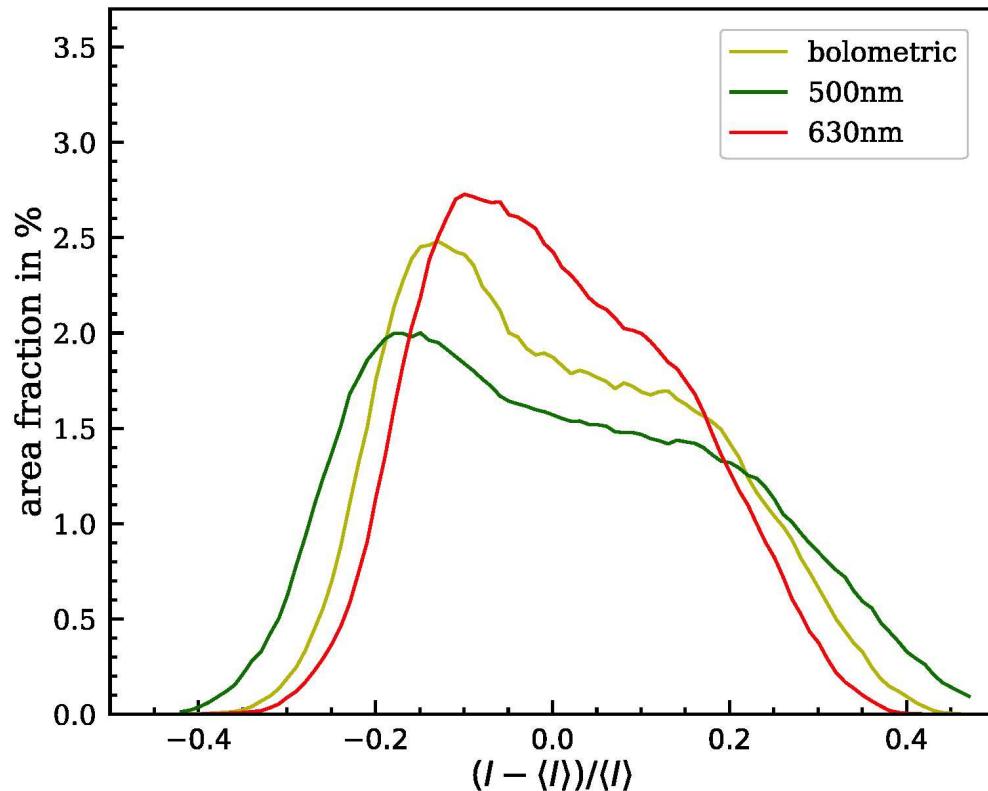
Hinode/SP (black) 630 nm vs.  
Sunrise/IMaX (grey) 525 nm



Hinode/SP vs.  
Sunrise/IMaX reconstructed



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



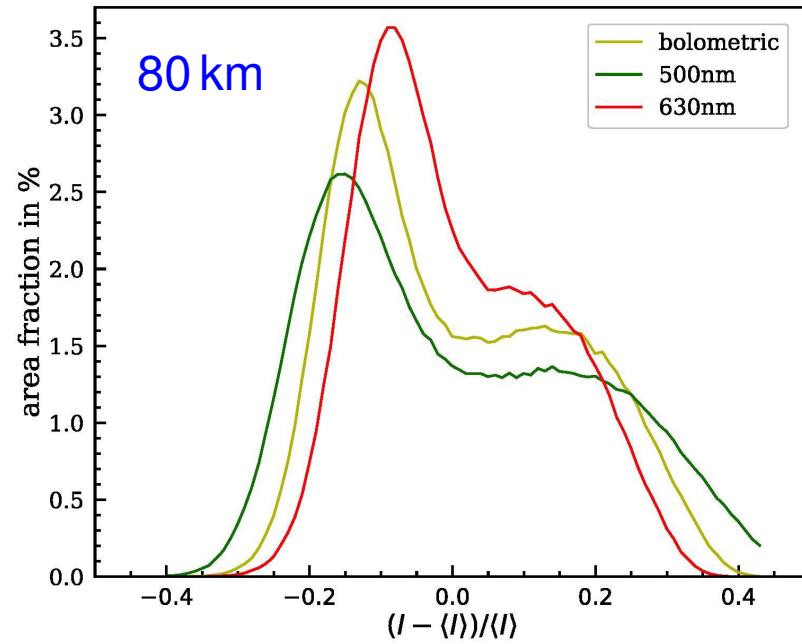
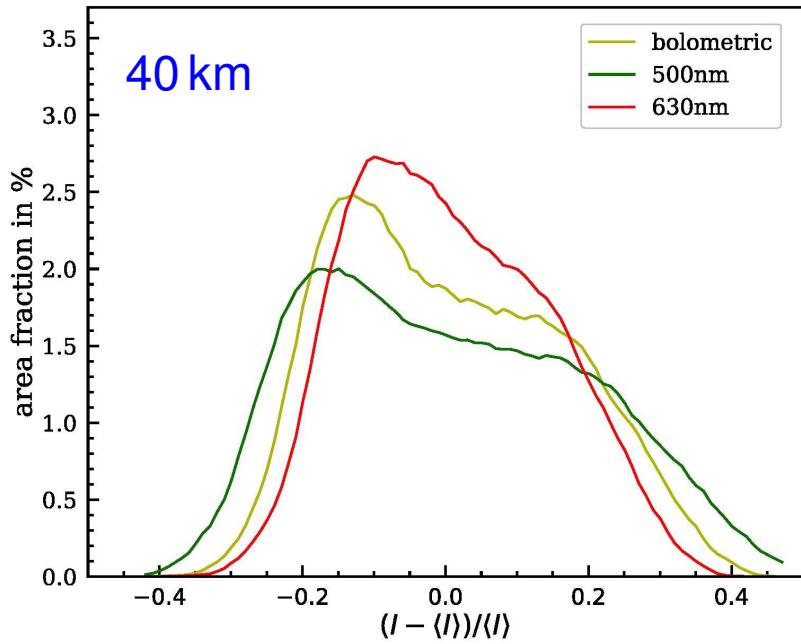
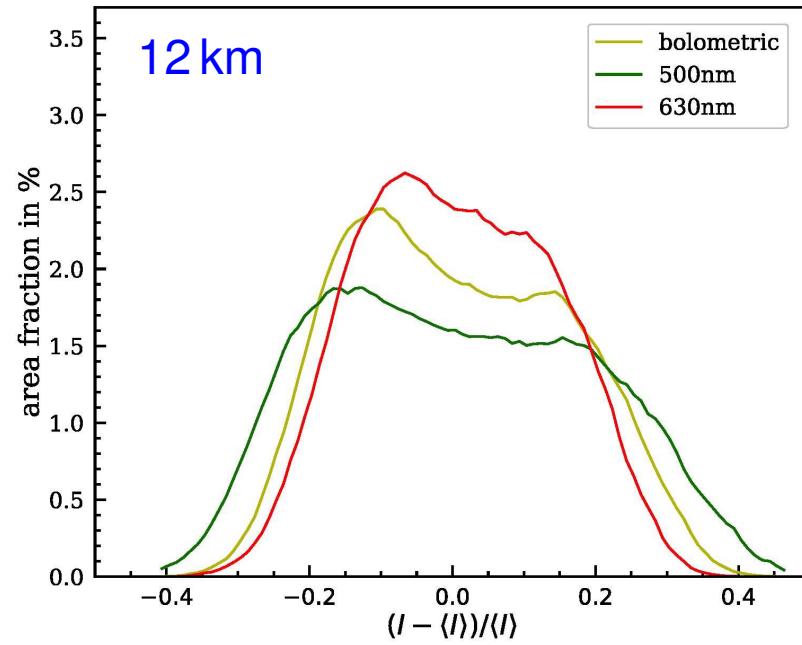
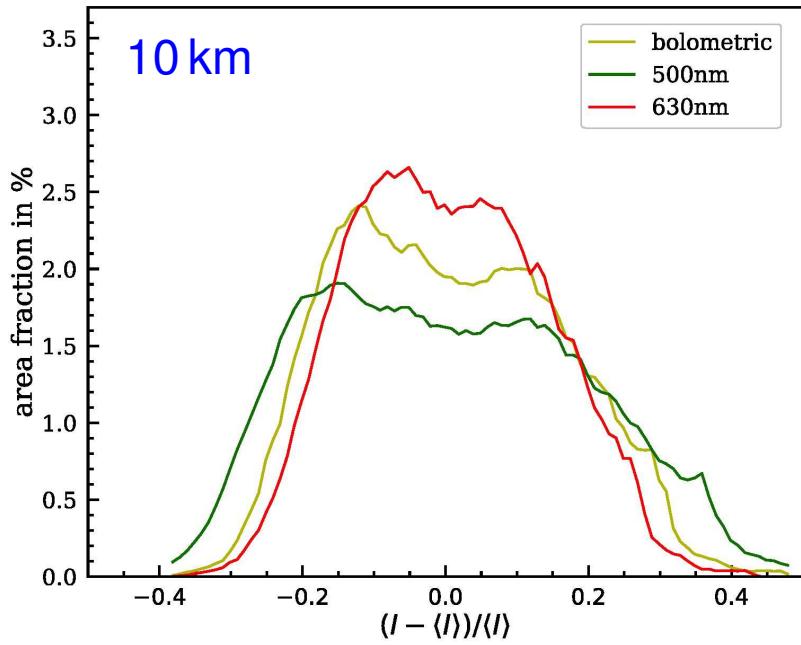
*Distribution of the relative intensity* of the vertically propagating radiation at  $\lambda = 500$  nm, 630 nm, and bolometric of a CO<sup>5</sup>BOLD simulation of *moderate spatial spatial resolution*. The grid-cell size is 40 km. The distribution is *bimodal*.

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

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

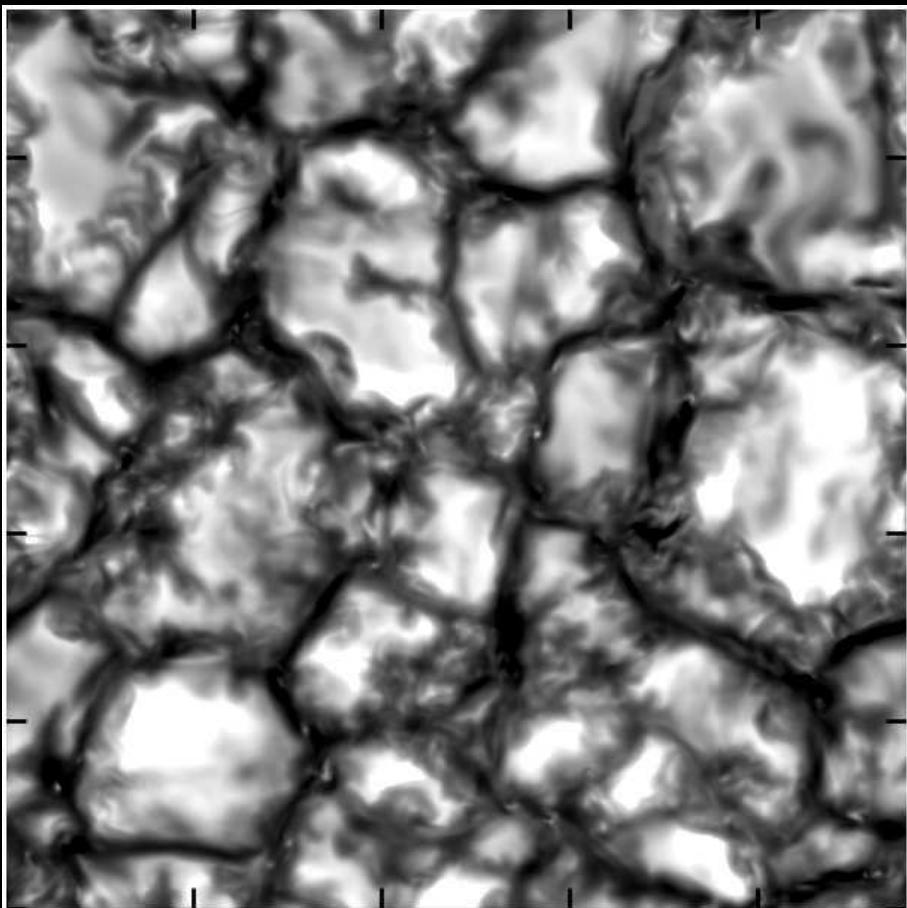
*Tremblay et al. (2013, A&A 557)* show distributions over a wide range of stellar types.

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



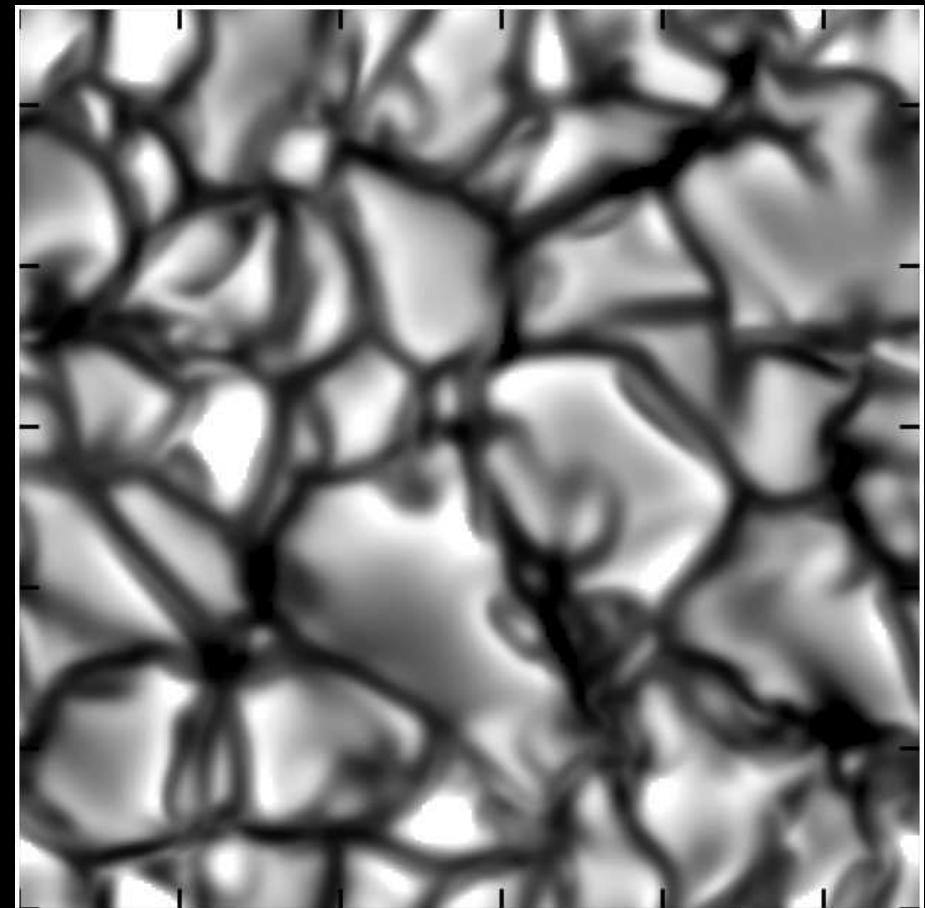
## 2. Intensity distribution as a function of spatial resolution (cont.)

$\lambda = 500 \text{ nm}$



Cell size 10 km, high-res solver

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



Cell size 40 km, low-res solver

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

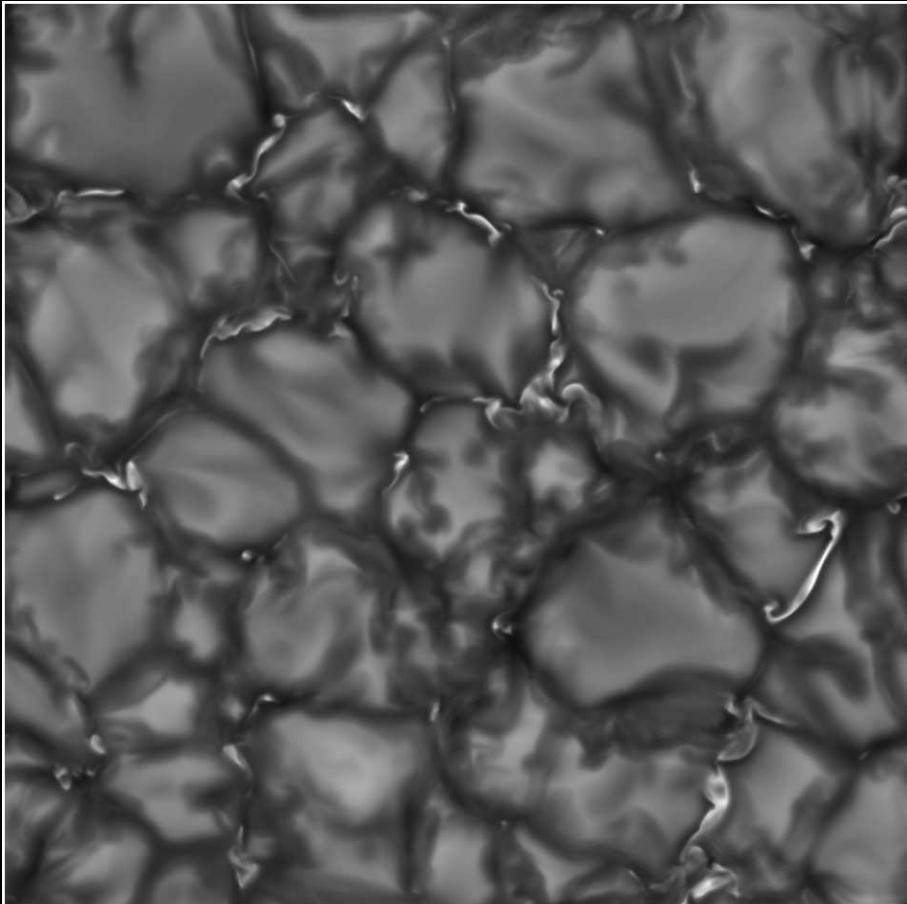
**Surprising twist:** The bimodality of the intensity distribution becomes less prominent with increasing spatial resolution.

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

### 3. Non-magnetic bright points

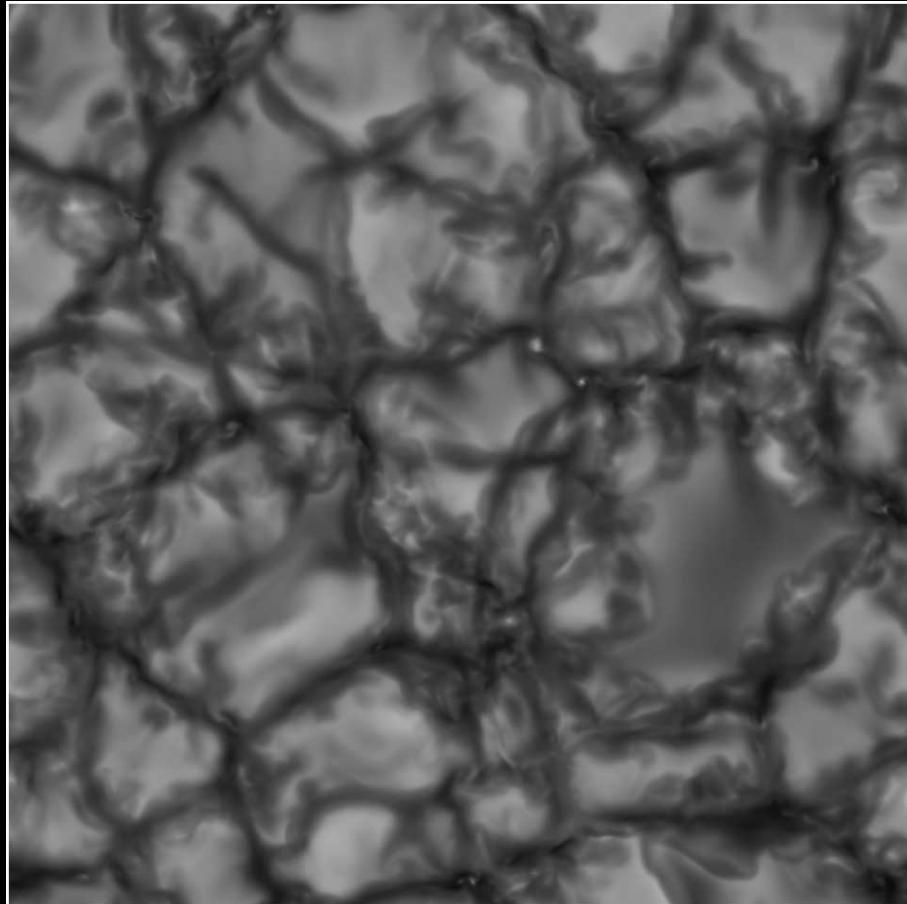
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Bolometric intensity maps



With magnetic fields:  
Magnetohydrodynamic simulation.

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



Without magnetic fields:  
Hydrodynamic simulation

Computations: *Centro Svizzero di Calcolo Scientifico*

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1. Intensity rms contrast as a function of spatial resolution
2. Intensity distribution as a function of spatial resolution
3. Non-magnetic bright points

References

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