Thoughts on the 1 mHz dip, and the description of granulation seen in power spectra

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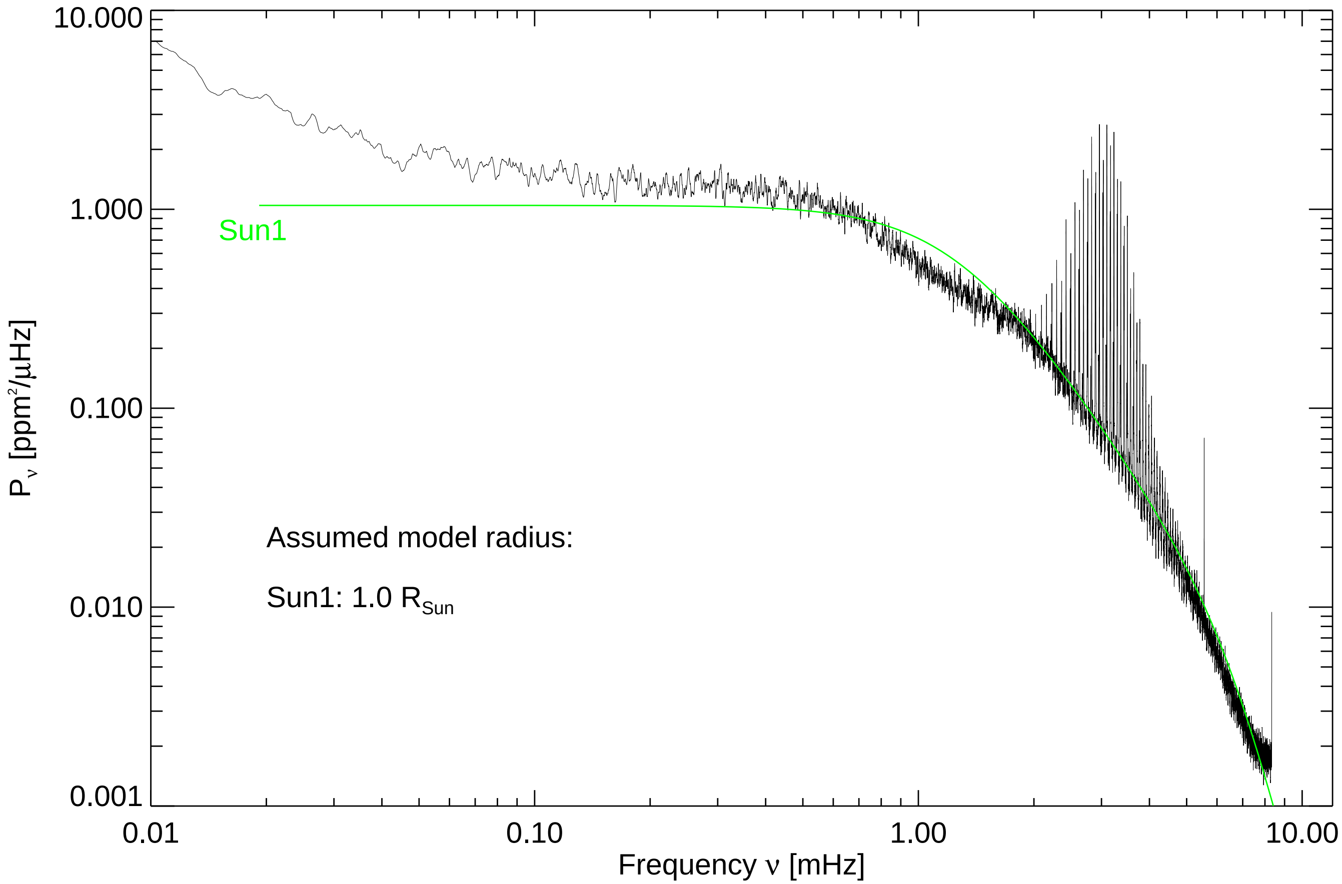
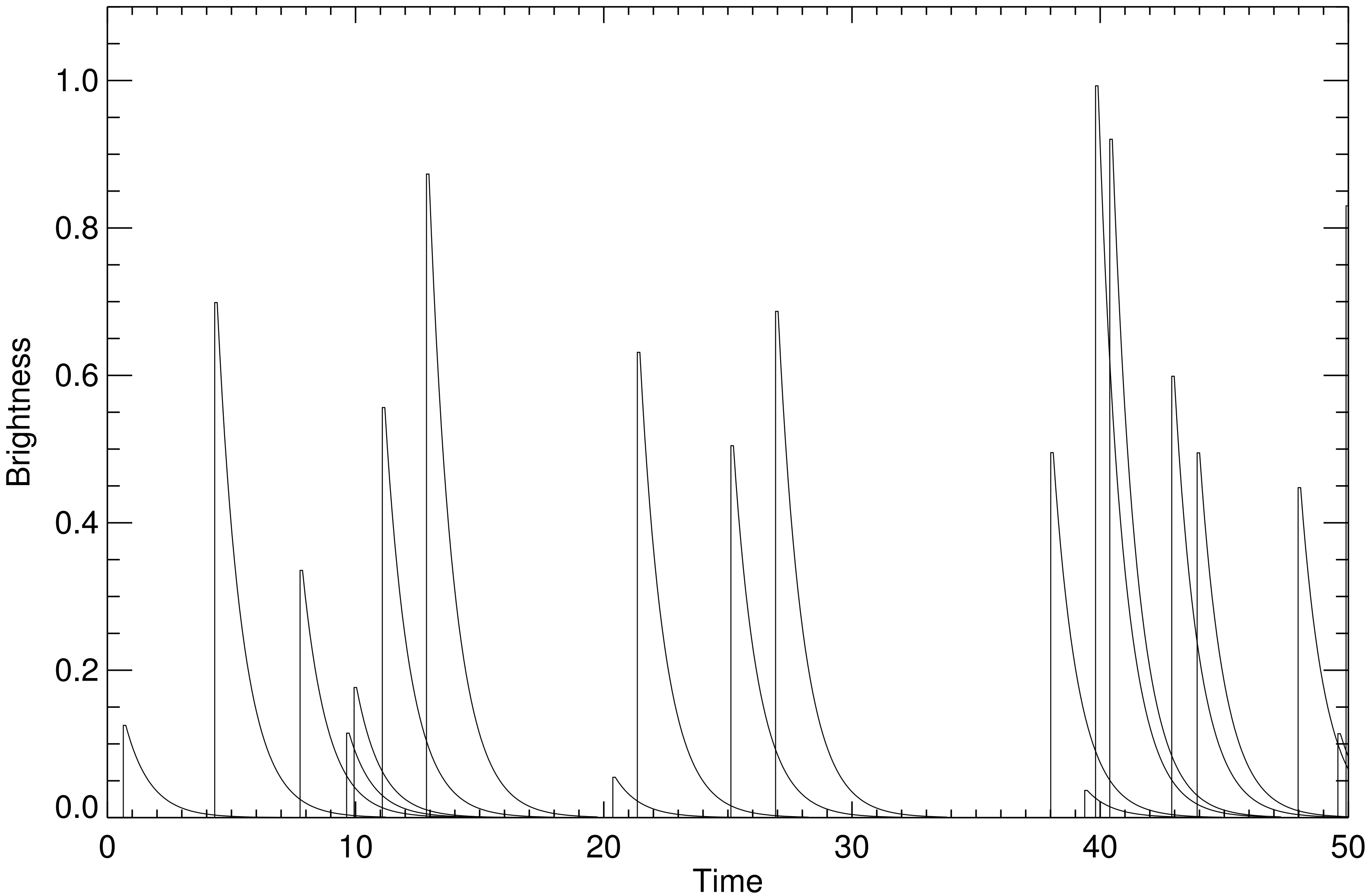
Overview – What produces the "dip" or "kink"?

- Why do my $\mathrm{CO}^5\mathrm{BOLD}$ simulations not really match the granulation background in the Sun?
  - discrepancy particularly in the dip/kink region around $1\,\mathrm{mHz}$



Overview – What is the shape of the granulation background?

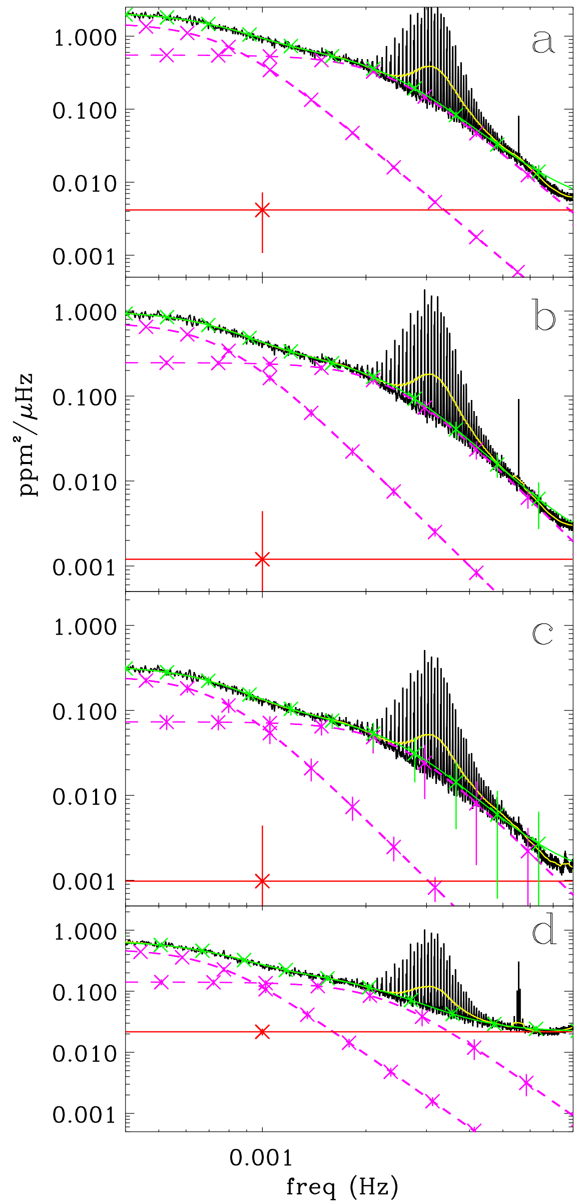
- "I would like to know the light curve of an individual granule!" (Thomas Kallinger, Meudon, 2015)



Light curve simulator?

The dip/kink – interpretation as effect of mesogranulation

- Soho/Virgo photometry: a) SPM-blue, b) SPM-green, c) SPM-red, d) PMO6
- Granulation background (purple dashed lines) result of superposition of two components: granulation and larger-scale mesogranulation



(Figure from Michel et al. 2009)

Fitting results of Michel et al.

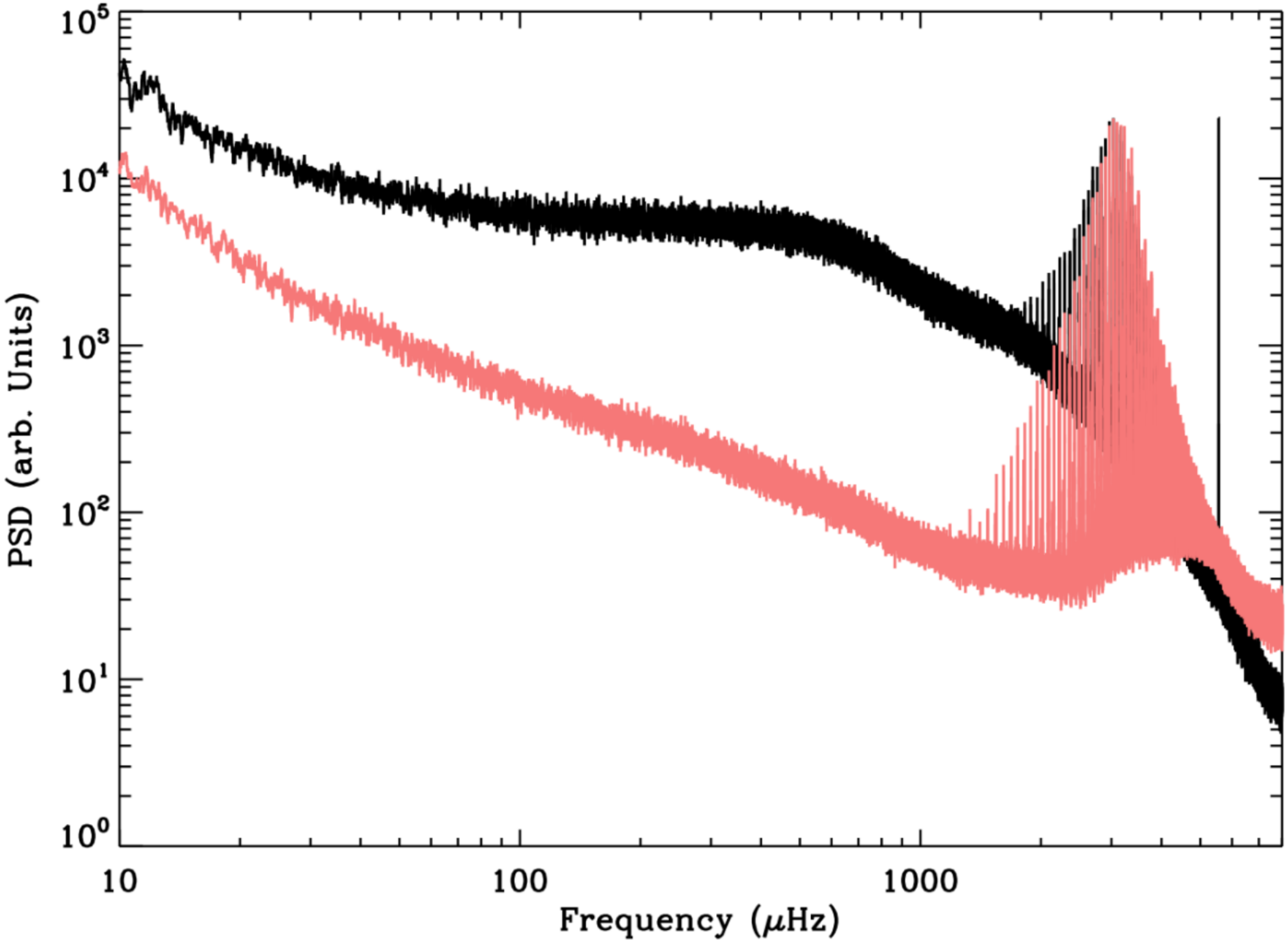
Data set	A_1 σ_{A1} $(\frac{ppm^2}{\mu\mathrm{Hz}})$	B_1 σ_{B1} (s)	A_2 σ_{A2} $(\frac{ppm^2}{\mu\mathrm{Hz}})$	B_2 σ_{B2} (s)	D σ_D $(\frac{ppm^2}{\mu\mathrm{Hz}})$
SPMb	1.52	1292	0.55	433	$4\ 10^{-3}$
	0.02	18	0.02	12	$3\ 10^{-3}$
SPMg	0.74	1302	0.25	419	$1\ 10^{-3}$
	0.02	37	0.02	27	$3\ 10^{-3}$
SPMr	0.26	1321	0.07	403	$1\ 10^{-3}$
	0.02	105	0.01	89	$3\ 10^{-3}$
PMO6	0.50	1349	0.14	439	$20\ 10^{-3}$
	0.02	55	0.02	42	$3\ 10^{-3}$

- Background modelled with two super-Lorentzians and noise component

$$P(\nu) = \sum_{i=1}^{2} \frac{A_i}{1 + (B_i \nu)^4} + D$$

- Taking the numbers for PMO6: the granular and mesogranular component contribute approximately equally to the fluctuations in the time domain.

Is there a depression the velocity power spectrum?



(Figure from Garcia et al. 2013)

More aspects . . .

- Kallinger et al. (2014): "depression" seen in other main sequence stars, located around $\nu_{\rm max}/2$

- Karoff et al. (2013): interpretation of the high-frequency component of the background as due to faculae

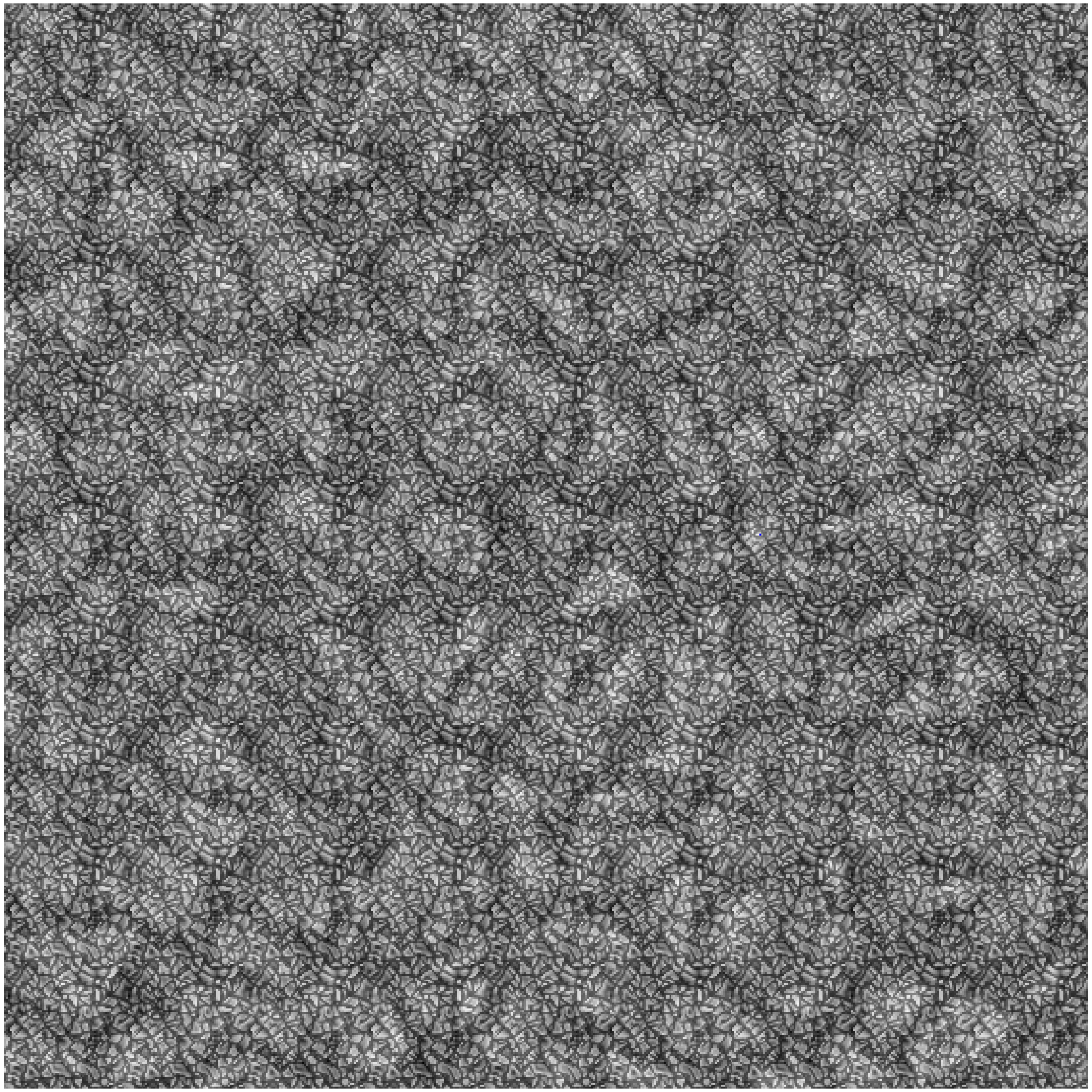
- My take on the interpretation as mesogranulation?
  CO^{5}BOLD simulations for solar granulation give a relation between temporal and spatial "contrast" (Ludwig 2006)

$$l \frac{\sigma_I}{\langle I \rangle} \approx 0.4\, l_{\rm gran} \frac{\delta I_{\rm rms}}{\overline{I}}$$

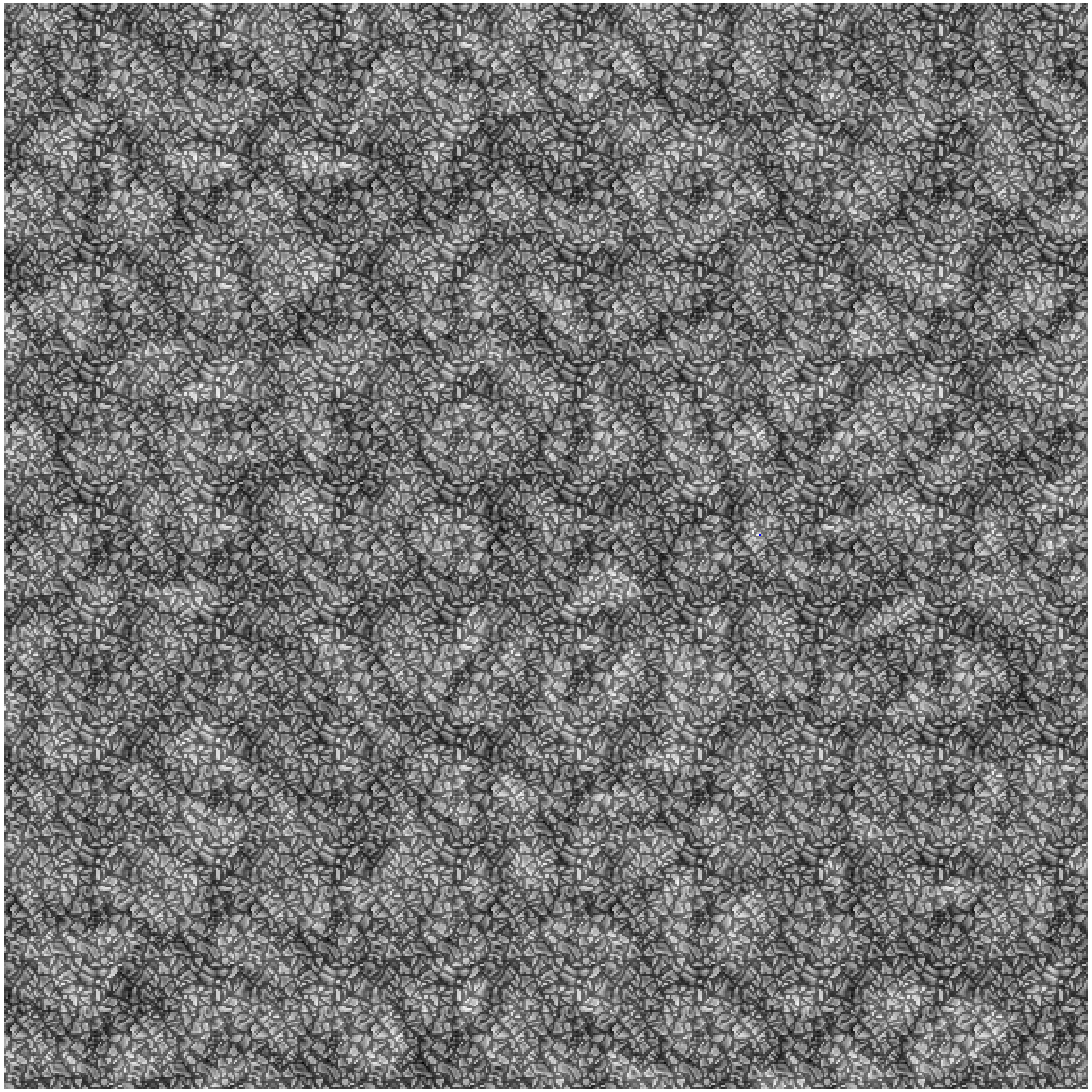
  l: scale on which the temporal fluctuations are observed, $l_{\rm gran}$: scale of granulation

- If mesogranulation is an enlarged version of granulation one would expect that its spatial contrast is about $1/10^{\rm th}$ of the granulation contrast.
  Should be visible . . .

Here an image showing mesogranulation and granulation!!!



Here an image showing mesogranulation and granulation!!!



Made-up of course, contrast rather 15 % for granulation and 5 % for mesogranulation

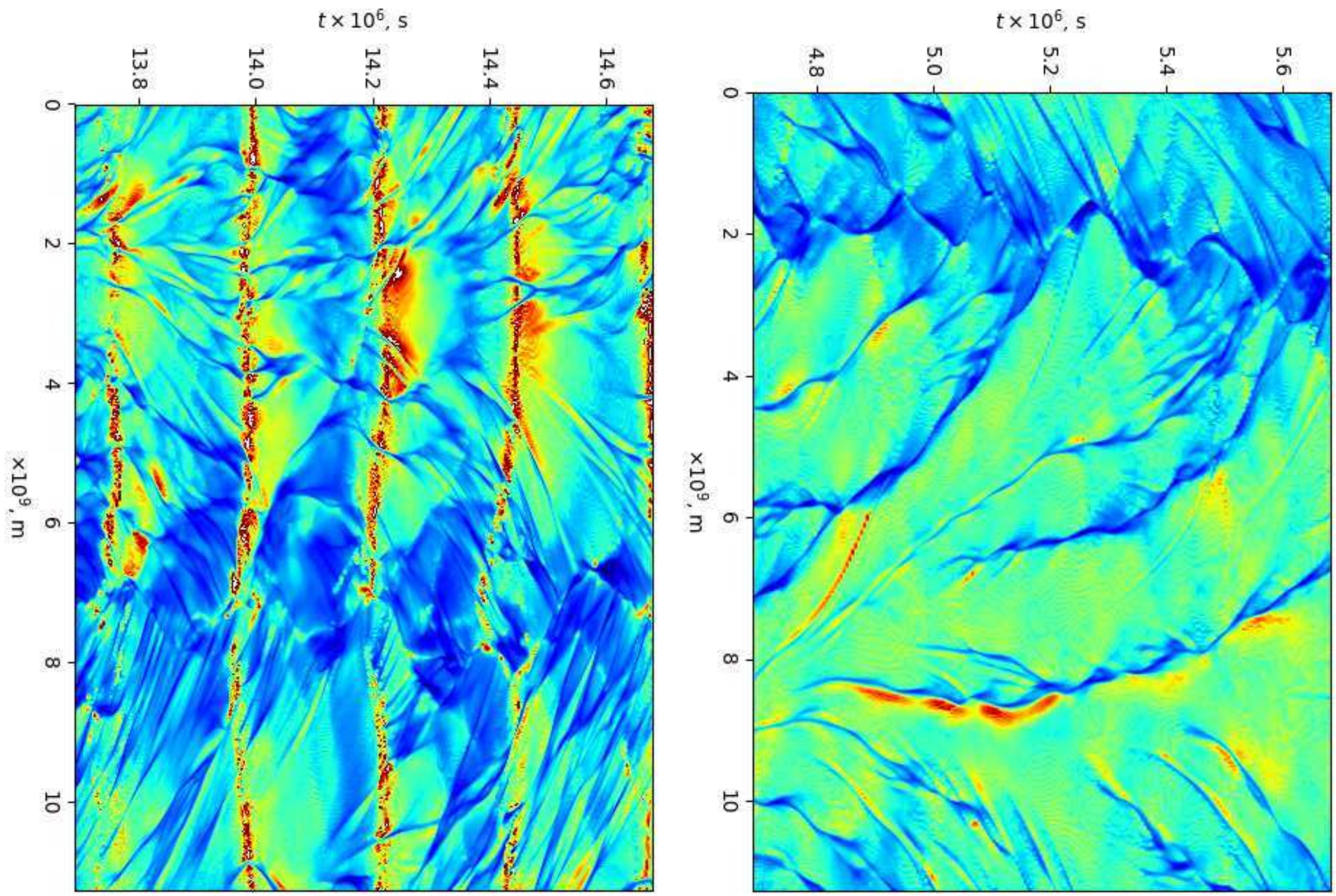
What effect causes the dip?

- Robert & Lionel: dip present in their simulations of long duration without magnetic field
- Remo asked: what duration is necessary to see the solar dip?
  - answer (calculated theoretically after a long working day): 3 h for a 1σ-detection, 27 h for 3σ
- In any case this means: dip physics accessible with simulations
- Plans for the workshop:
  - looking at the structures living at temporal frequencies around 1 mHz
  - looking at Soho/Virgo data, including the center-to-limb variation
- Is the dip a consequence of oscillation-convection interaction? (Robert thinks "no", but why?)

Lightcurve of an individual granule?

- Regner: Two-sided exponential already most of the answer?
- Serious attempt (mostly by Mia) to isolate and follow granules. However...
  - what in fact is a granule?
  - how can one track a granule?
- Going simpler: looking at the brightness evolution of a small (granular size) fixed patch
  - there are moments of maximum brightness
  - quiz: what typically happens at moments of maximum brightness?
- Further thought: disk-integrated brightness is the result of a superposition of many signals having the same probability distribution
  - can one exploit the central limit theorem effectively?
- What about the loss of the arrow of time?
  Mark: it is just averaging...

And now something completely different: granulation in a Cepheid (model)



(Figure from Vasilyev et al. 2017)