Solar velocity field determined tracking coronal bright points

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Agenda

1. **Introduction**
2. Data
3. Methods of data reduction
4. Results and comparisons
5. Discussion and conclusions
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Introduction

Two concepts:

- Solar velocity field
- Coronal bright points

Solar velocity field

- Solar differential rotaion
  $\Omega = A + B \sin^2 \psi + C \sin^4 \psi$
- Residual rotation velocity / torsional oscillactions, $\Delta\omega_{rot}$ = Δvrot
- Meridional motions, ω_{mer} = vmer
- correlation $\Delta\omega_{rot}$ and ω_{mer}
- Reynolds stress, $Q = < \Delta\omega_{rot} \cdot \omega_{mer} >$
- Large scale motions, L > 50 000 km
- Random walk, diffusion of magnetic elements

Coronal bright points

- magnetic tracers associated with bipolar magnetic features; 1/3 of them lie over ephemeral regions (new emerging regions of magnetic flux) and the remaining 2/3 lie above cancelling magnetic features (consisting of opposite polarity fragments that approach and disappear)
- Skylab, Yohkoh, **SOHO**, TRACE, Hinode, **SDO**

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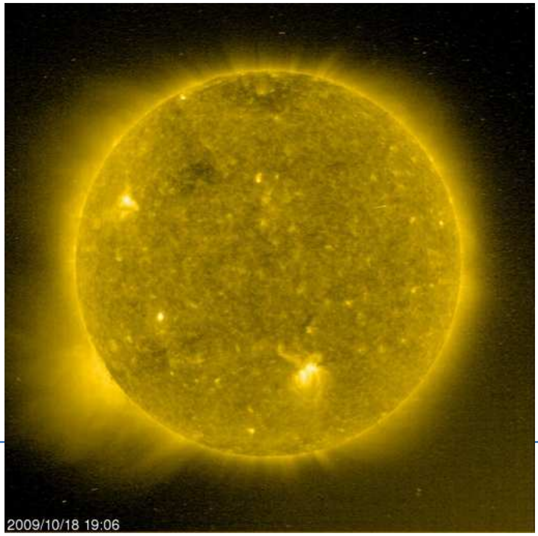
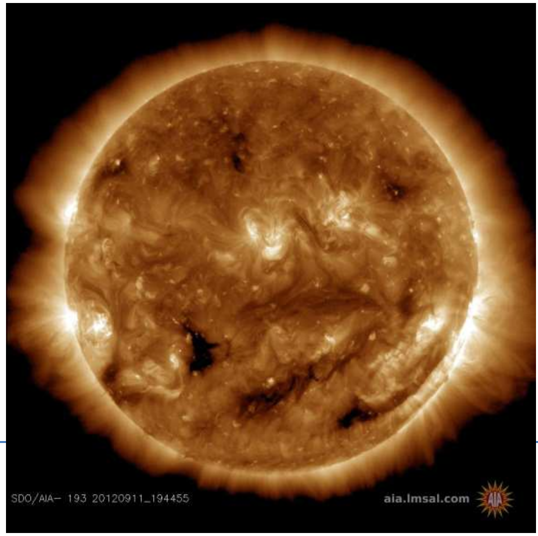
Data: SOHO/EIT, SDO/AIA

- Solar and Heliospheric Observatory (NASA/ESA), EIT (1998-2006, EUV, Fe XV, 28.4nm, 6h, 2.6”)
  - Interactive (dataset 1 < 11 images, dataset 2 < 24 images)
  - Automatic (3 images)
- Solar Dynamics Observatory (NASA), AIA (two days 2011, EUV, soft X, 10 min, 0.6”)





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Methods of data reduction

- Measured positions -> heliographic coordinates -> latitudinal and longitudinal velocity components
  - Daily shift method
  - Tracing, linear least square fit
- Filters (0.85 R, $8 < \omega < 19$ °/day, $-4 < v_{mer} < 4$ °/day, …)
- Synodic rotation rates -> siderereal rotation velicities (Skokić et al., 2014)
- Height correction (Roša et al., 1998; Brajša et al., 2004)

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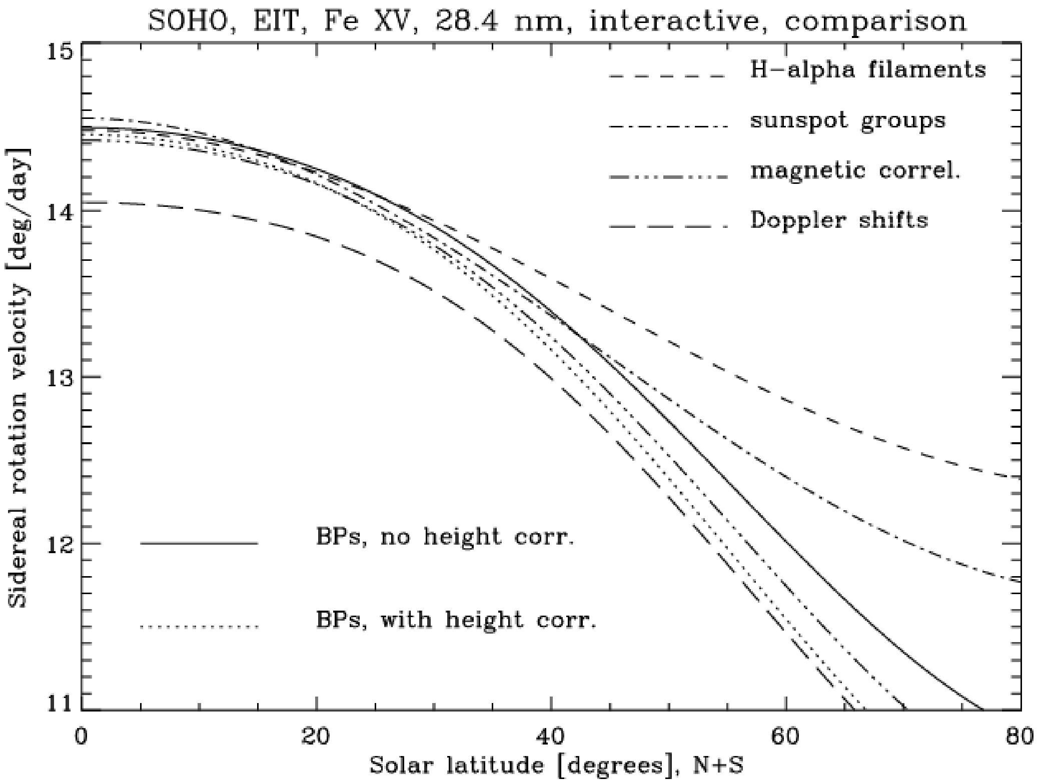
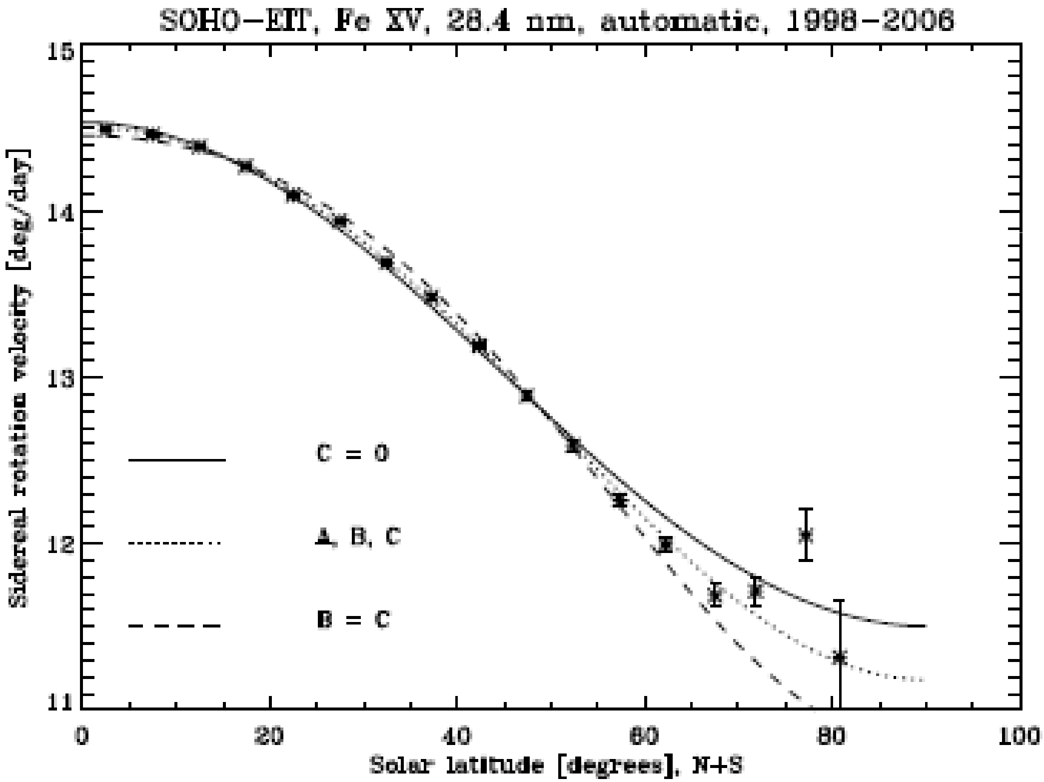
Solar differential rotation – SOHO/EIT

Brajša et al. (2004)



Solar differential rotation – SOHO/EIT

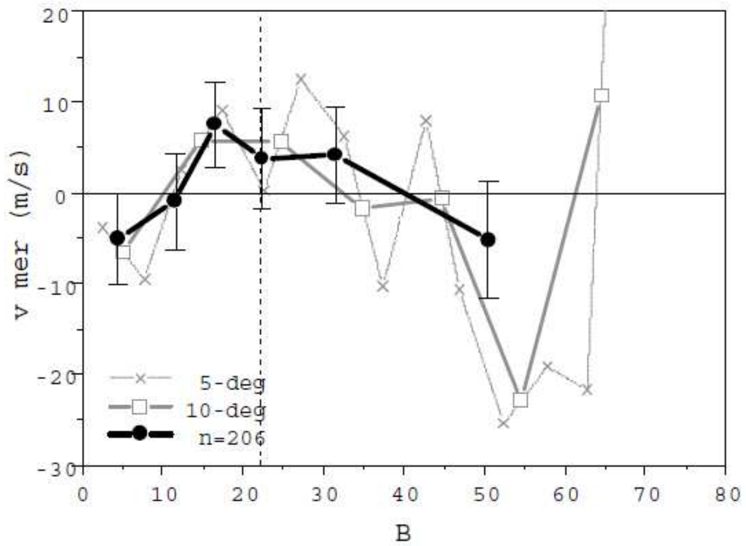
Wöhl et al. (2010)



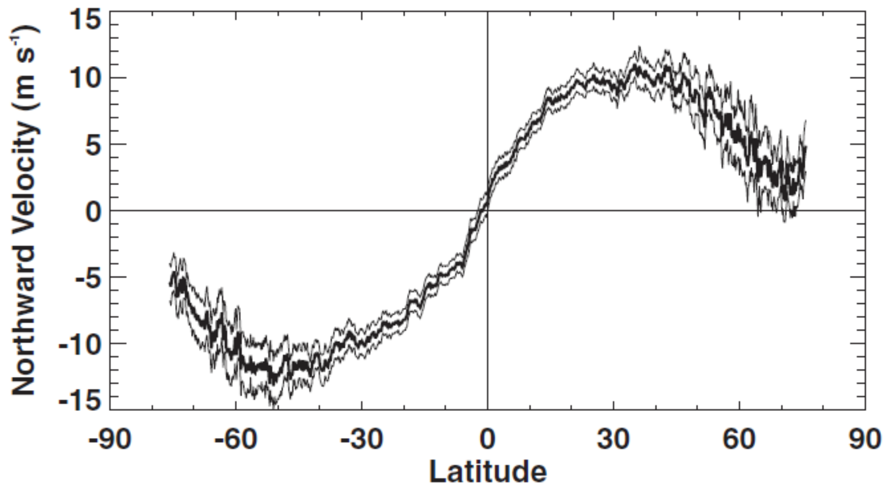
Meridional motions - SOHO/EIT

- Up to ≈ 10 m/s
- However, errors of the same order of magnitude
- Results are dependent on the method
- Cycle dependence: larger velocity in minimum of activity (Hathaway & Rightmire, 2010)

SOHO-EIT: Vršnak et al. (2003), interactive

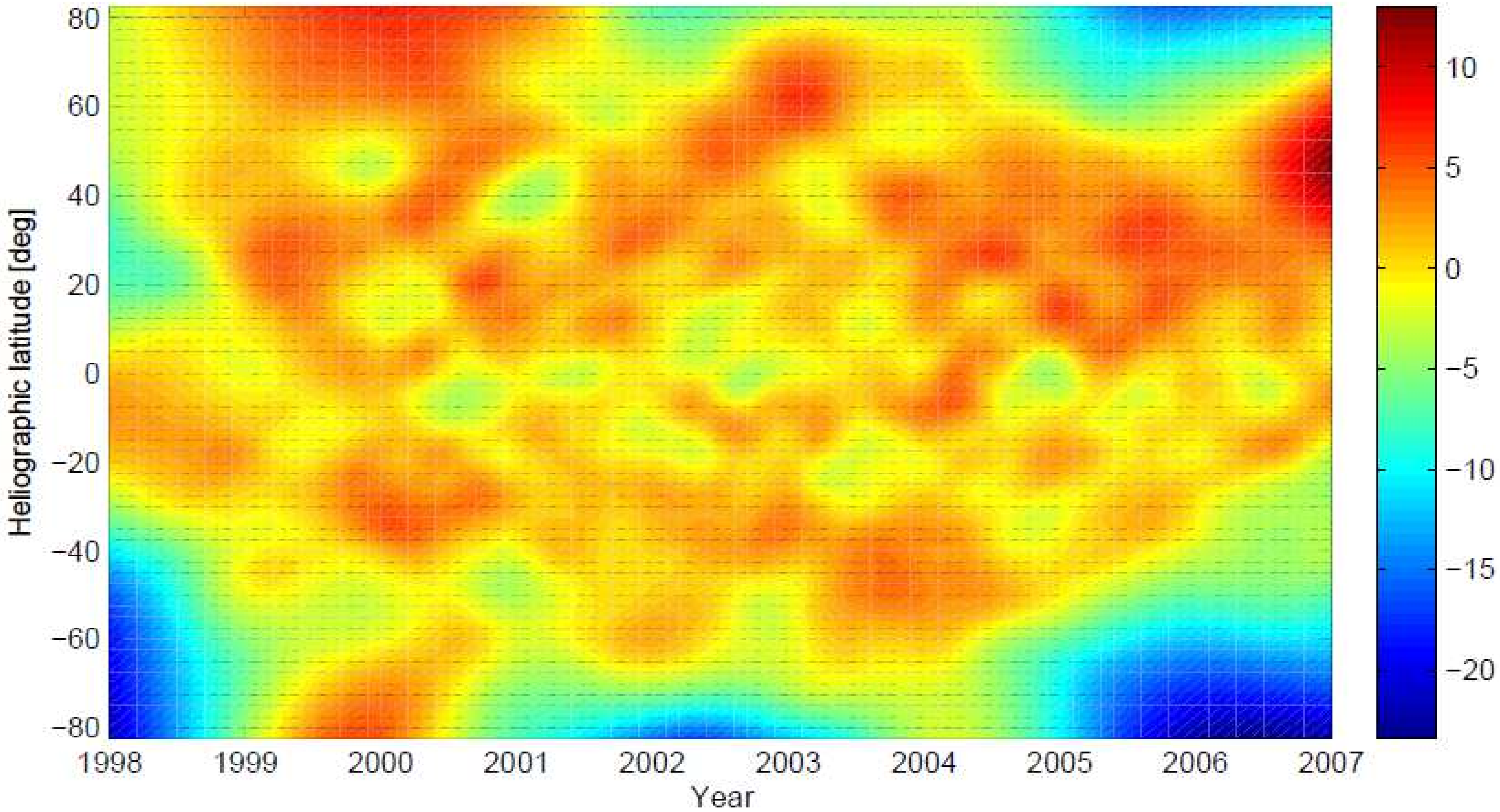


Hathaway & Rightmire (2010)



Meridional motions – SOHO/EIT

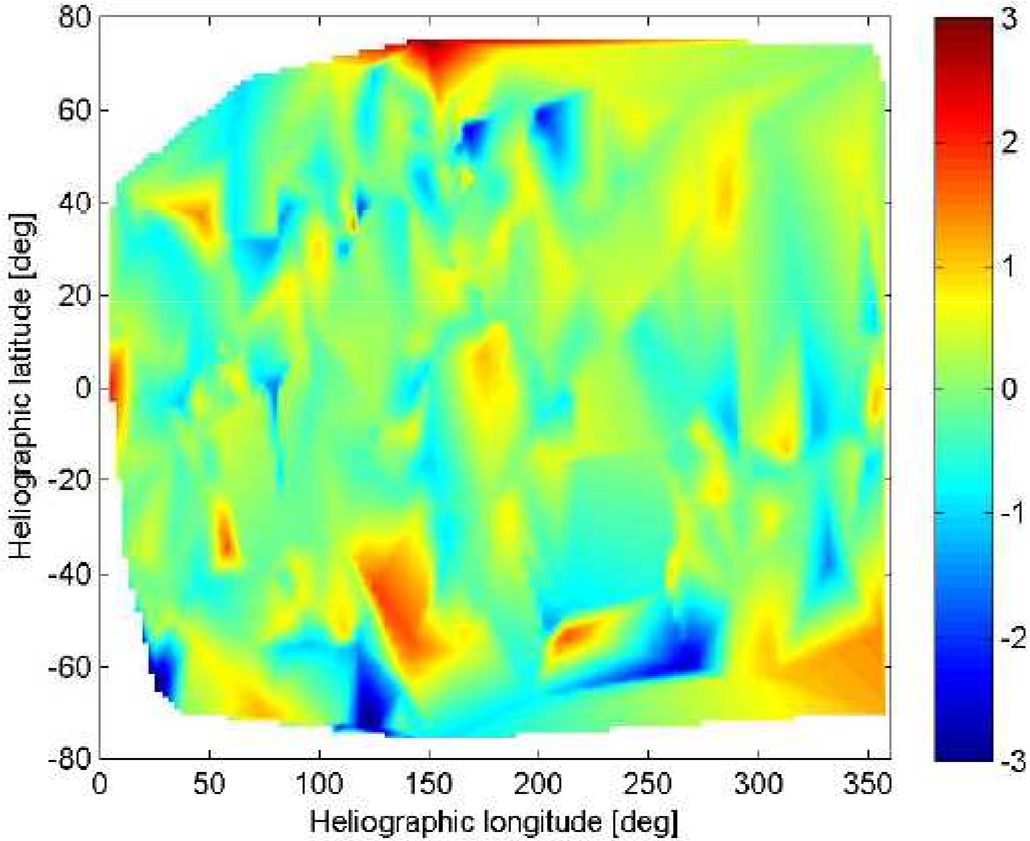
automatic method, vmer ~ 10 m/s



Meridional motions – SOHO/EIT

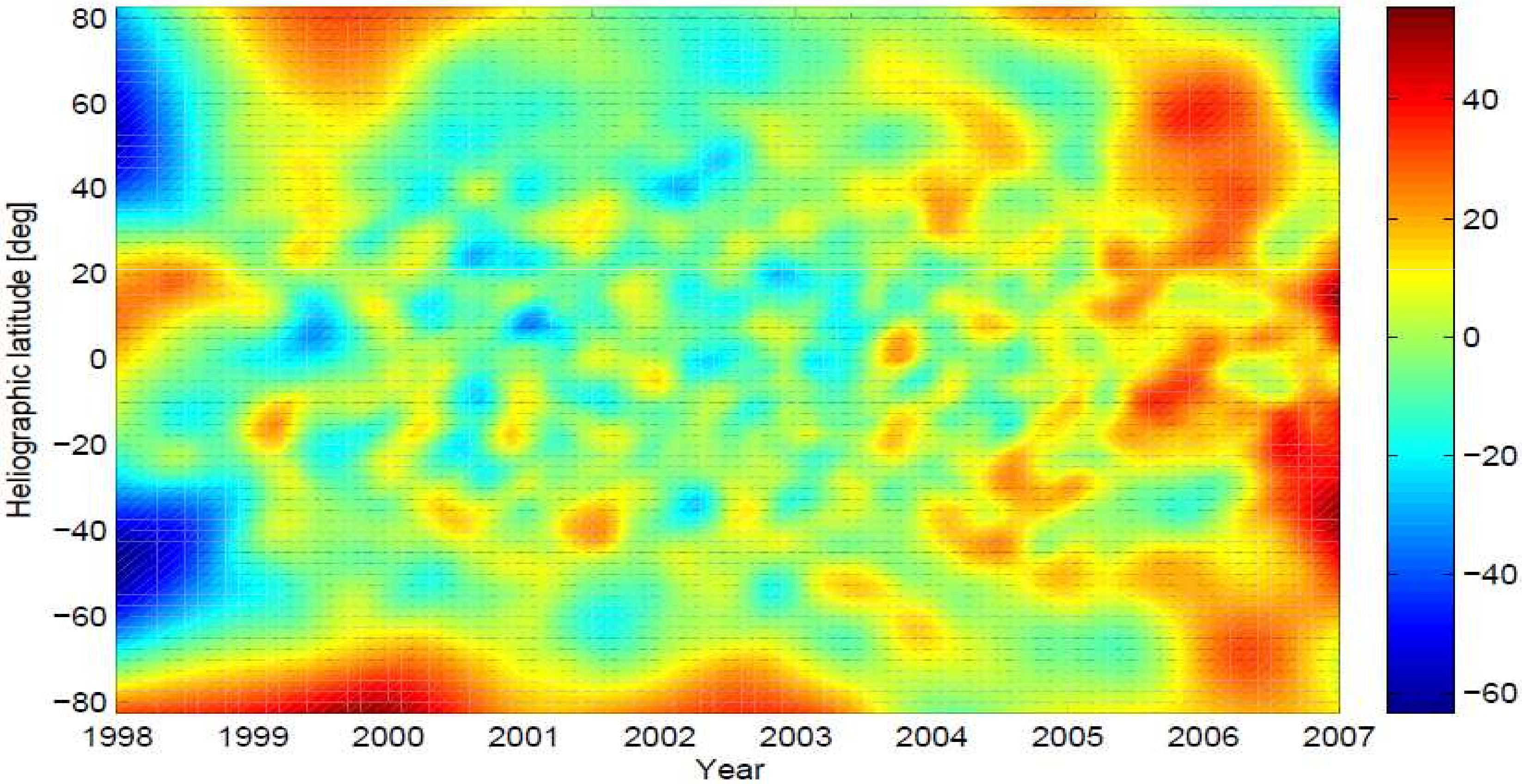
Non-axisymmetric motions (October - November 1999), deg/day

1 deg/day = 140 m/s (interactive method)



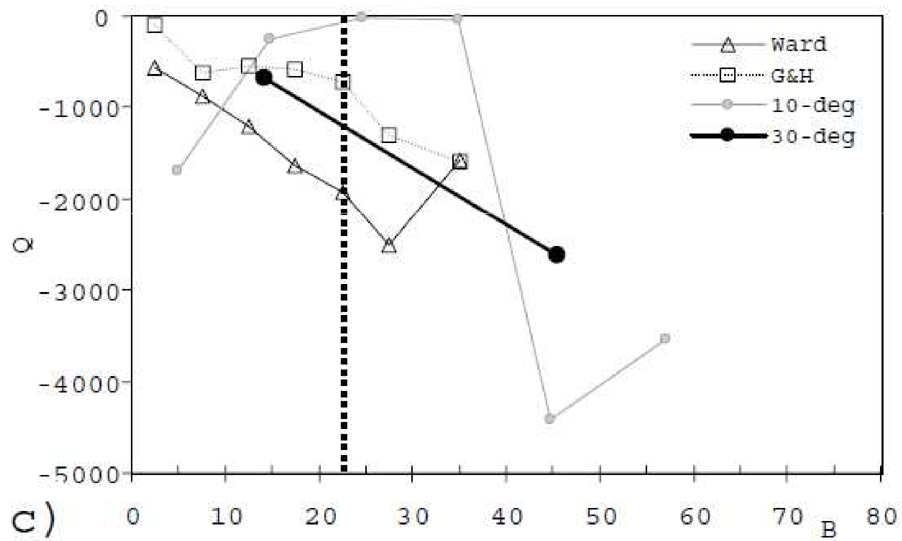
Torsional oscillations – SOHO/EIT

automatic method, Δvrot in m/s



Reynolds stress SOHO/EIT

- Interactive method
- Correlation of the velocity components of sunspots: sign and amount consistent with the observed solar differential rotation (Ward, 1965)
- Similar results obtained later with sunspots (Howard & Gilman, 1986) and CBP (Vršnak et al., 2003)
- Laditude dependent
- New research needed to obtain more reliable results

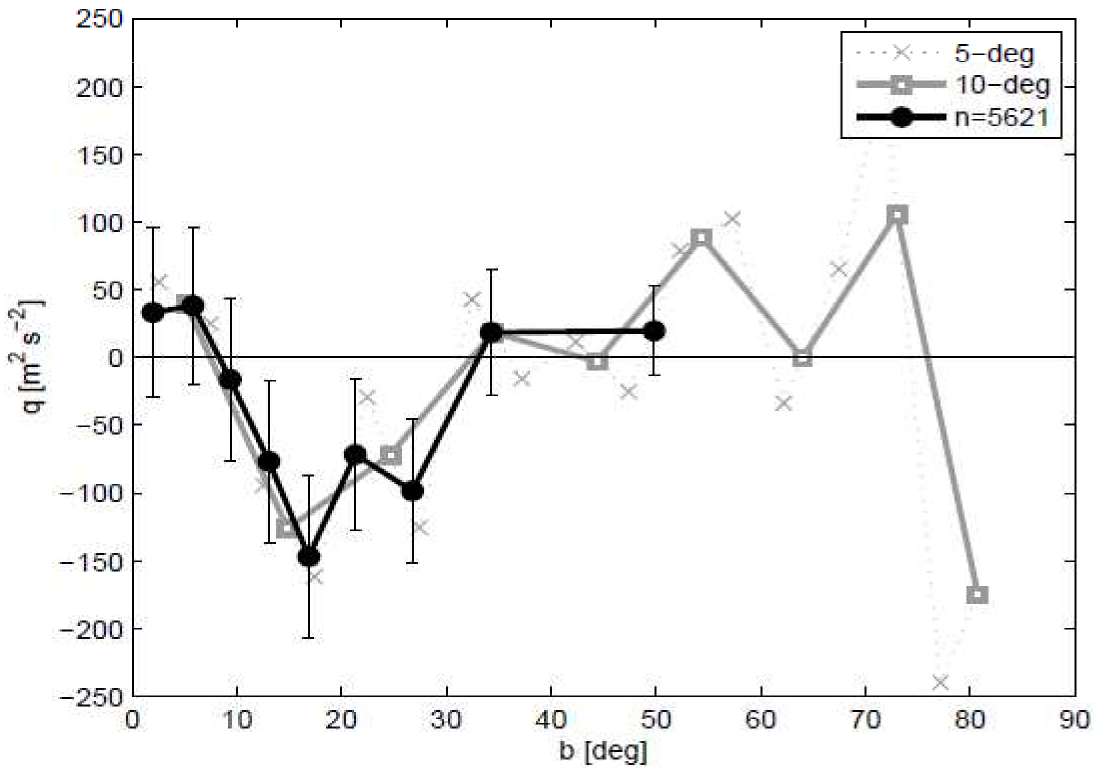


Velocity correlations – SOHO/EIT

Automatic method

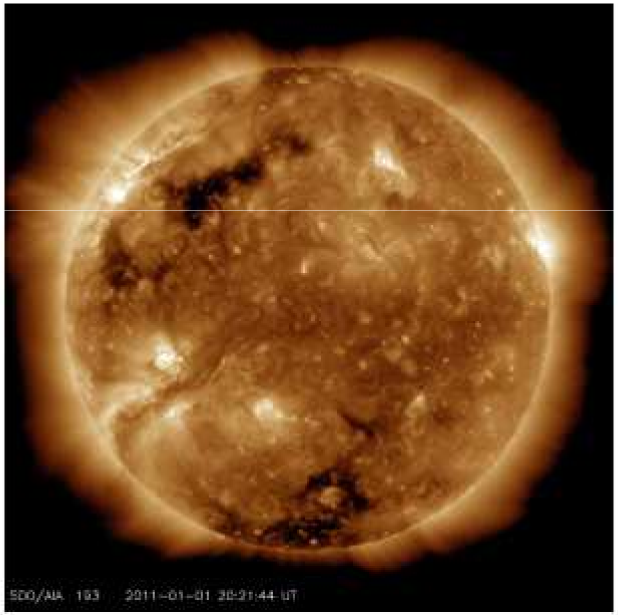
Velocity correlation, vmer = (-0.003 ± 0.001) Δvrot

Reynolds stress, ~ -100 $(m/s)^2$, min. at b≈20°

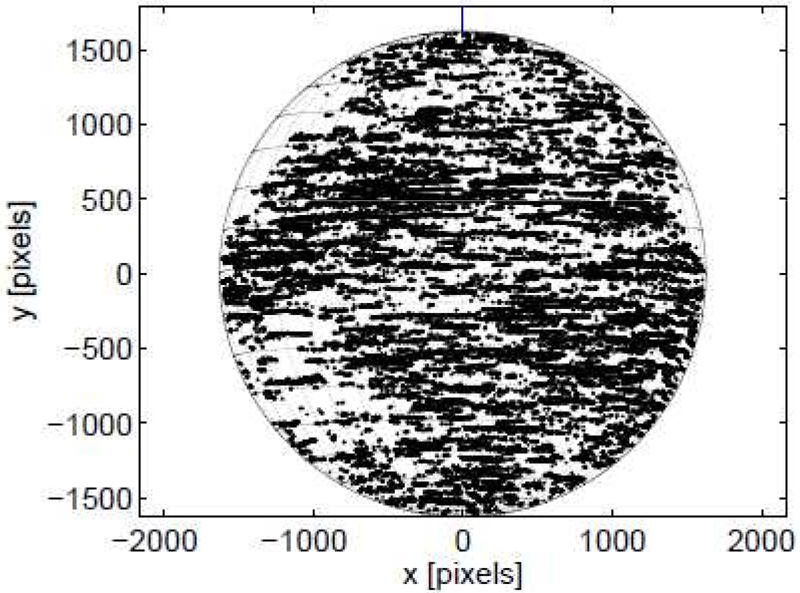


SDO/AIA: 19.3 nm

2 days, ~ 50 000 measurements, segmentation algorithm

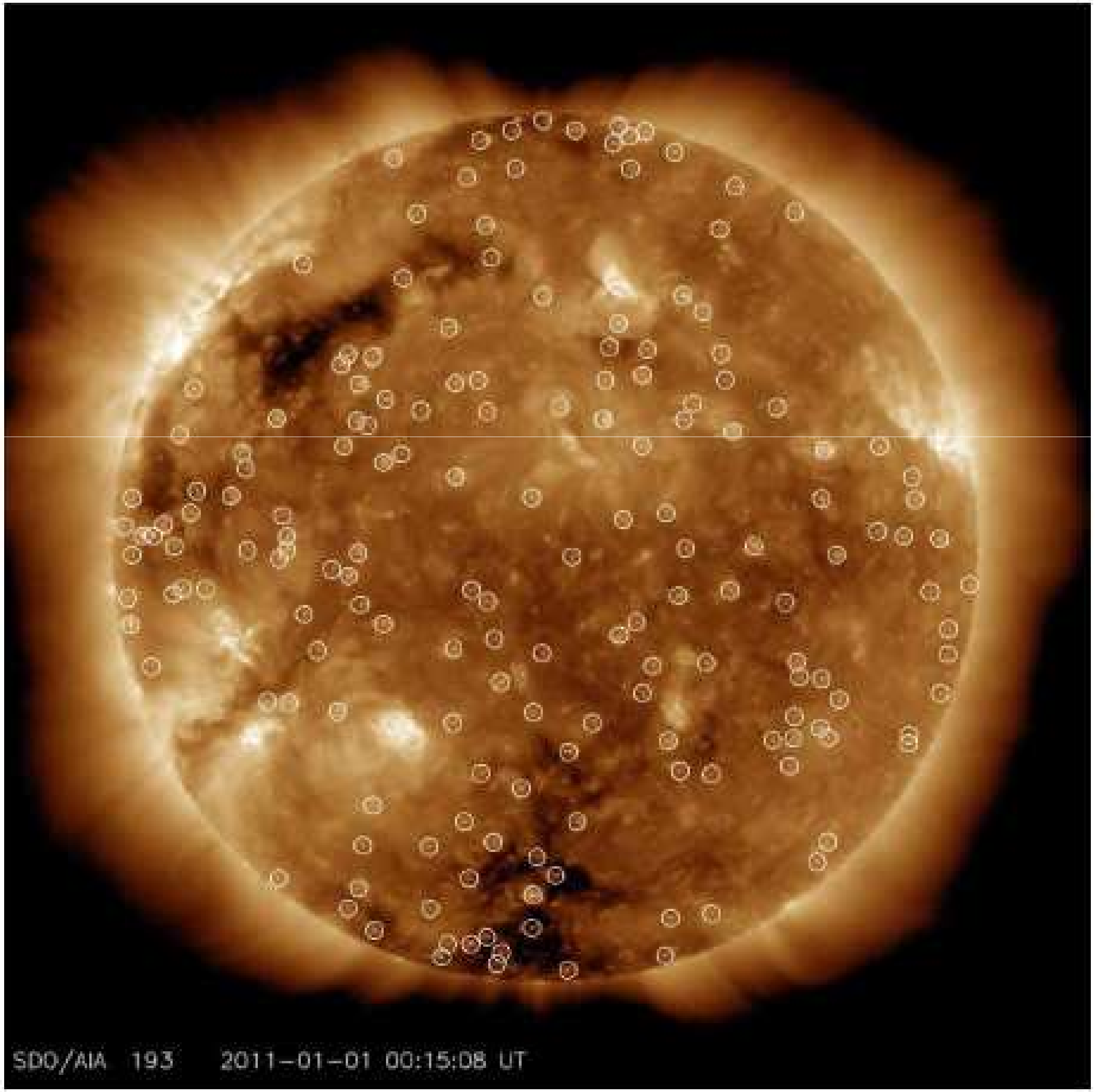


(a)

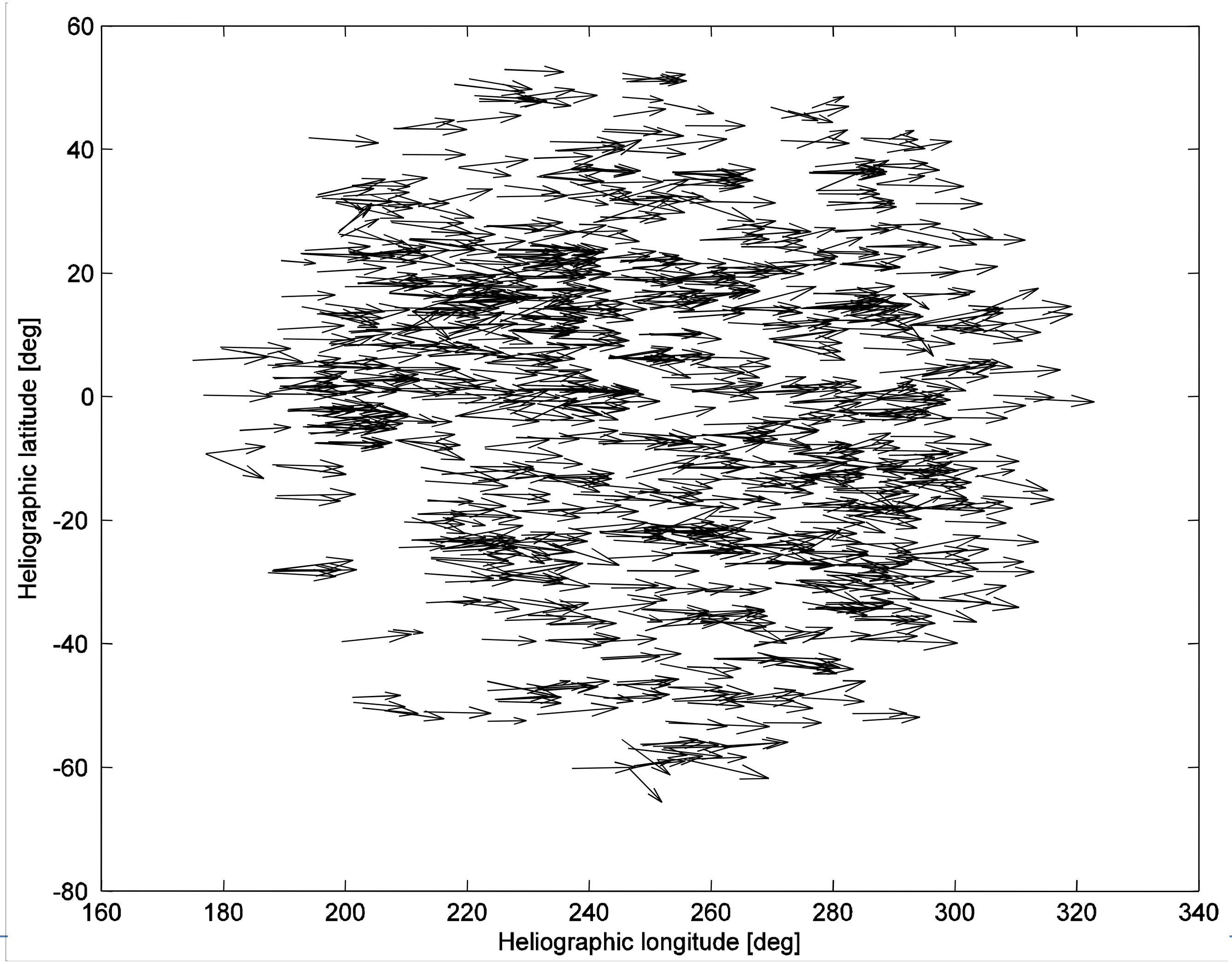


(b)

SDO/AIA: 19.3 nm

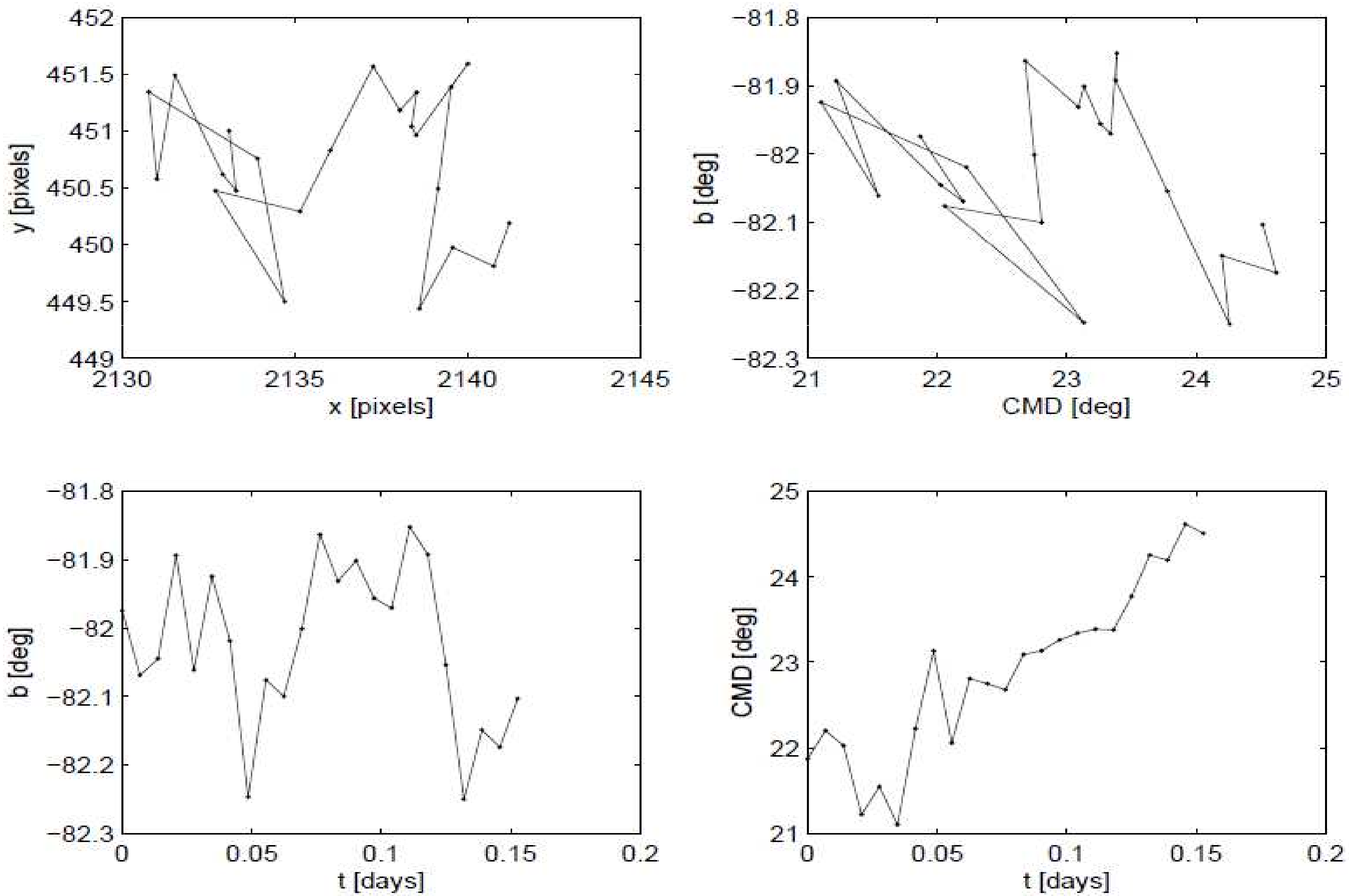


SDO/AIA: 19.3 nm



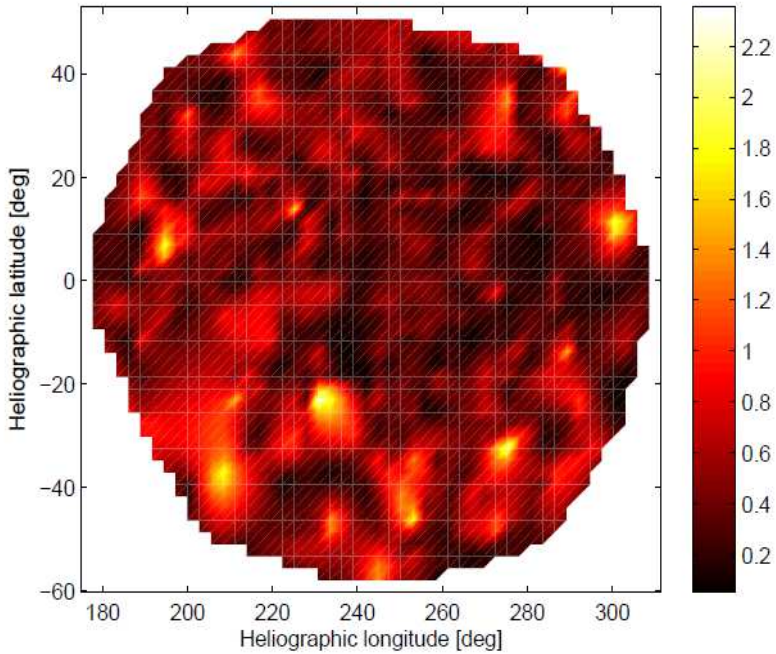
SDO/AIA

Proper motions of CBPs , min. 10 measurements

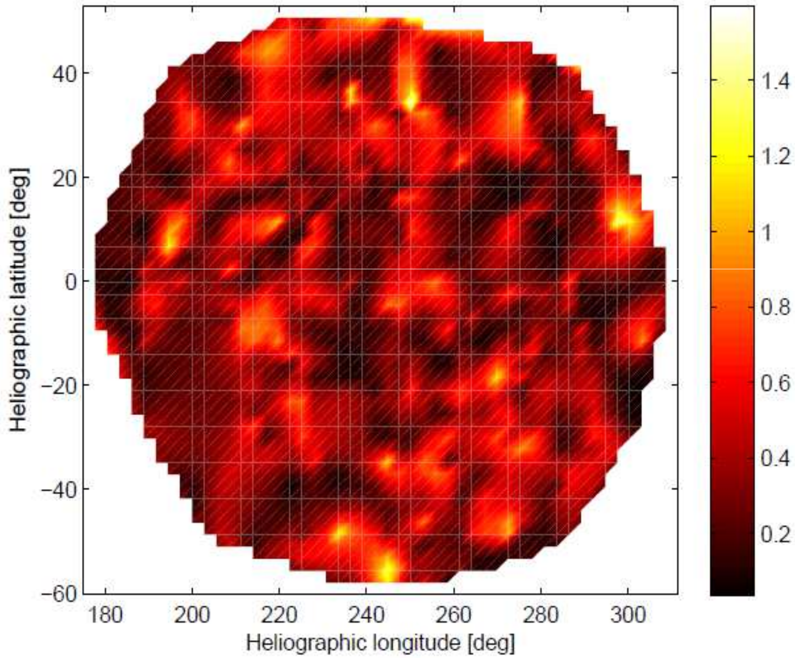


SDO/AIA

Velocity errors



meridional



rotational

SDO/AIA

Differential rotation (Sudar et al., 2014a)

A=14.47 ± 0.10

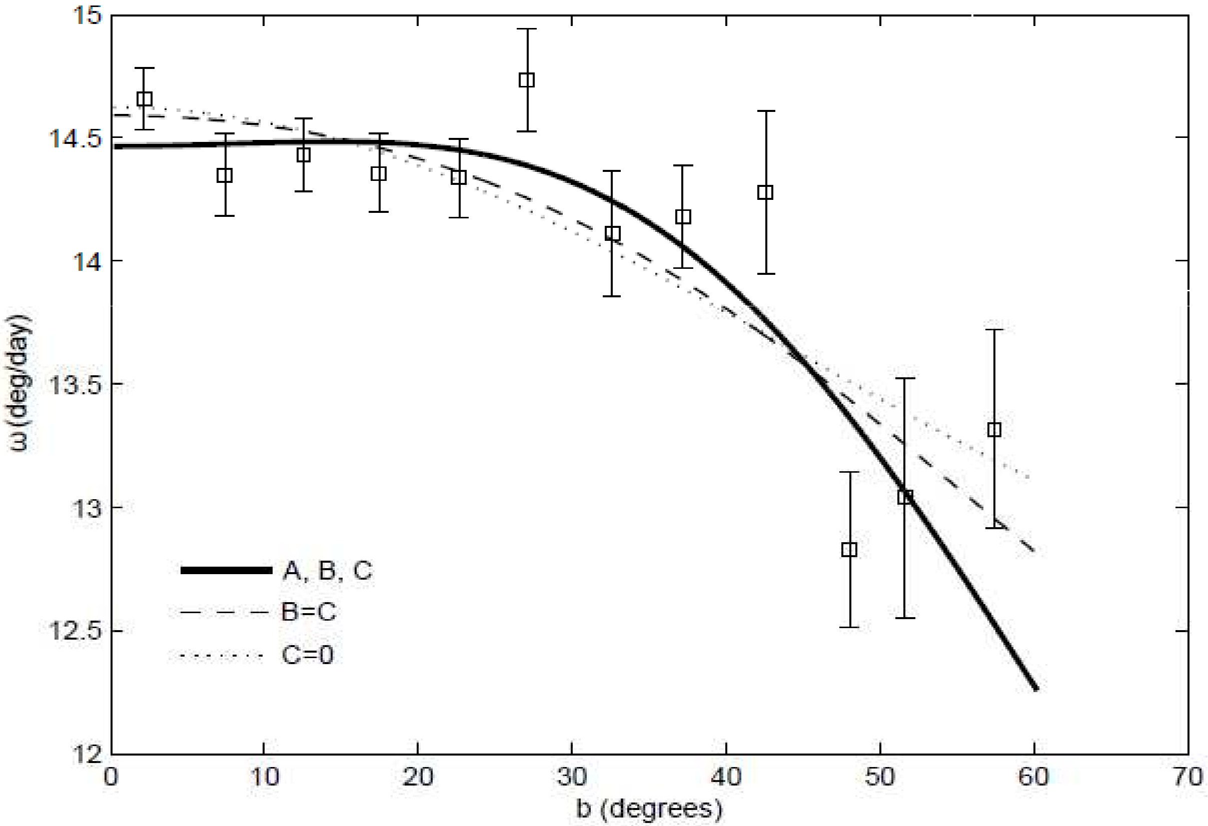
B=0.6 ± 1.0

C=-4.7 ± 1.7

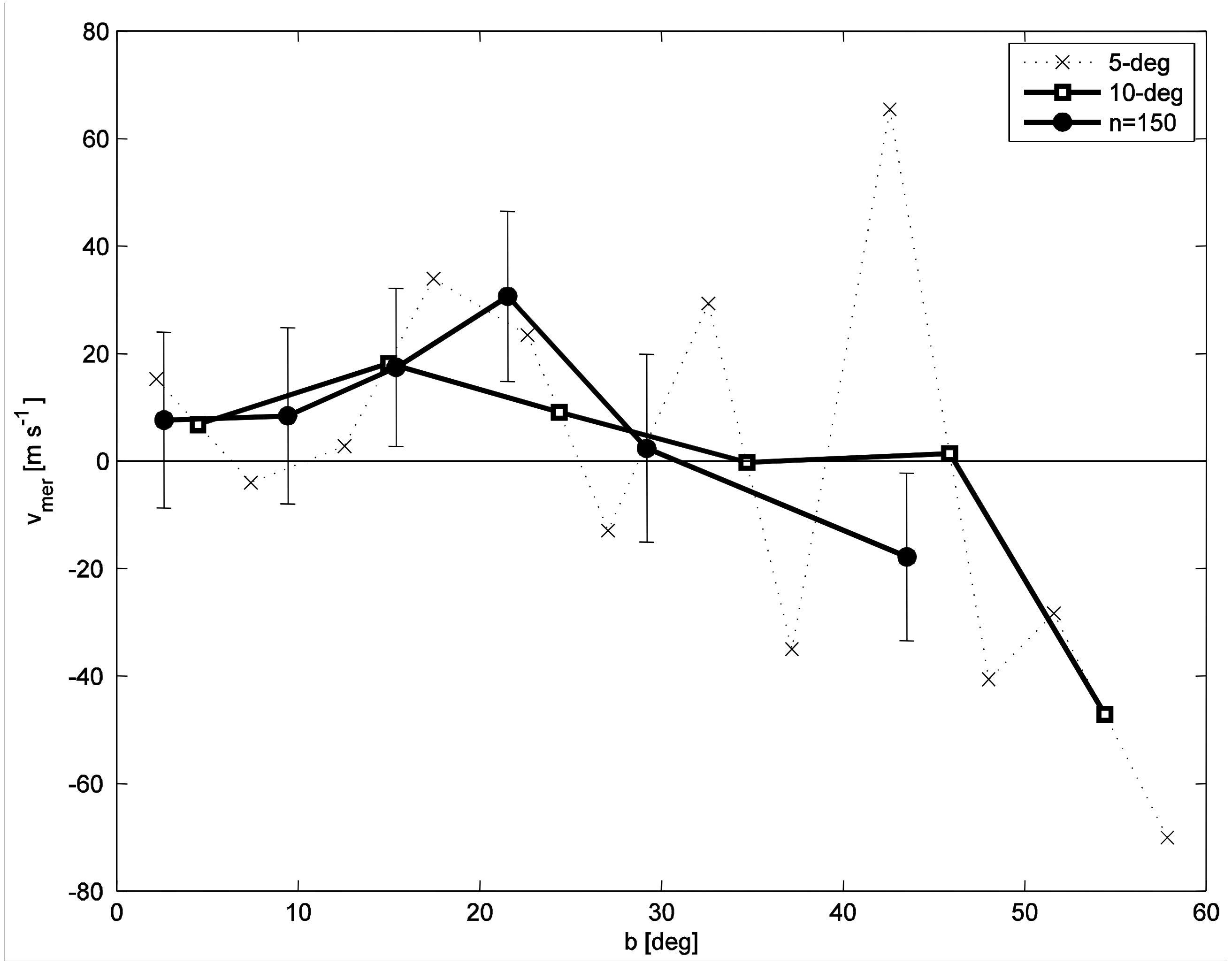
C=0

A=14.62 ± 0.08

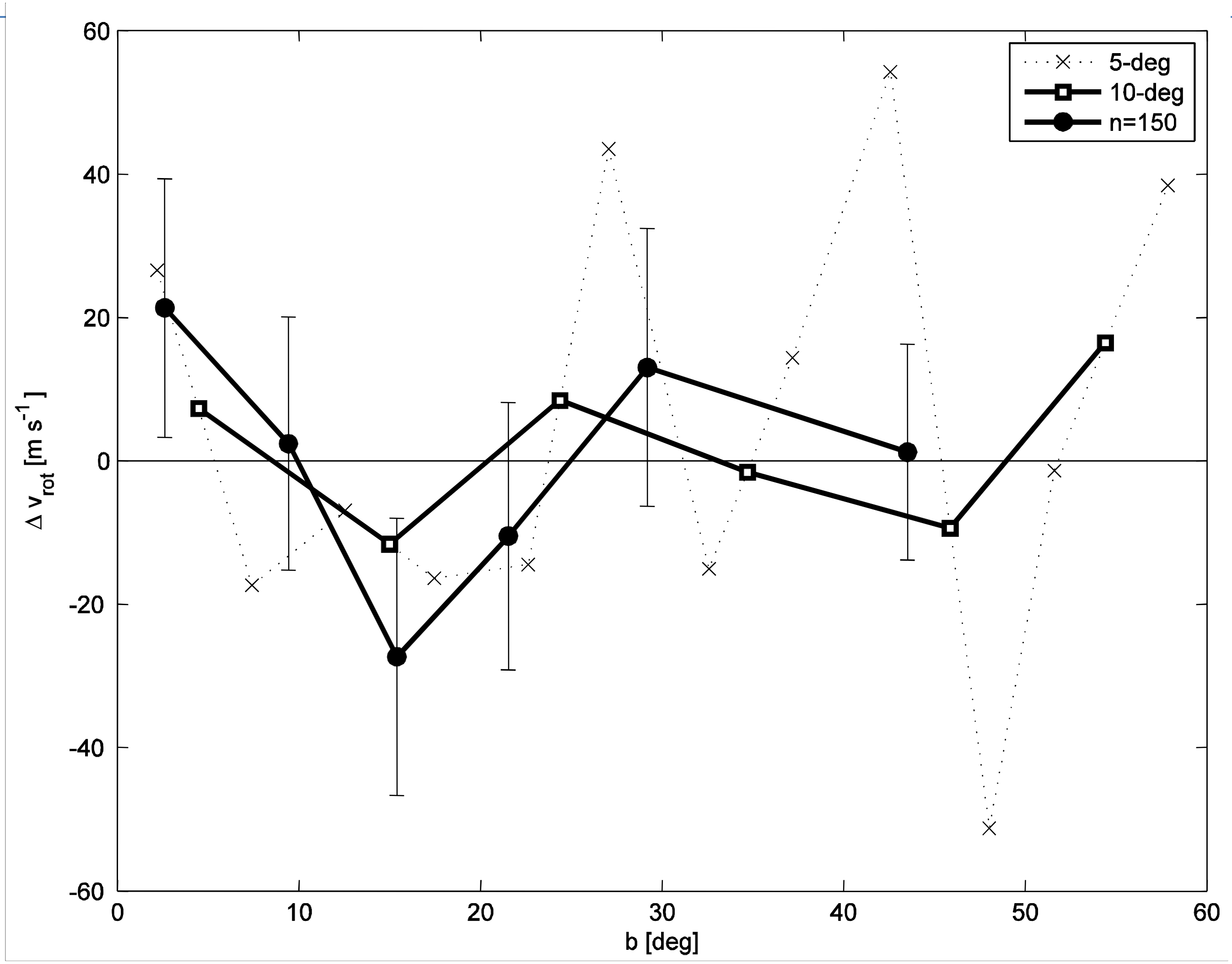
B=-2.02 ± 0.33



SDO/AIA: meridional motions



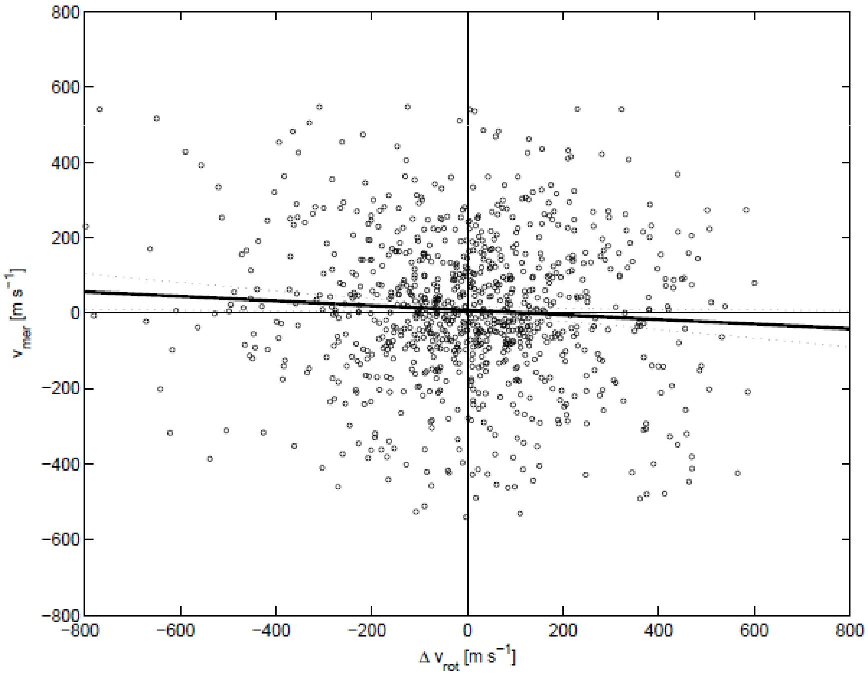
SDO/AIA: rotation velocity residual

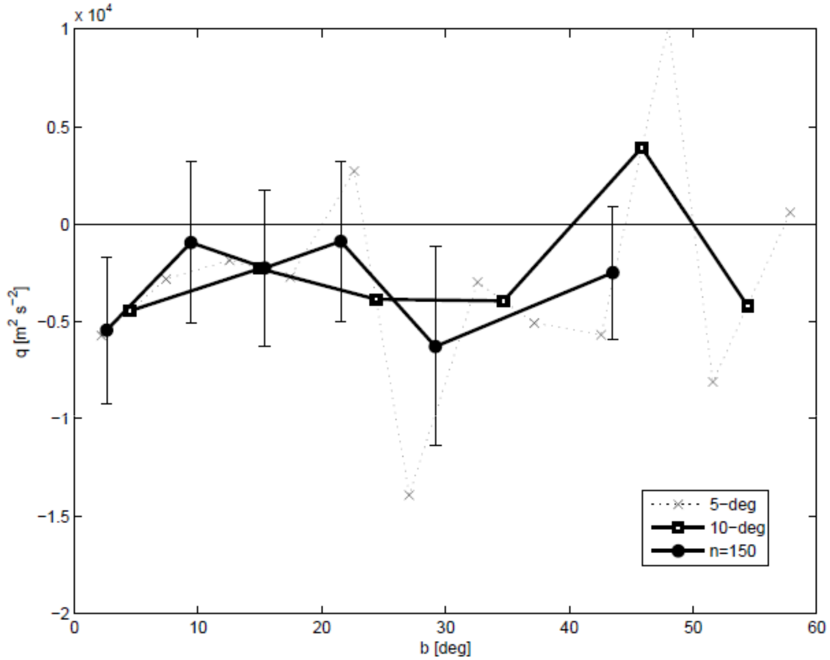


SDO/AIA

Reynolds stress,

vmer=(-0.06 ± 0.03)Δvrot

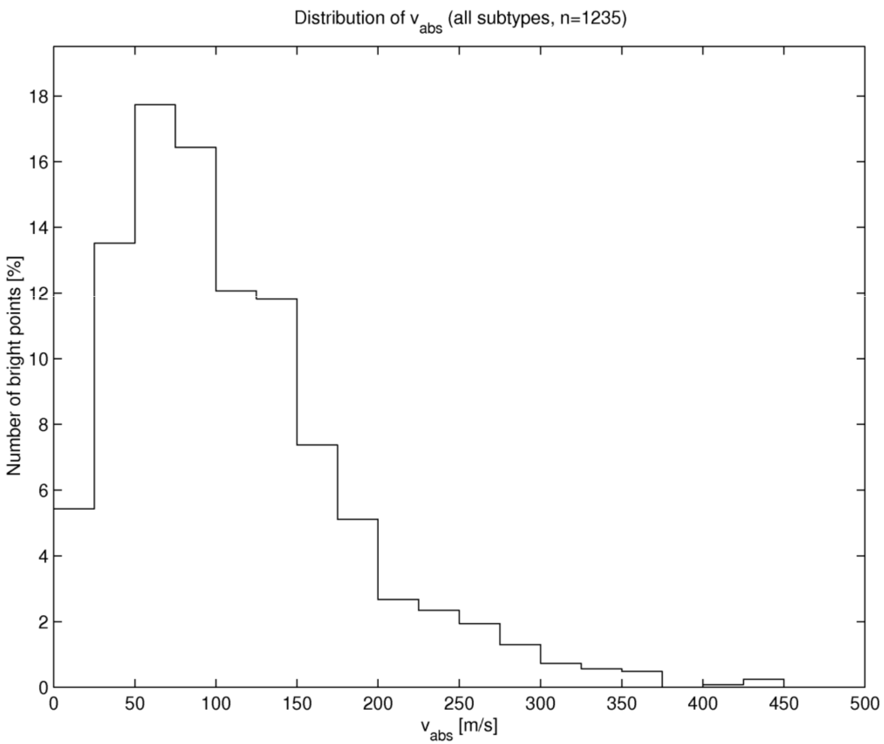


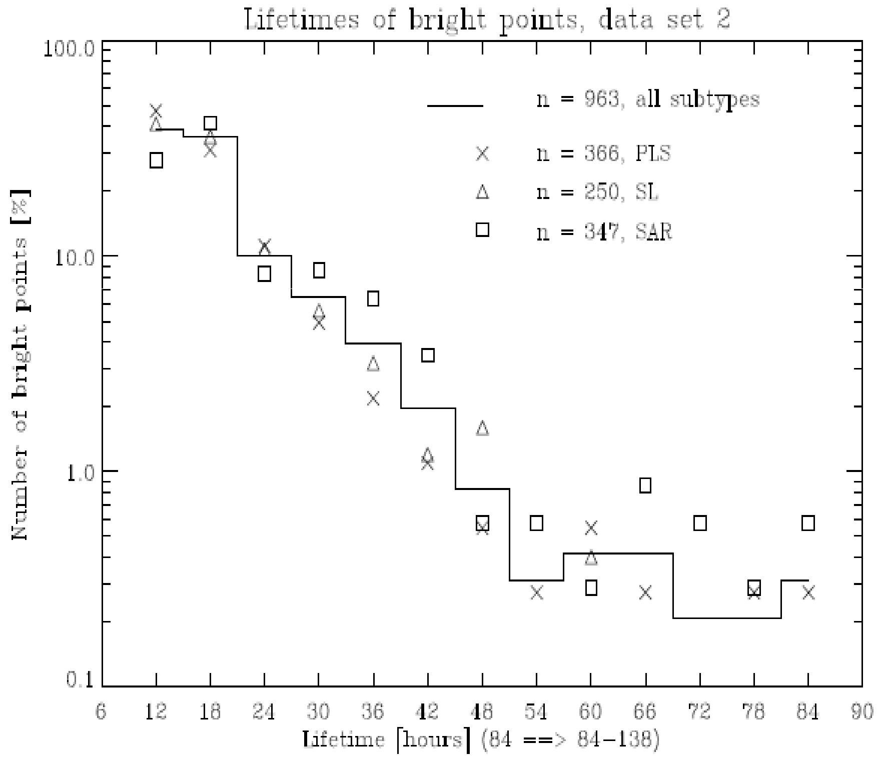


Q ~ -5000 m²/s²

Absolute velocities and lifetimes

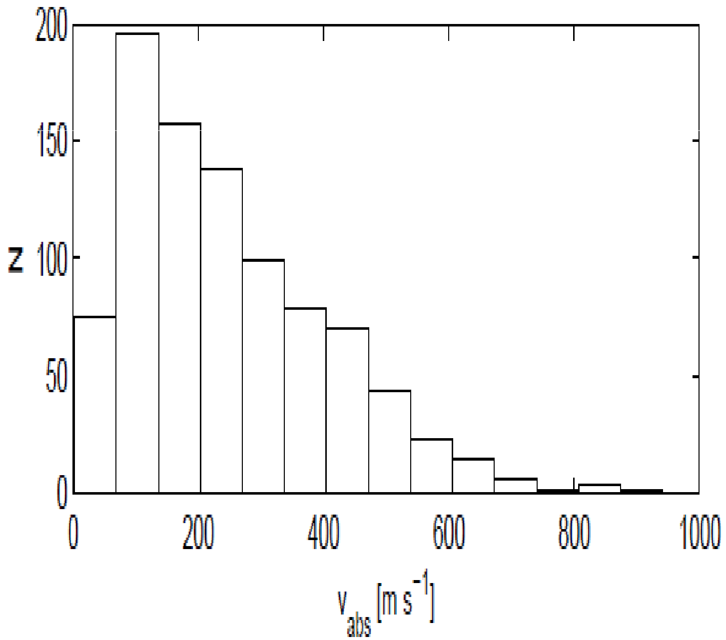
- SOHO/EIT, 1998-1999, interactive method (Brajša et al., 2008)

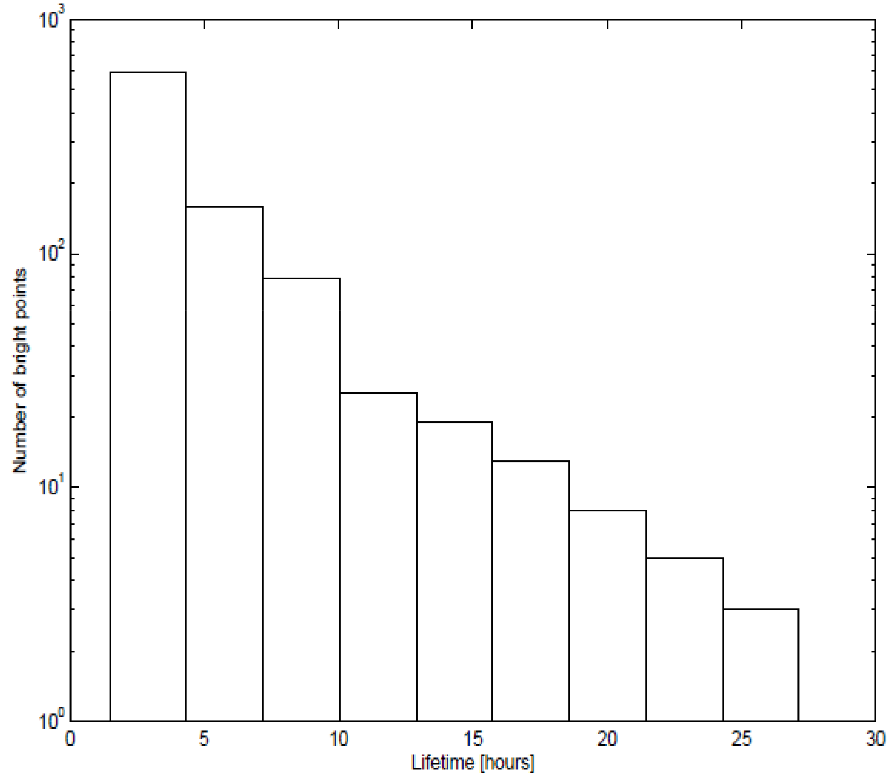




Absolute velocities and lifetimes

- SDO/AIA (1-2 January 2011)





Random walk model

SOHO/EIT (Brajša et al., 2008)

- lifetime ≈ 12-60h
- v_abs ≈ 50-70 m/s
- mean free path ≈ 3000-15000 km
- diffusion coefficient of random walk, D ≈ 150-250 km^2/s

$$D = \frac{\langle l^2 \rangle}{4\tau}.$$

SDO/AIA

- lifetime ≈ 4-25h
- v_abs ≈ 100-250 m/s
- mean free path ≈ 3000-8000 km
- diffusion coefficient of random walk, D ≈ 200-250 km^2/s

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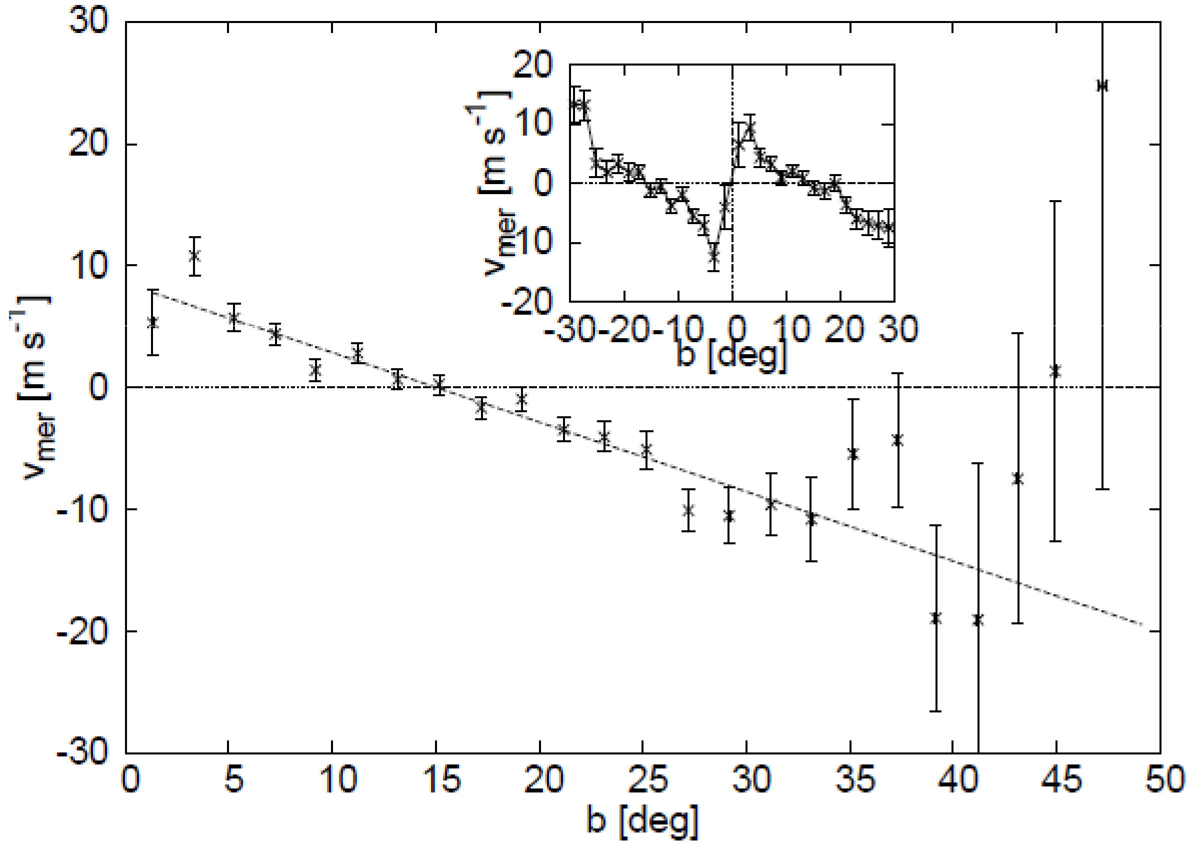
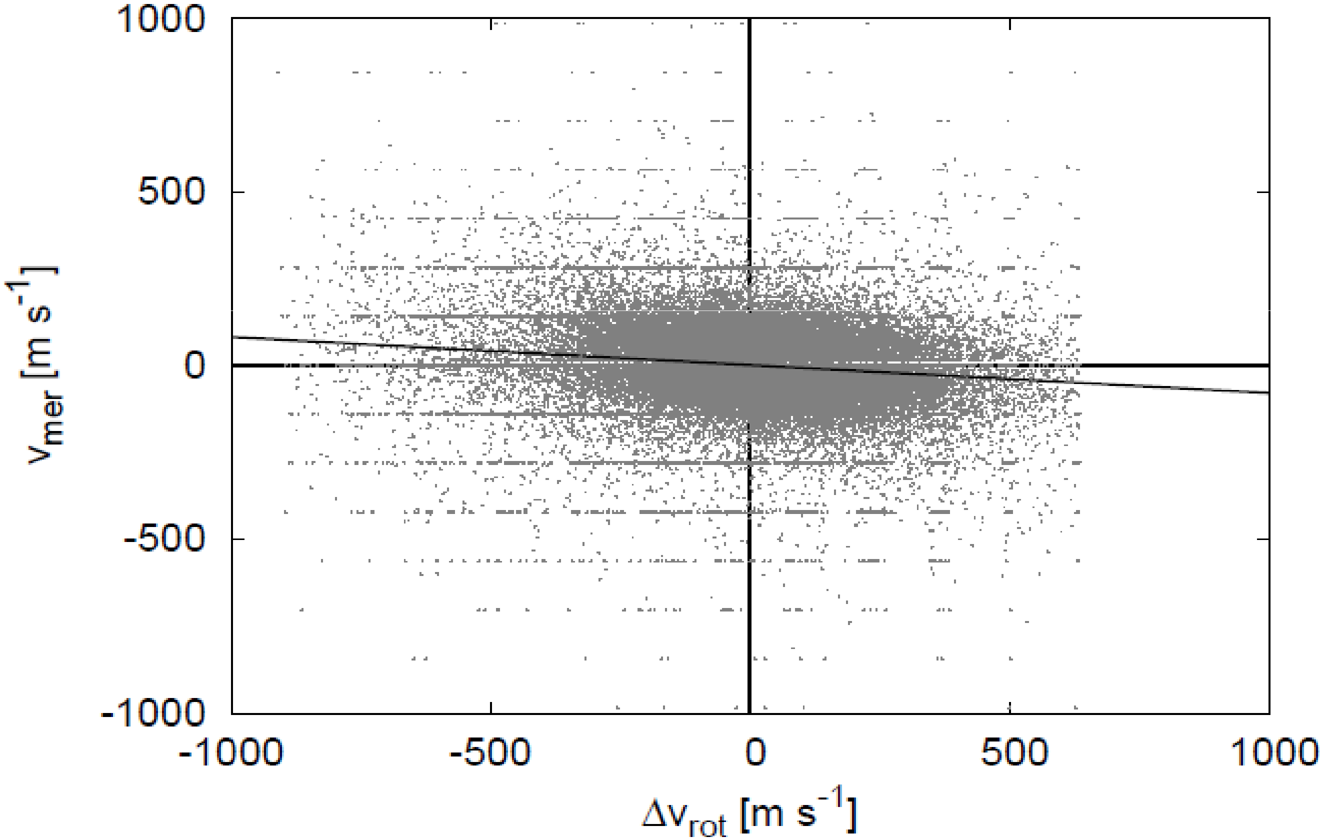
Sunspot groups: Extended Greenwich

- Meridional motions (Sudar et al., 2014b)



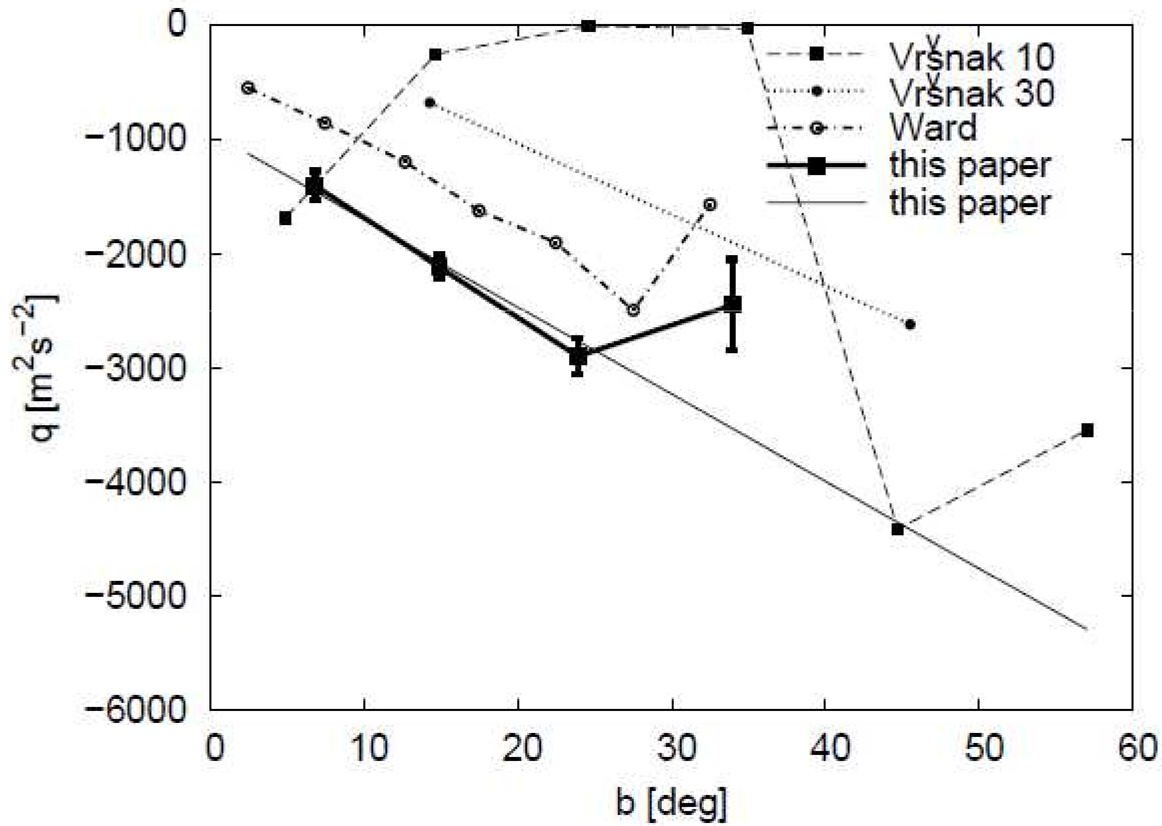
Sunspot groups: Extended Greenwich

- Correlation: *vmer* = (−0.0804 ± 0.0017) · Δ*vrot [m/s]*



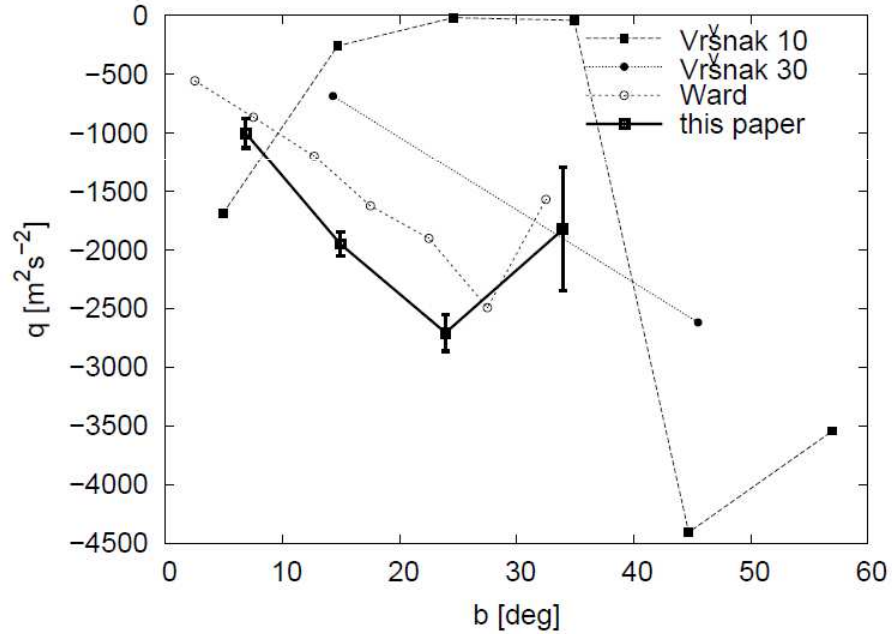
Sunspot groups: Extended Greenwich

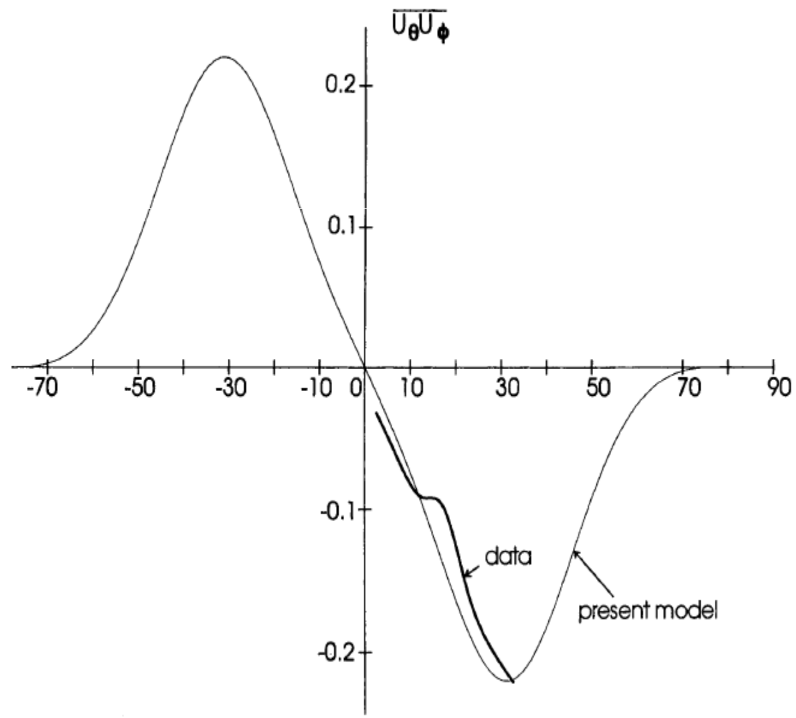
- Reynolds stress, ≈ -2000 $(m/s)^2$, min. at b≈30°



Reynolds stress: comparison with theoretical models

Canuto et al. (1994)

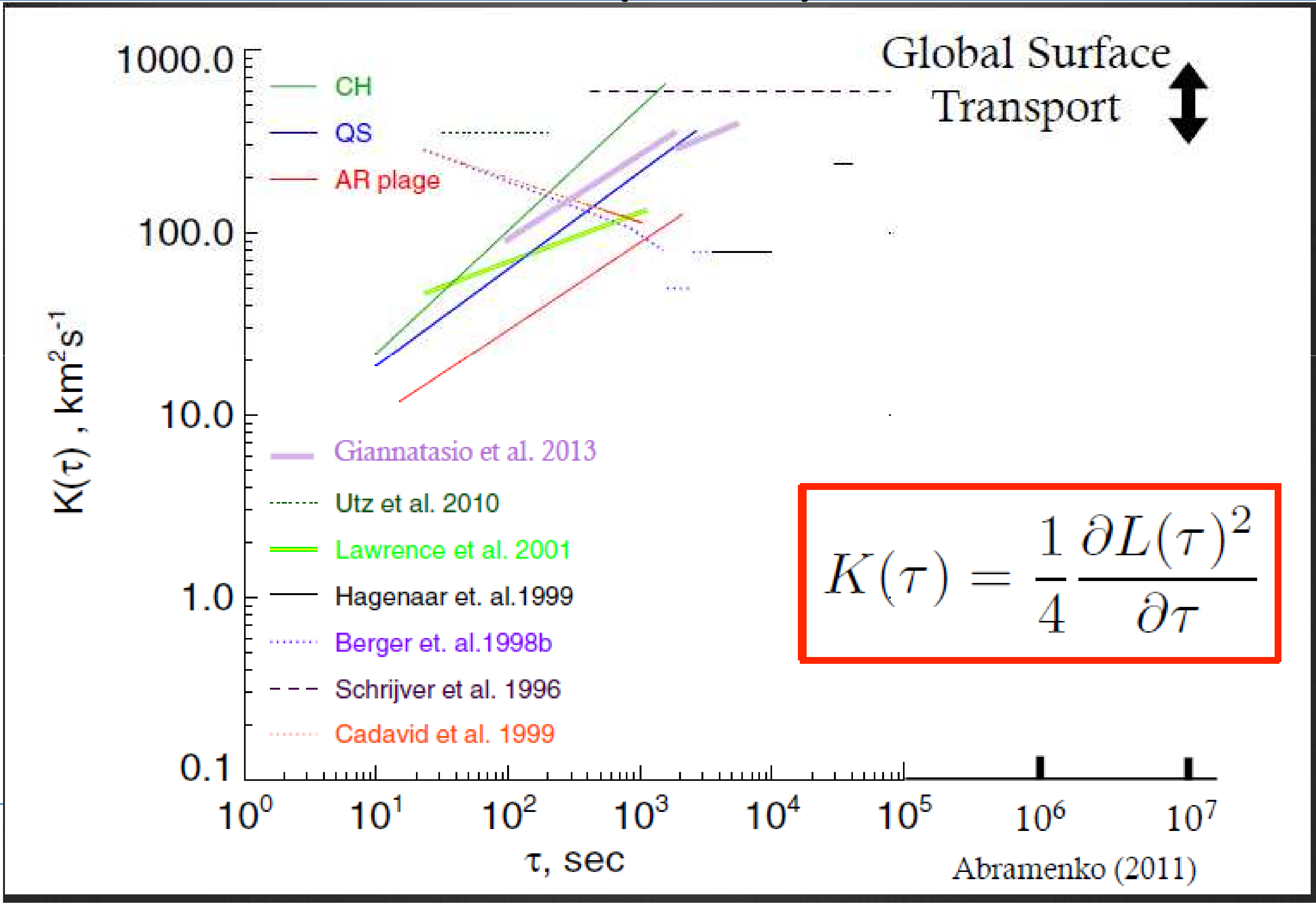




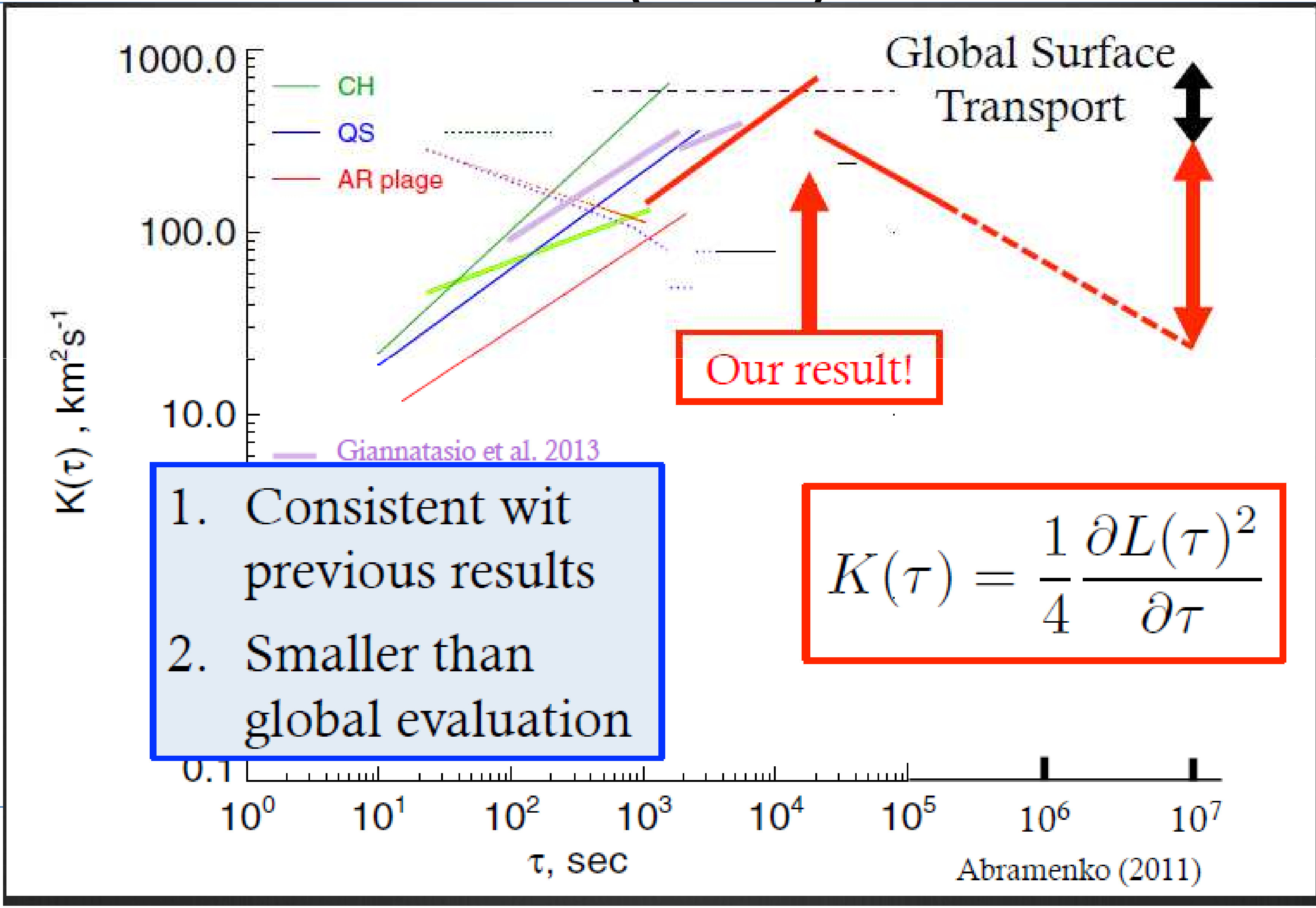
SDO: other efforts

- Lorenc et al. (2012): manual, semi-automatic method (similar to our SOHO/EIT interactive method)
- Dorotovič et al. (2014), Shahamatnia et al. (2014): improvement of that method; still not fully automatized
- In a general agreement with our results

Tracking magnetic elements, Hinode: Iida (2014)



Tracking magnetic elements, Hinode: Iida (2014)



Conclusions

- Coronal bright points are excellent tracers for the determination of the solar velocity field
- Good spatial and temporal coverage , localized structure
- Possibility to:
  - Study solar rotation on the monthly basis
  - Use CBPs for tracking magnetic elements
- SOHO, Hinode, SDO

Acknowledgements

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- SOHO is a project of international cooperation between ESA and NASA, and we are grateful to the EIT team for developing and operating the instrument.
- We would like to thank SDO/AIA science teams for providing the observations.