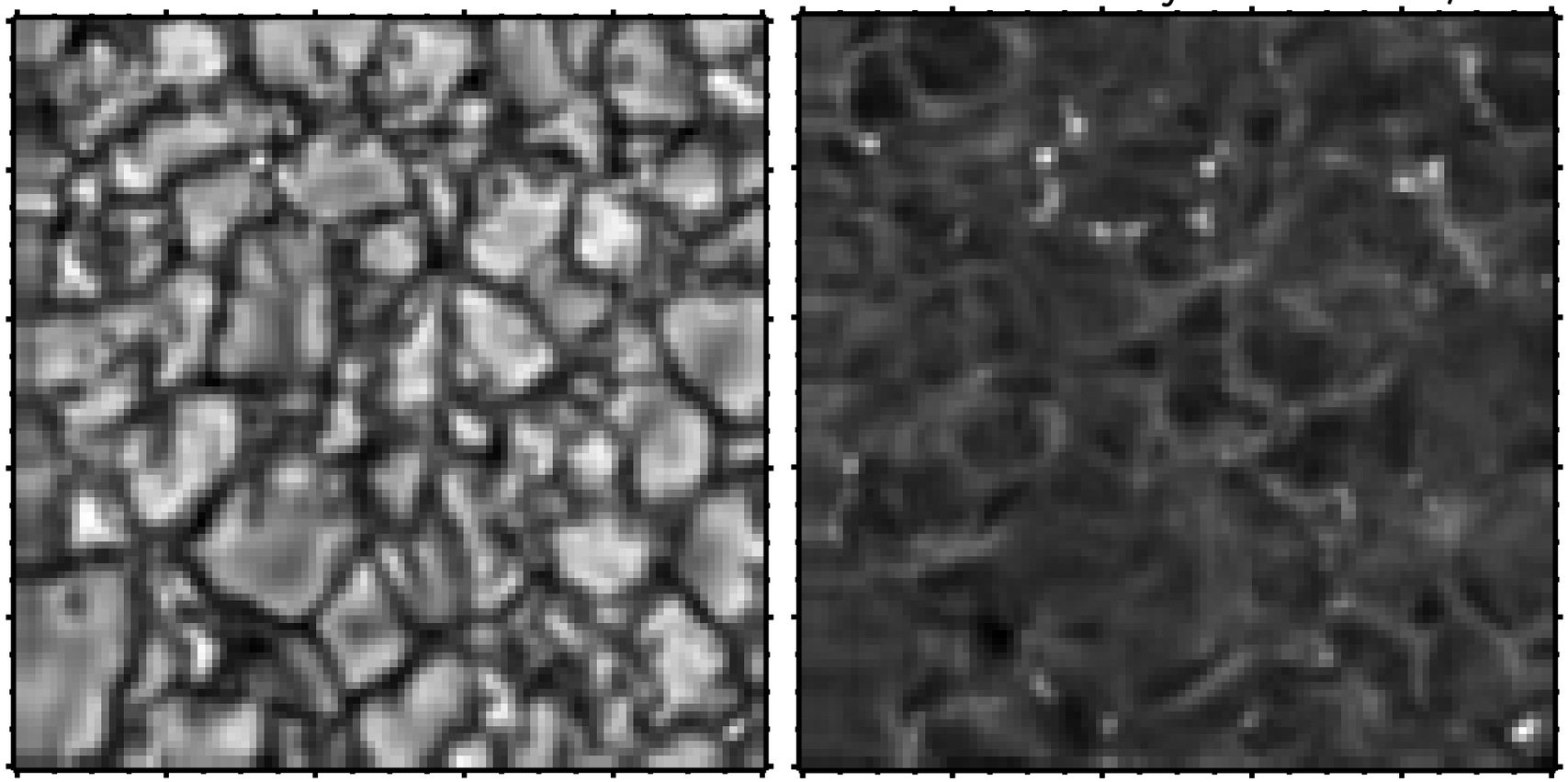
Study of the relation between the reversed granulation and the gas compression/expansion

taken by Hinode-SOT/SP



Continuum Intensity (Surface layer)　　Line core Intensity (middle layer)

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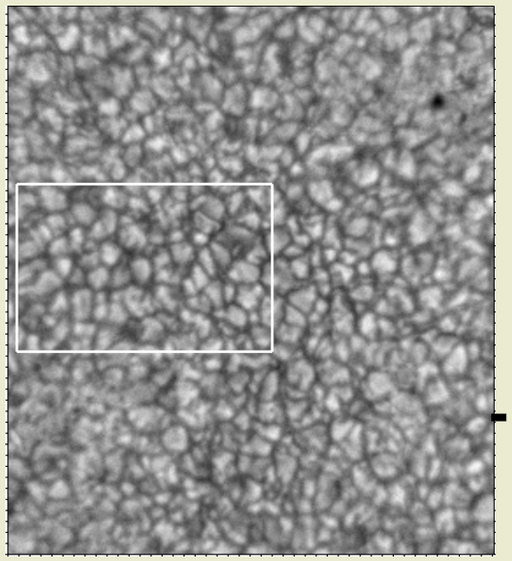
What is Reversed Granulation?

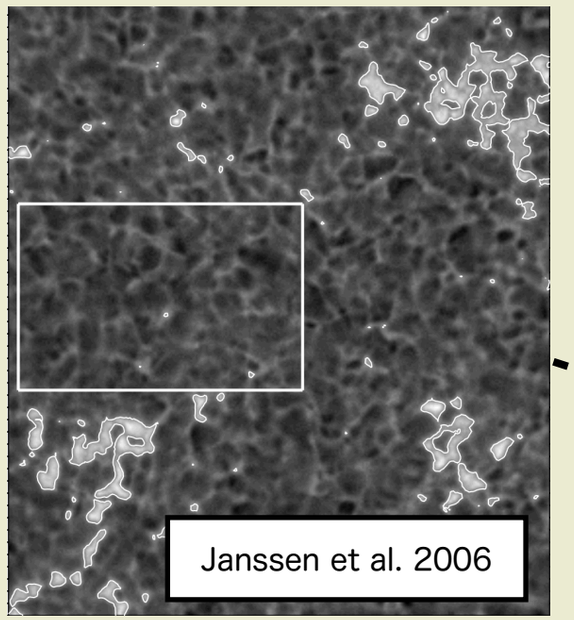
Intensity pattern at the middle layer of the photosphere (height > ~130km)
is opposite to that of the surface granulation

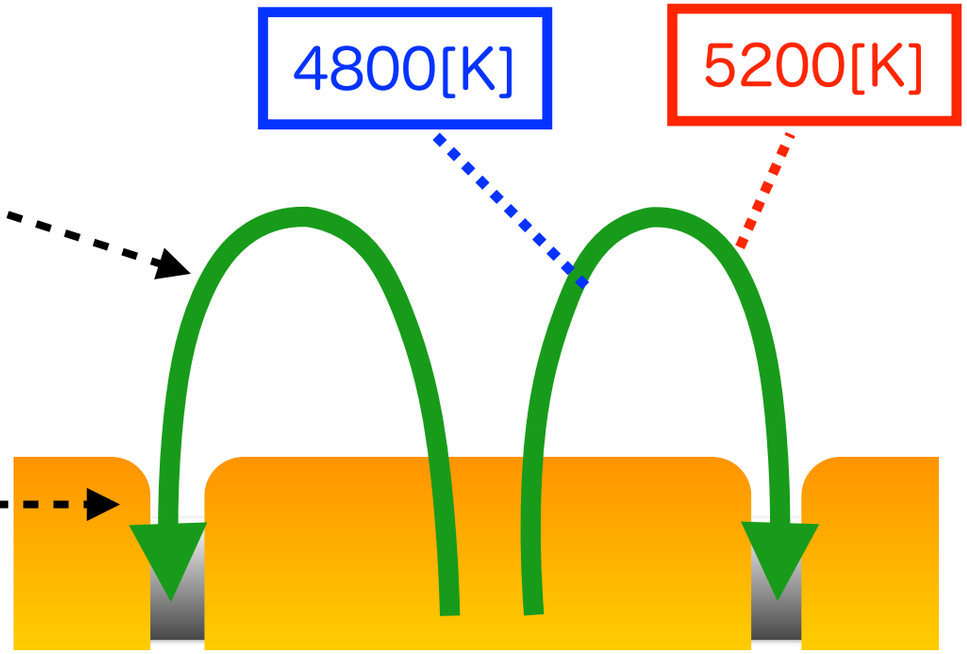
Ruiz Cobo et al. 1996 | Faurobert et al. 2013

Granulation



Reversed Granulation





Reversed granulation indicates:

Gas material, when moving from granule to intergranular lane, is somehow heated up.

Several candidates to explain the reversed granulation

Magnetic field (Unlikely?)

Leeanarrts et al. 2005

- It could be seen in internetwork region
- Non-magnetized numerical simulation also reproduces it

p-mode, internal gravity wave

de Wijn 2009 | Rutten 2004

- Observation shows they are cospatial with the reversed granulation pattern

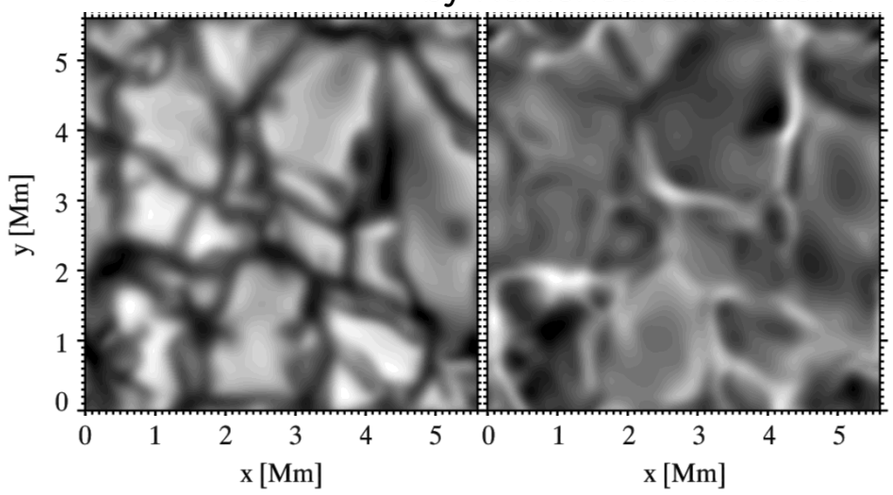
Gas-compression, Radiative heating

Nordlund et al. 1985

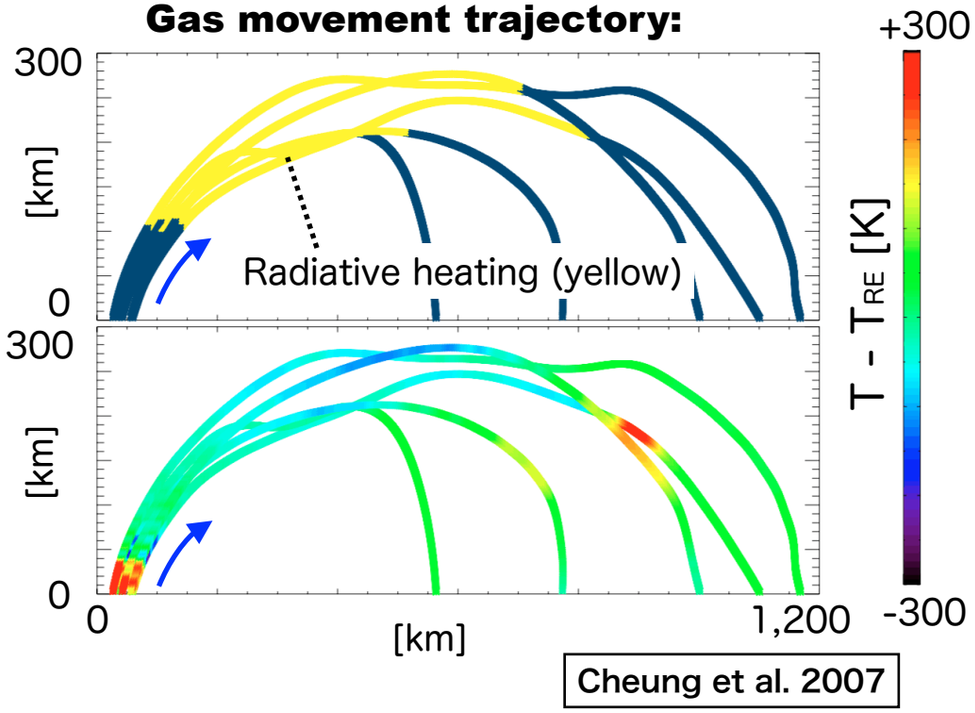
- Gas is compressed in intergranular lane by surrounding granular flow
- Gas in intergranular lane at the middle height is heated by radiation

$$\frac{\mathrm{D}\ln T}{\mathrm{D}t} = \underbrace{-(\gamma_3 - 1)\nabla \cdot \boldsymbol{v}}_{\text{compression/expansion}} + \underbrace{\left(\frac{\partial \ln T}{\partial s}\right)_{\varrho} \frac{Q_{\mathrm{rad}}}{\varrho T}}_{\text{Radiation}}$$

by Numerical Simulation



Gas movement trajectory:



Cheung et al. 2007

Several ideas are proposed but not conclusive,
due to mainly lacking their observational proofs

Observational Studies in the Past

Balthasar et al. 1990

Correlation coefficient between I_{cont} and I_{core} (typically -0.2 ~ -0.3)

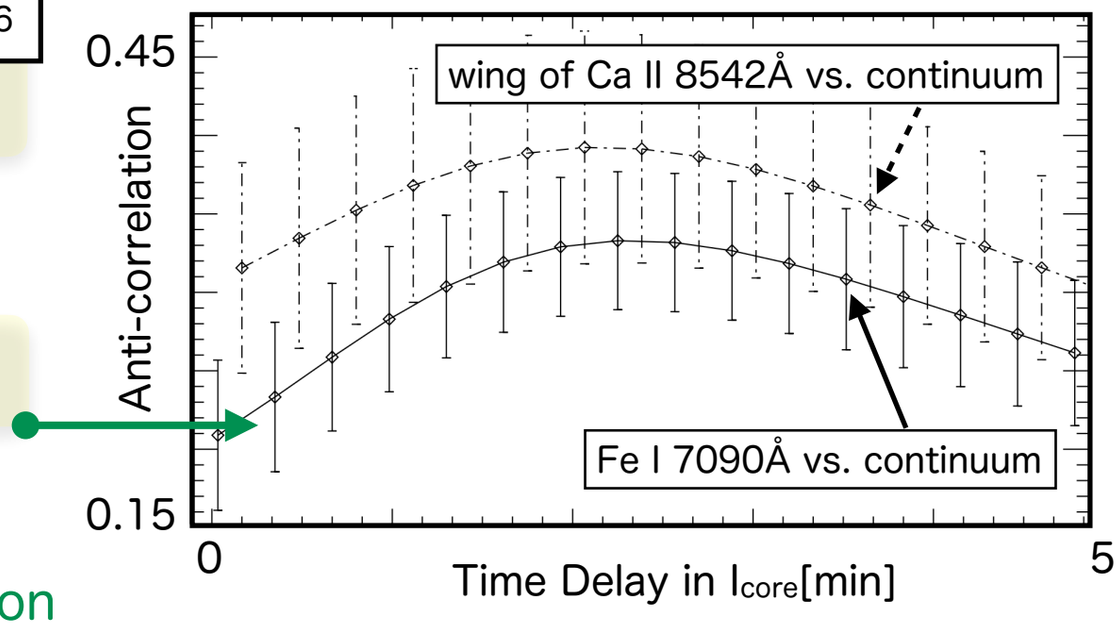
Poor resolution Rutten et al. 2004 | Janssen et al. 2006

→ Better Correlation: -0.4 @1.5”

Time delay of 2 min in I_{core} behind I_{cont}

→ Better Correlation: -0.5

※ upflow with 2 km/s takes 2 min to reach 120 km



➡ Clearly somehow related to gas convection

Issue No reports for the relation between horizontal flow field (gas compression/expansion) and the reversed granulation, so far

This study ➡ Doppler analysis at the solar Limb

Observation and Analysis

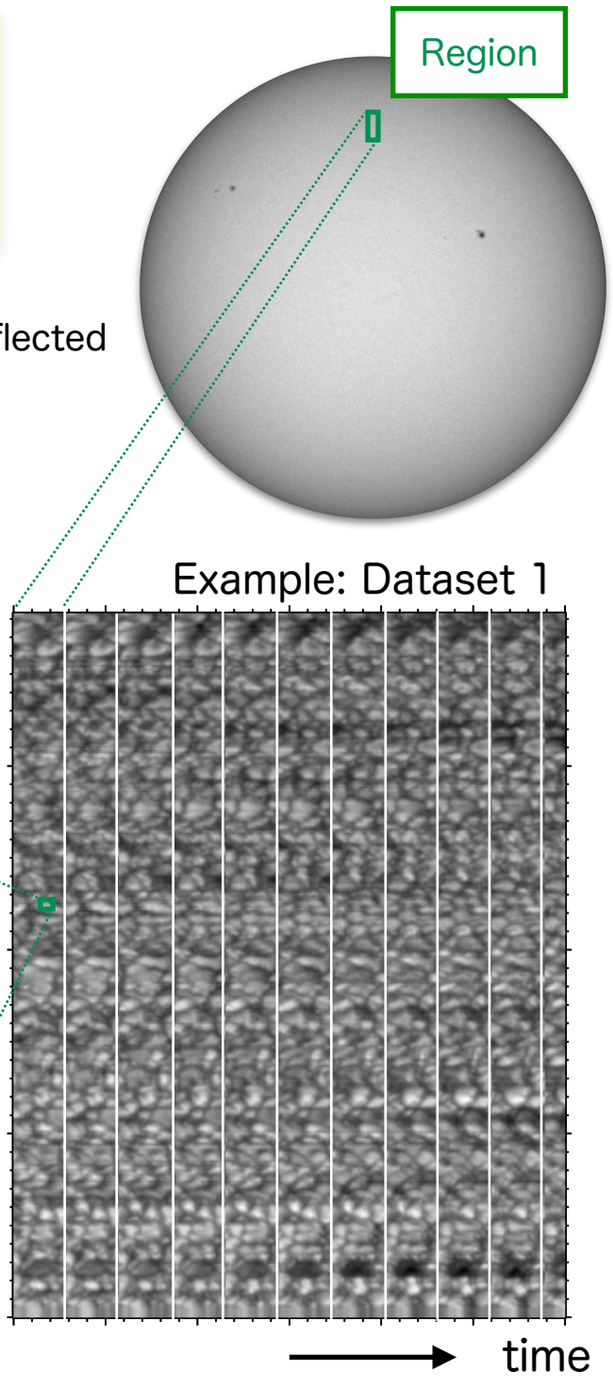
Hinode/SP

Spatial resolution: 0.3”

Spatial sampling: 0.15”x0.16”

Region: [0”, 760”]※

※In the LOS, 63% of horizontal flow is reflected



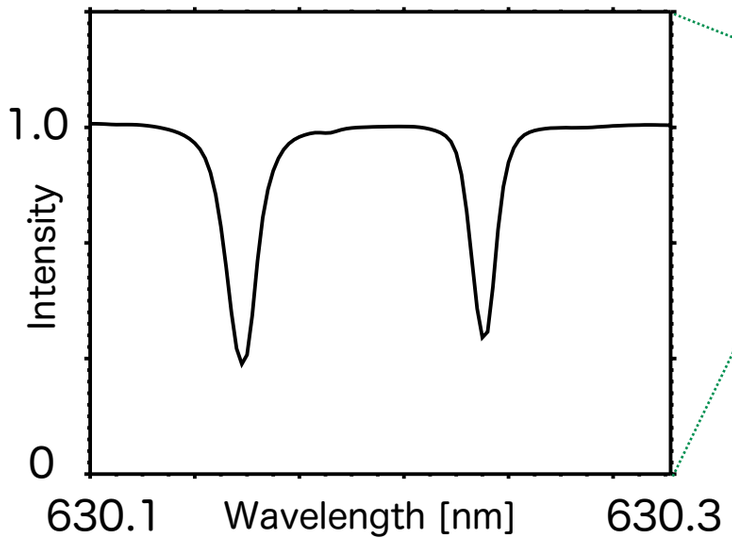
Dataset 1

FOV: 4.5” x 61”

Cadence: 30 sec

Dataset 2

FOV: 90” x 162”

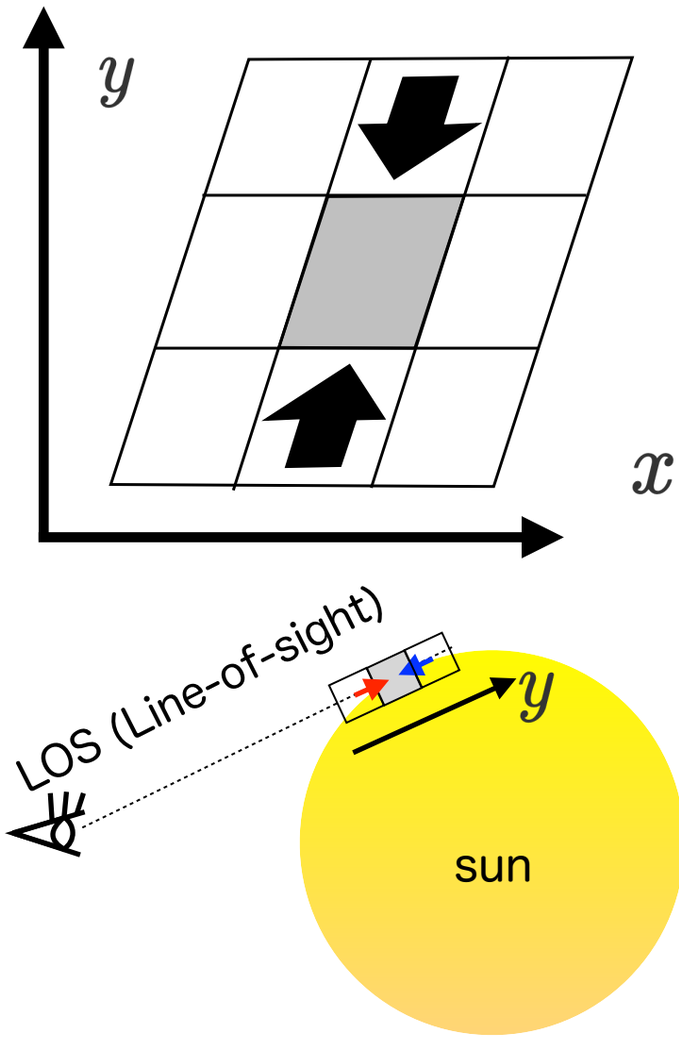


※Deconvolution analysis is applied Oba et al. 2017

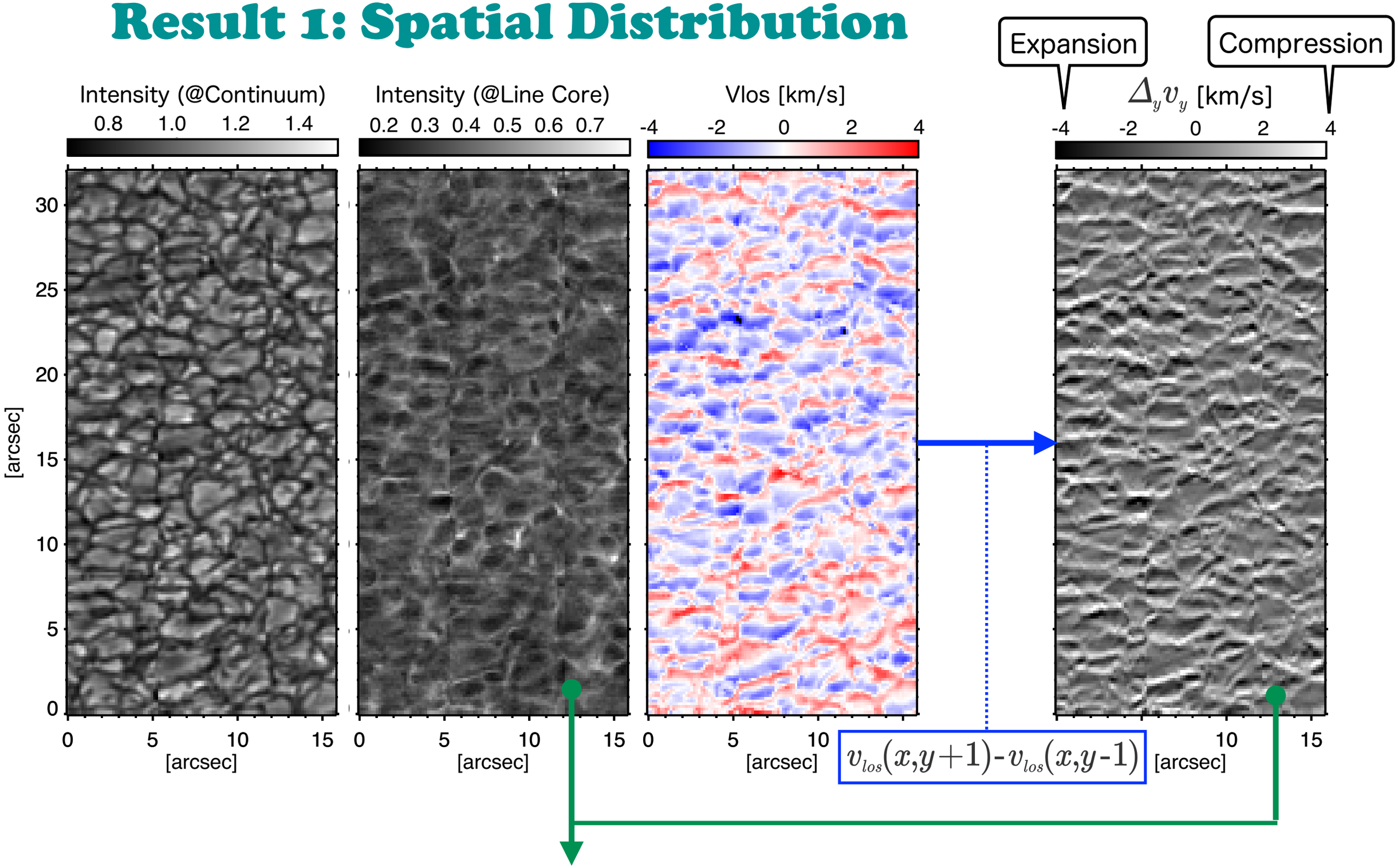
Evaluation for Expansion/Compression

$\Delta_y v_y(x,y)$ is introduced

$= v_{los}(x,y+1) - v_{los}(x,y-1)$



Result 1: Spatial Distribution

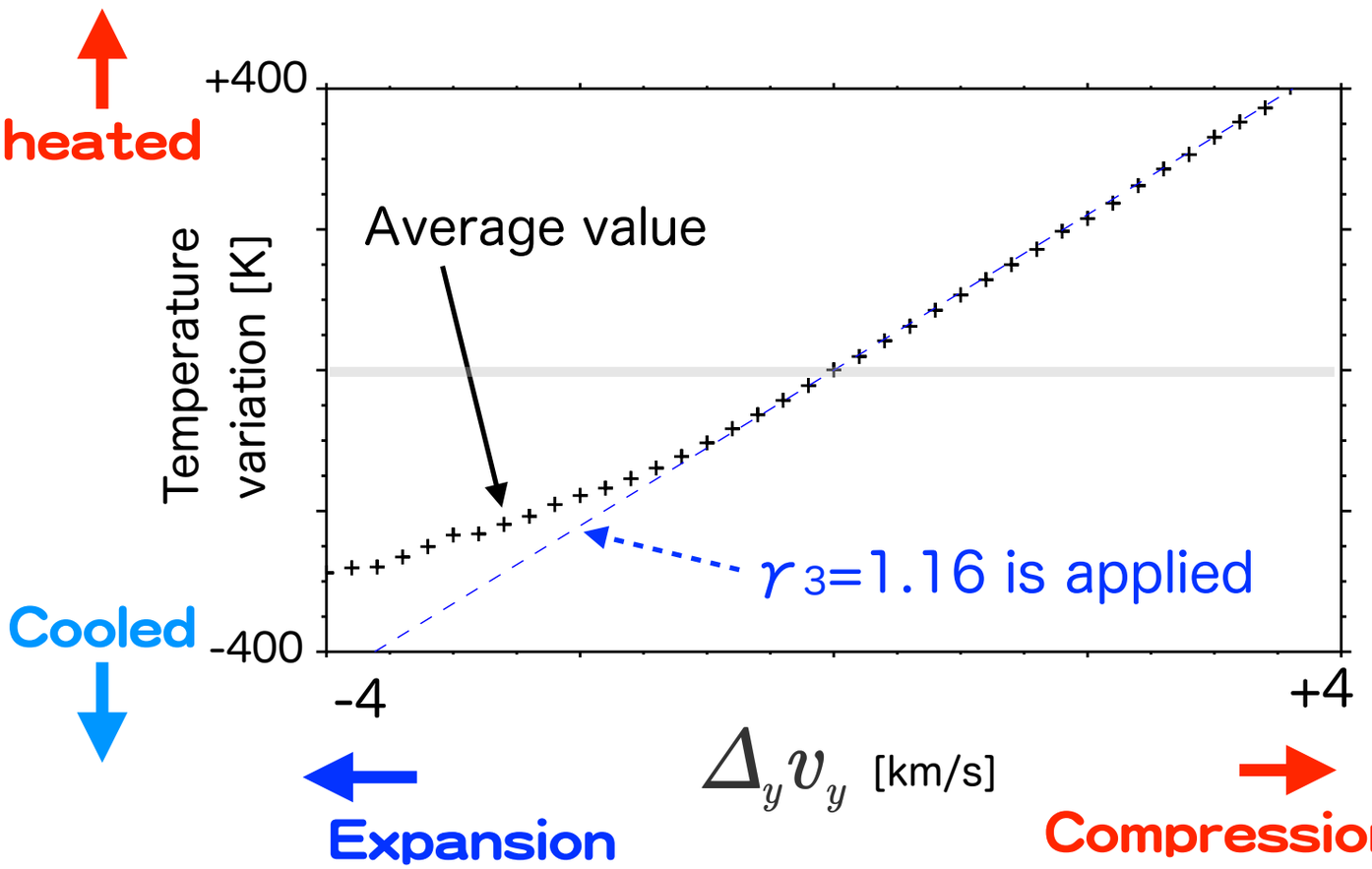


Correlation Coefficient

Intensity (@Line core) vs. Gas compression/expansion: 0.64

Result 2: Average of Temperature variation as a function gas compression/expansion

※Temperature: determined from intensity via the Planck function



Cheung et al. 2007 | Mihalas et al. 1985

※ ignore the radiation term

$$\frac{\mathrm{D}\ln T}{\mathrm{D}t} = -(\gamma_3 - 1)\nabla \cdot \boldsymbol{v} \propto \Delta_y v_y$$

Adiabatic exponent

Temperature variation:
proportional to gas compression/expansion

Temperature variation at the middle photosphere

It is determined by the act of compression/expansion

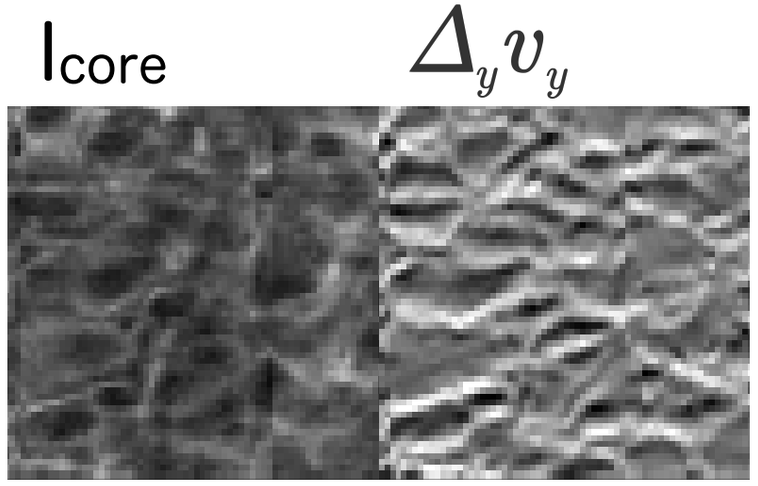
Compression increases the temperature, while expansion does not well decrease the temperature

Discussions

For result 1: Compression/Expansion vs. I_{core}

Strong correlation: 0.64

Temperature variation at the middle layer could be qualitatively explained by the gas expansion/compression



Expansion@granule ← Overshoot with decreasing pressure

Compression@Intergranular lane ← Colliding with anti-directed flow

For result 2: Temperature variation due to gas compression / Expansion

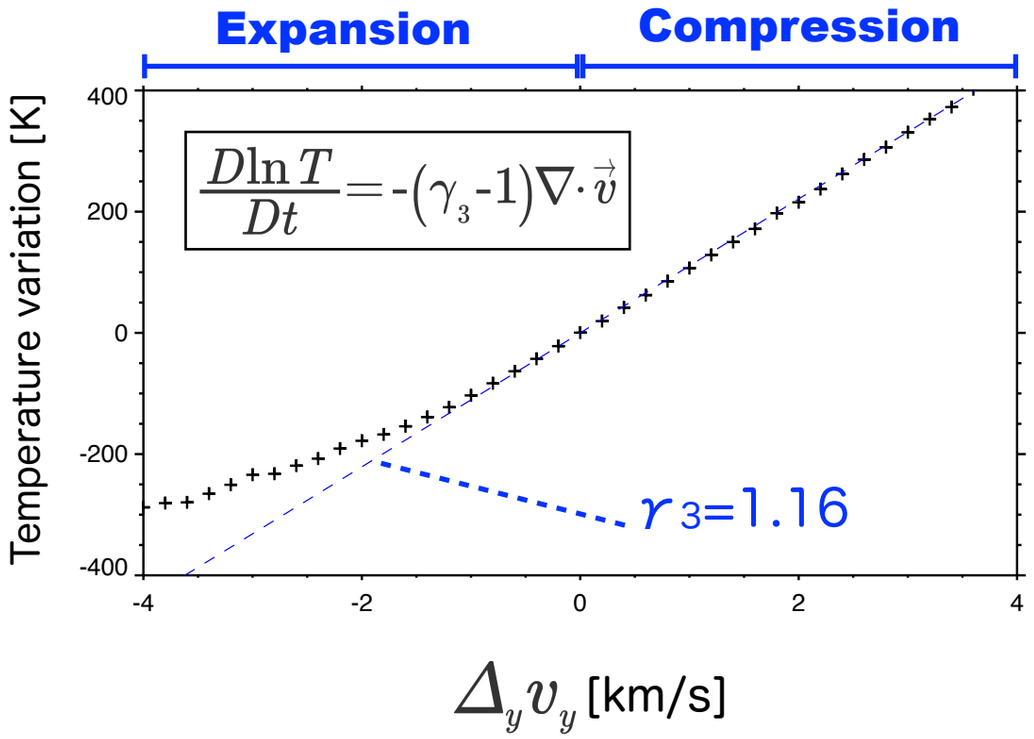
Compression: γ_3=1.16, Expansion: 1<γ_3<1.16

Compression increase the temperature,
while expansion does not well decrease the temperature

- Radiative heating above granule contributes to heat partially

and/or Nordlund et al. 1985 | Cheung et al. 2007

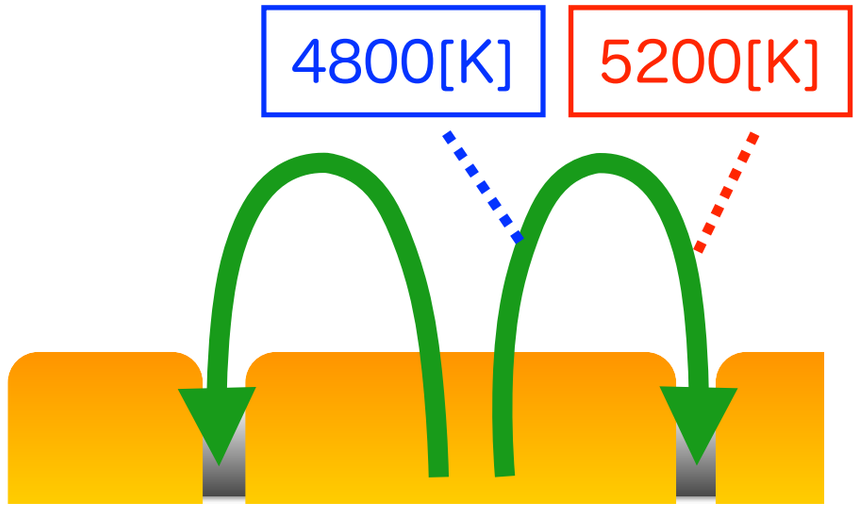
- Change of γ_3 in granules and intergranular lanes



Summary

Reserved granulation

Temperature enhancement when moving
from a granule to an intergranular lane



Candidates Gas compression/Expansion, p-mode, internal gravity wave, ⋯

This study: Horizontal flow field derived from observations is used for the first time to evaluate the gas compression/expansion

➡ Observationally support the gas compression/expansion contributes to create the reversed granulation

※Radiation may partially heat the gas above granules

Future works

- Quantitative evaluation of γ_3 in granule and intergranular lane using numerical simulation

- Multiple Doppler analysis in coordination with the Solar Orbiter