Doppler velocities of the solar photosphere very close to the limb observed with Hinode SOT

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Abstract

The convective motion of the solar photosphere causes the spectral line shift and asymmetries. The purpose of this study is to quantitatively reveal the Doppler velocity caused by the convective motion near the solar limb. We analyzed the Doppler velocities of the Fe I 630.15 nm line using Hinode SOT/SP data. We classified the absorption lines observed on the disk into those from granules, intergranular lanes, and magnetic regions. Our result shows that the Doppler velocities of the average line profile decreases in the blueshift toward the solar limb, and the Doppler velocities dose not vary above 80 degrees. The Doppler velocities of granules show decreases in the blueshift toward the solar limb.

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Significant center-to-limb variation of the Doppler shift in the solar photosphere

- Observation : up to 72 deg (Löhner-Böttcher et al., 2019)
- Simulation : up to 80 deg (Cegla et al., 2018)

Causes of the Doppler shift variation

- Disk center : Since the upflow is bright, the blueshift is observed.
- Near the limb
  - The Doppler velocity includes the velocity of the horizontal flow.
  - The redshift is observed because of the 3D flow structures.

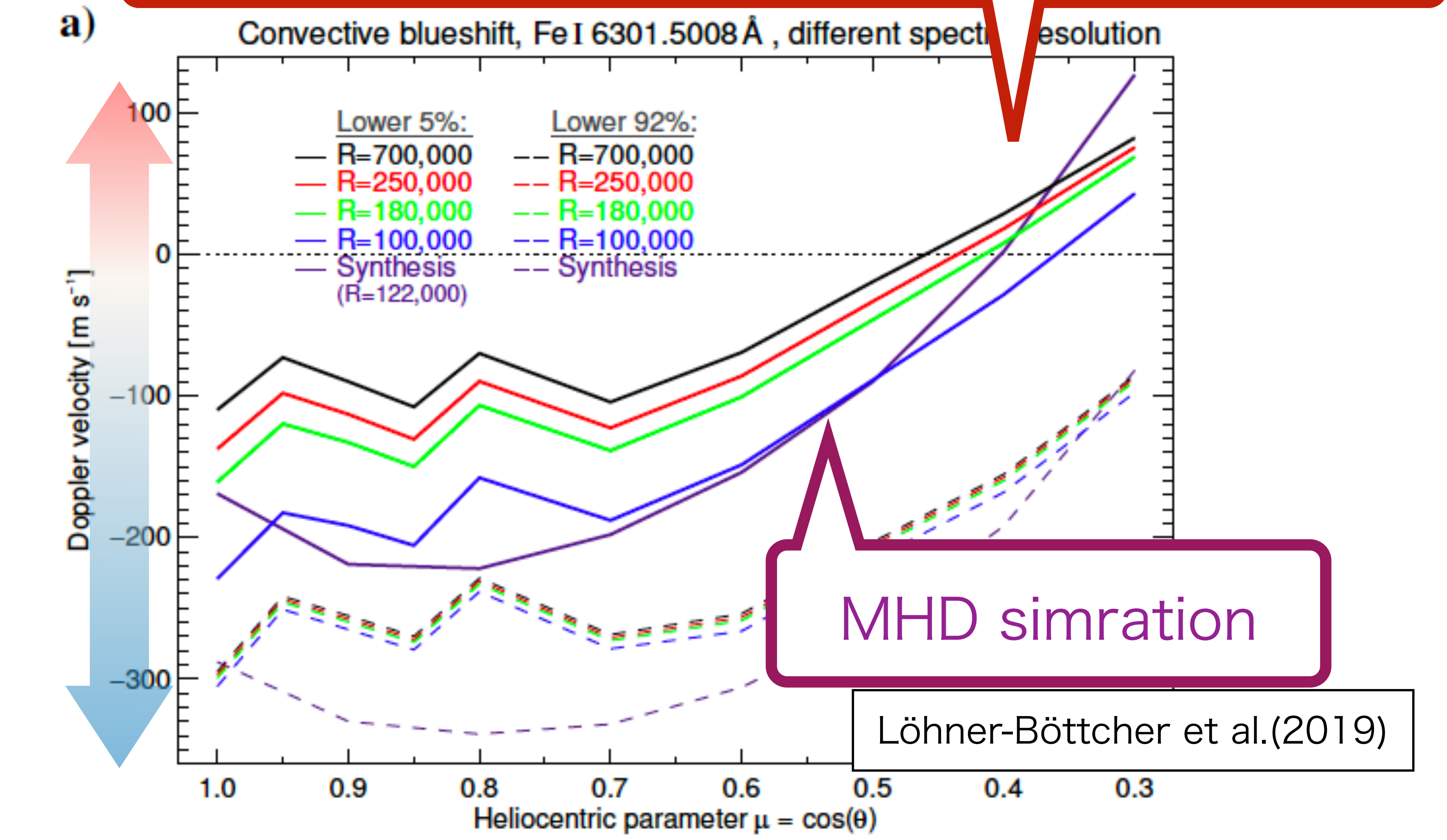
Qualitative understanding of the redshift near the limb

Granules in the front hide the structure in the back.

Since the wall of granules in the back is bright, the redshift is observed.

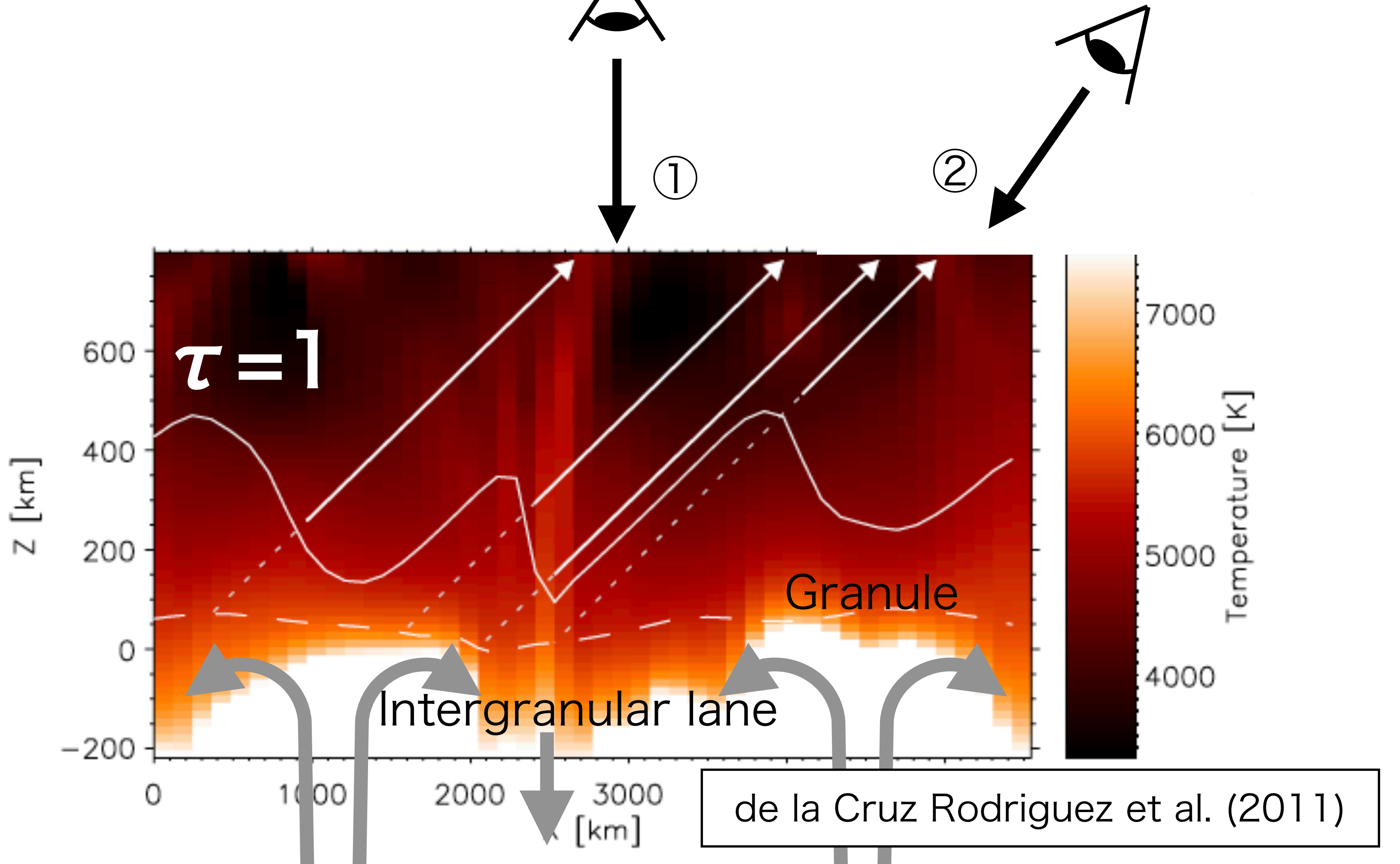
The purpose of this study is to quantitatively reveal the Doppler velocity caused by the convective motion near the solar limb.

Observed by Löhner-Böttcher et al.(2019)
(red : spectral resolution of 250,000)



Löhner-Böttcher et al.(2019)

① disk center ② near the limb



de la Cruz Rodriguez et al. (2011)

Cross section of temperature distribution

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Observation

Taken by Hinode SOT/SP

Target : North polar region

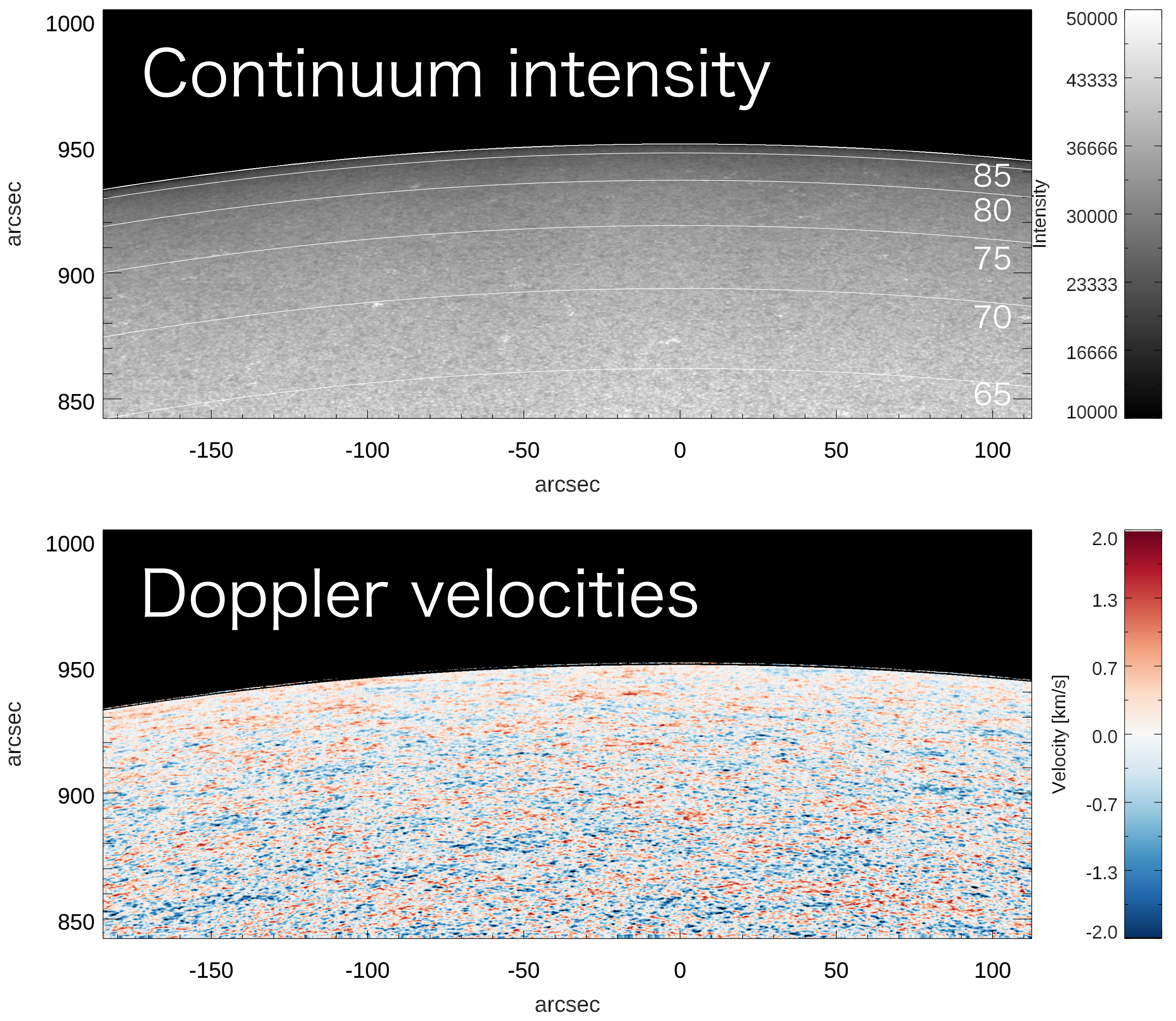
Spectrum line : Fe I 630.15 nm

The Fe I line exhibits absorption within the solar disk while it becomes emission up to about 1 arcsec above the limb (Lites et al. 2010).

Calibration of the data

SP_PREP (Lites and Ichimoto, 2013) uses the average line center position of the absorption profiles for the wavelength calibration.

- No absolute velocity reference



SETUP

Time : 00:28:28 ~ 05:57:47, 6th September 2007

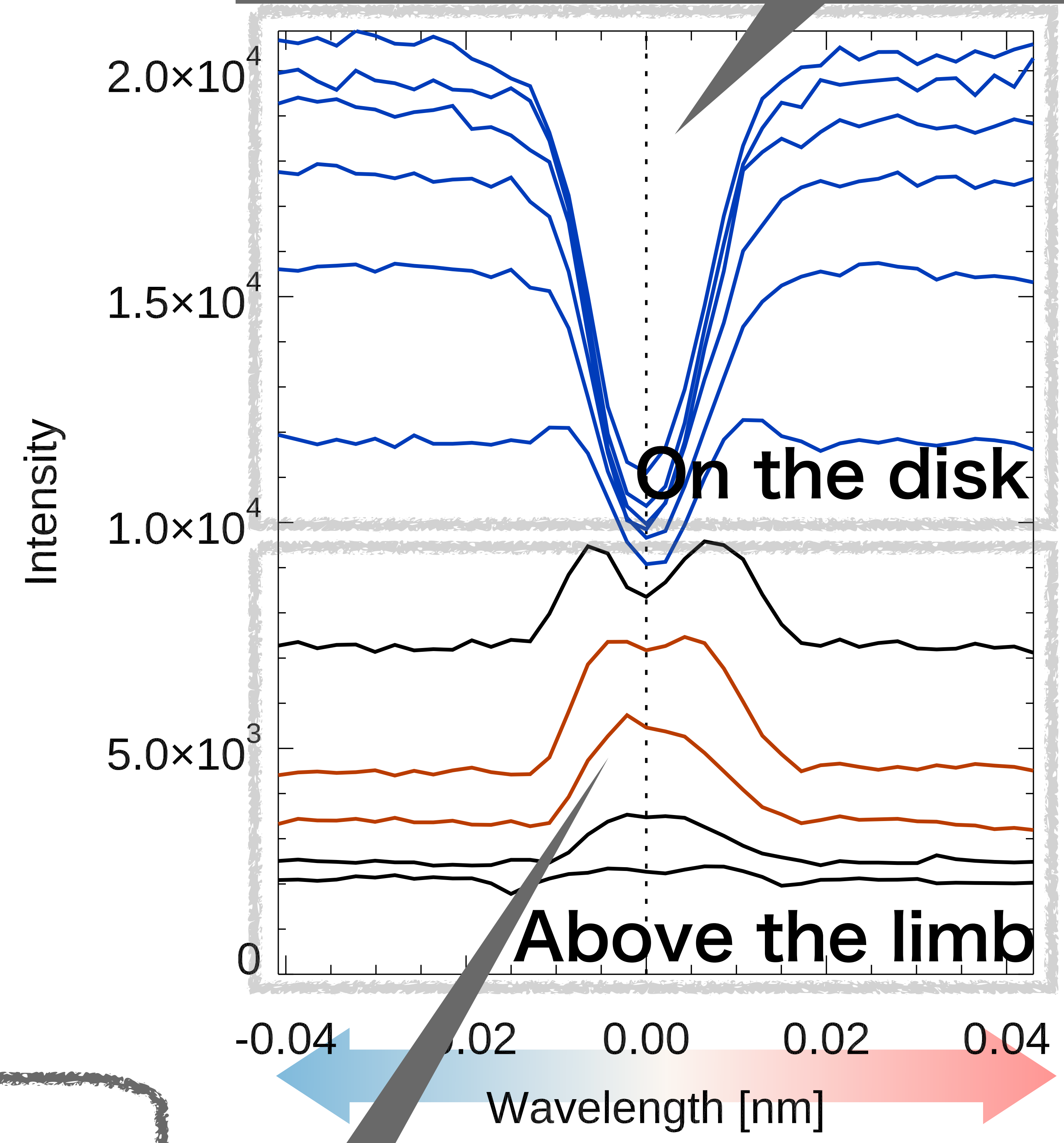
Spectrum line : Fe I 650.15 nm line (Spectral sampling 21.5 mÅ/pixel)

Integration time : 9.6 s

Field of view : 162” x 297” arcsec (Spatial sampling 0.”16 x 0.”15)

We observed absorption lines on the disk.

Line profile near the limb



The emission lines can be observed within 1” above the limb.

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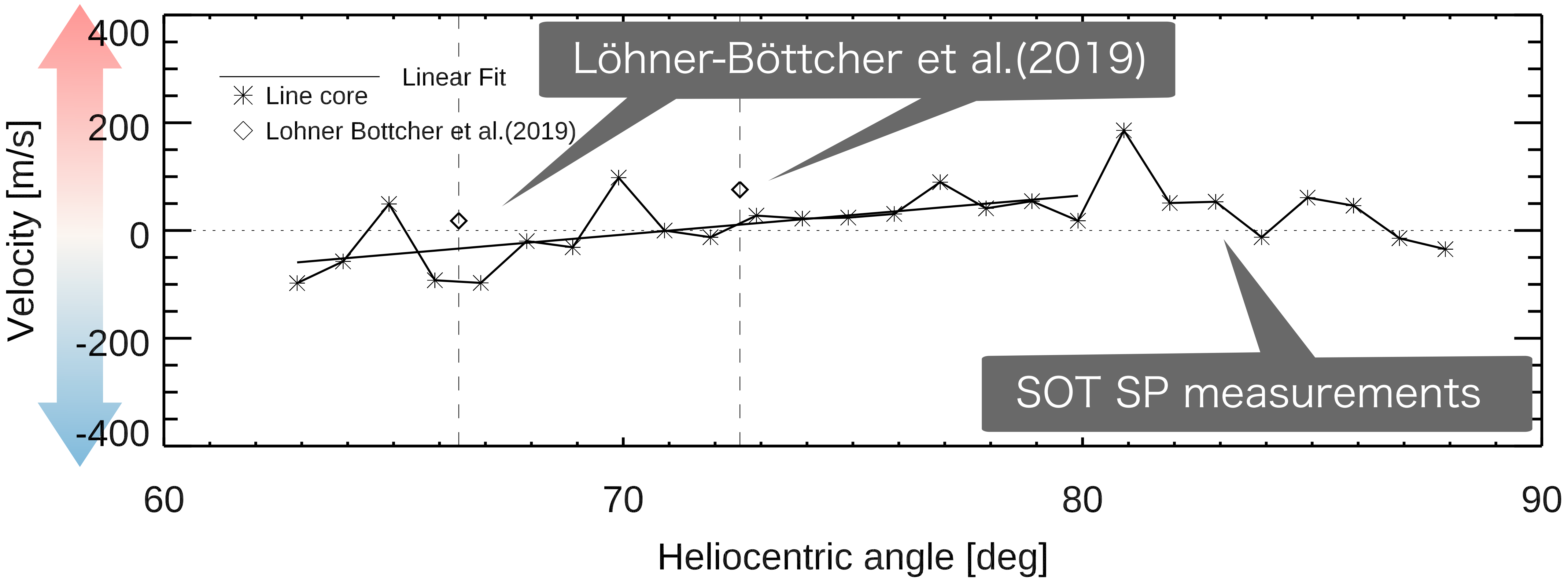
Method

Correction of the absolute Doppler velocity

- Observation with LARS at VTT on Tenerife (Löhner-Böttcher et al., 2019) shows 18 m/s at 66.4 deg in the heliocentric angle.
- Linear fitting of the SOT SP measurement between 63 deg and 80 deg shows -52 m/s at 66.4 deg.
- We apply an offset of 60 m/s.

Average Doppler shift as a function of the heliocentric angle



Classification of the absorption lines : granules, intergranular lanes, and magnetic regions

- Using thresholds of the continuum intensities and the polarization degree

Doppler velocities of the average absorption profiles

- The spectrum profiles are averaged at each heriocentric angle from 63 to 88 deg.

Center of gravity to get the Doppler velocities of the emission lines above the limb

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Results

Absorption

Mean (black solid line)

- The Doppler velocities vary from -200 m/s to 50 m/s toward the limb.
  - Consistent with observation up to 72 deg (Löhner-Böttcher et al., 2019)
- **Above 80 deg, the Doppler velocities become almost constant.**

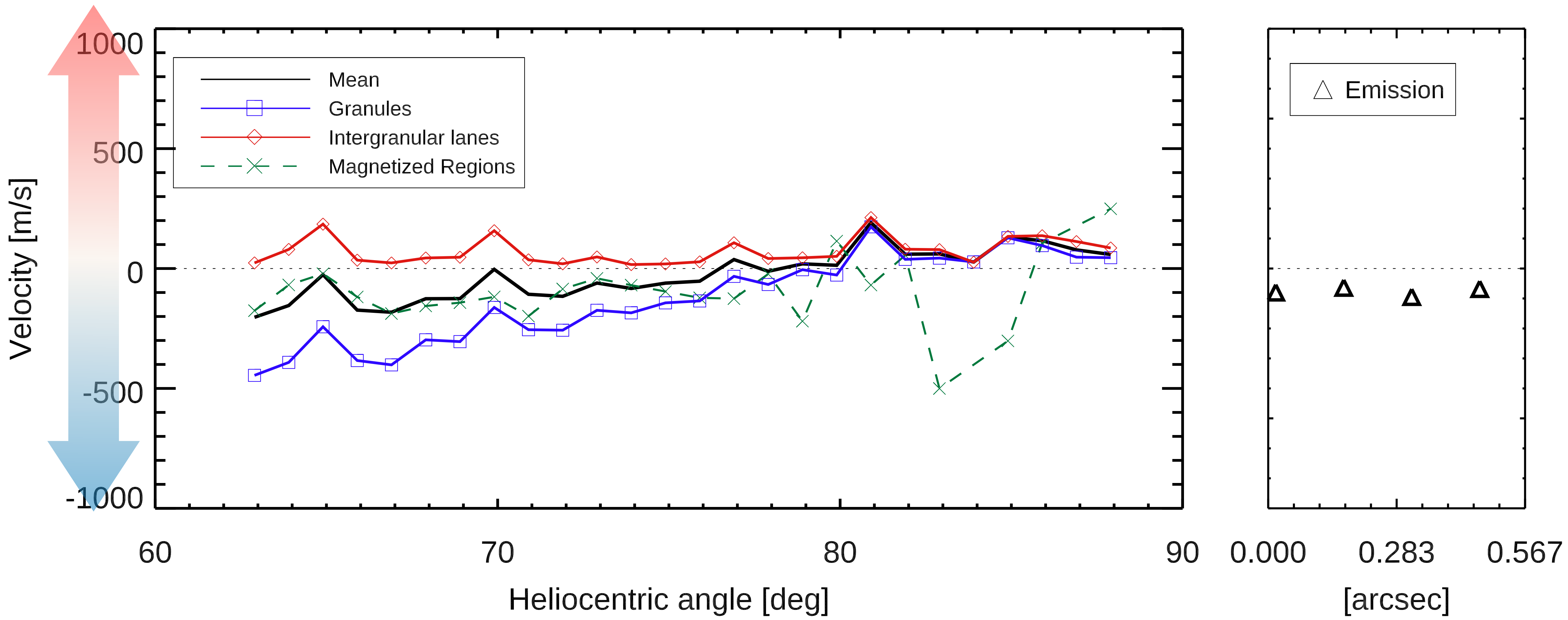
Granules (blue solid line)

- The Doppler velocities vary from -500 m/s to 50 m/s toward the limb.
  - The Doppler shift variation seen in the mean profiles is mainly due to the granules.
  - Consistent with simulation up to 80 deg (Cegla et al. 2018)

Intergranular lanes (red solid line)

- The Doppler velocities are almost constant.
  - **Inconsistent with the simulation** (Cegla et al. 2018), which showed that the Doppler velocities of intergranular lanes increase in blueshift.

Average Doppler shift as a function of the heliocentric angle



Emission above the limb

- The Doppler shifts are small compared with that of absorption line on the disk near the limb.
  - It could be simply explained by averaging of the velocity structure.

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Discussion and Future work

1	**The Doppler velocities became almost constant above 80 deg.** The staying constant could be explained by averaging over the randomly distributed horizontal flows. The small redshift of 50 m/s could be explained by the geometrical effect.
2	**The Doppler velocities of intergranular lanes are inconsistent with the simulation.** The spatial resolution may not be enough so that the bright granules obscures the Doppler shifts in the intergranular lanes.
3	**There is no velocity difference between the granules and the intergranular lanes at the limb.** The contrast of the continuum intensity between granules and intergranular lane decreases, so it is difficult to distinguish them.

Next : We will use a radiative MHD simulation in the photosphere and line synthesis to reproduce the observed results of the Doppler shifts near the limb.

References

Cegla, H.M., et al. 2018, ApJ, 866, 55

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Lites, B.W., and Ichimoto, K., 2013, Solar Phys, 243, 3

Lites, B.W., et al. 2010, ApJ, 713, 450

Löhner-Böttcher, J., et al. 2019, A&A, 624, A57

Thank you for listening!