Large-scale velocity fields in the solar photosphere

Michal Švanda

Astronomical Institute, Academy of Sciences, Ondřejov
Astronomical Institute, Faculty of Mathematics and Physics, Charles University, Prague

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Motivation

- Motions in the solar photosphere exist
- Motions in the photosphere interact with the magnetic field
- Motions in the photosphere influence the active phenomena
- Do we really need more???

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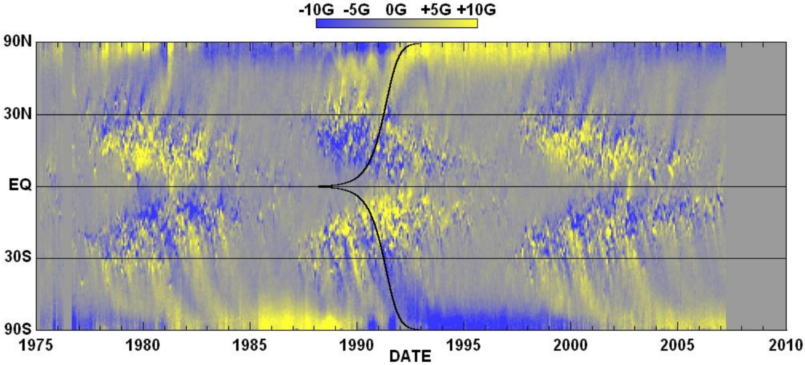
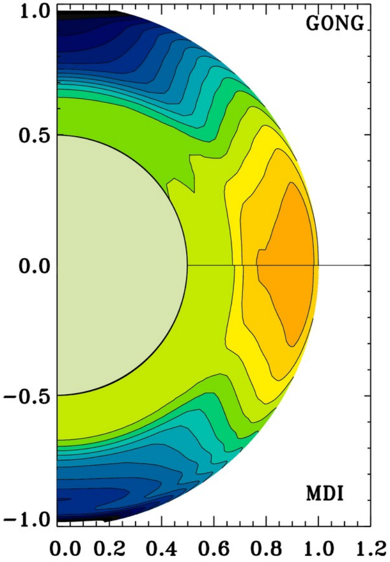
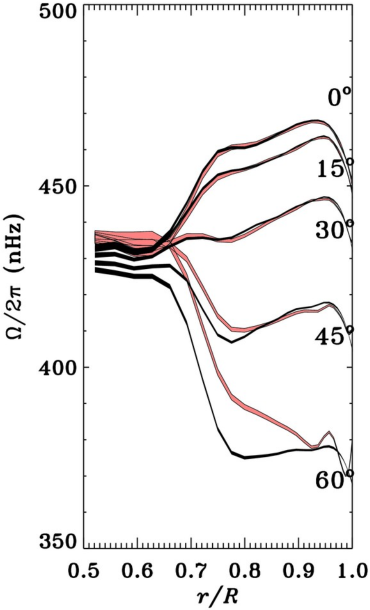
Flux transport



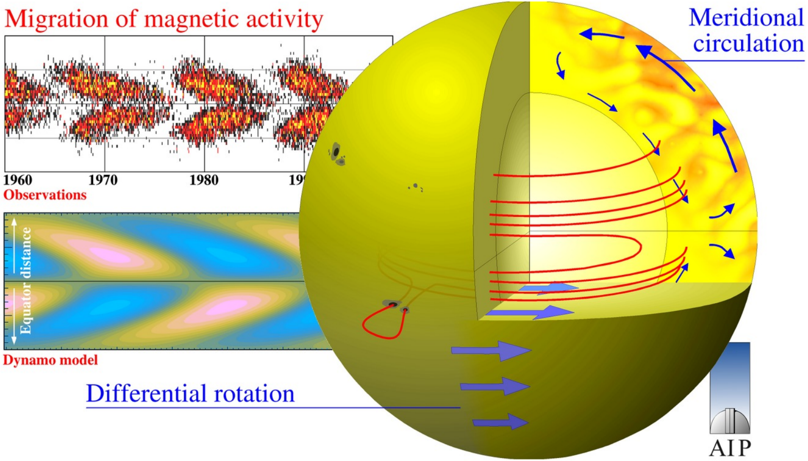
NASA/MSFC/NSSTC/Hathaway 2007/05

Solar rotation





Magnetic field generation

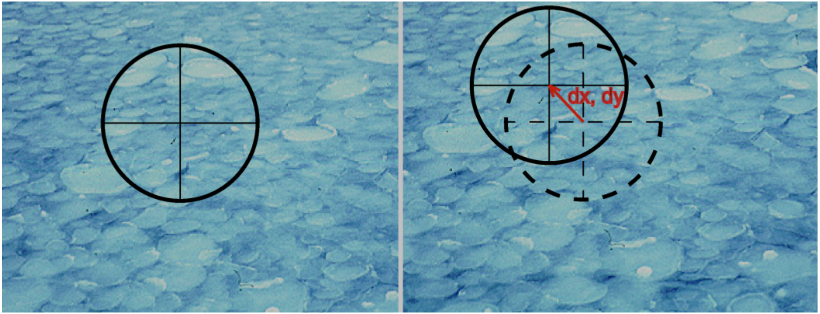


Methods of measurements

Basically, there are three methods of measurements of photospheric flow fields

- *Direct Doppler measurements* (provides only one line-of-sight component, some important discoveries but today used as a “proxy”)
- *Tracking techniques* (local correlation tracking, feature tracking, anything-that-can-be-tracked tracking)
- *Local helioseismology* (time-distance, ring-diagram)

Local correlation tracking

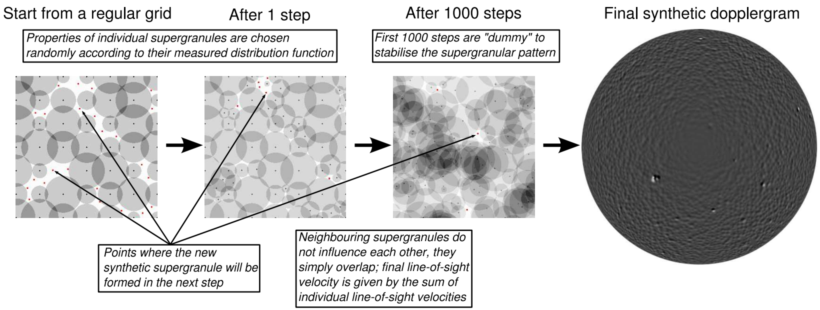


Common method used for analysis of data series in solar physics.
NOVEMBER, L.: 1986, APPL. OPT. 25, 392–397

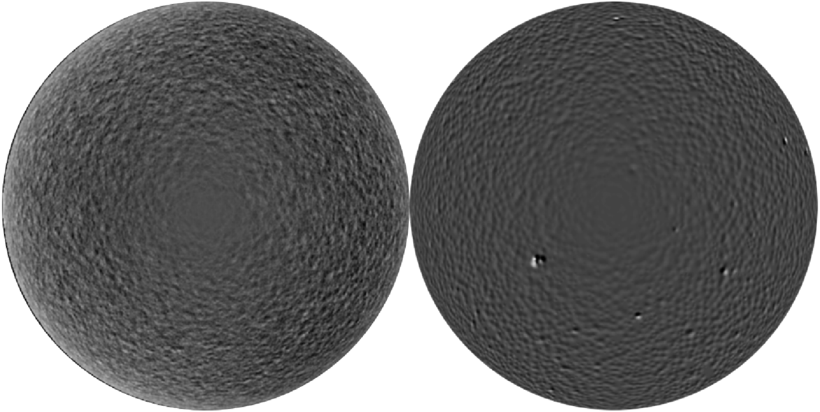
Used data

- High-cadence (1 frame per minute) set of full-disc dopplergrams obtained by Michelson Doppler Imager (MDI) onboard the Solar and Heliospheric Observatory (SoHO) (pixel-size 2″)
- Early application (ŠVANDA ET AL.: 2005, HVAR OBS. BULL. 29, 39–48) resulted in flows with some “interesting” properties
- Too many free parameters, synthetic data needed to adjust those parameters
- SISOID code = *SI*mulated *S*upergranulation as *O*bserved *I*n *D*opplergrams

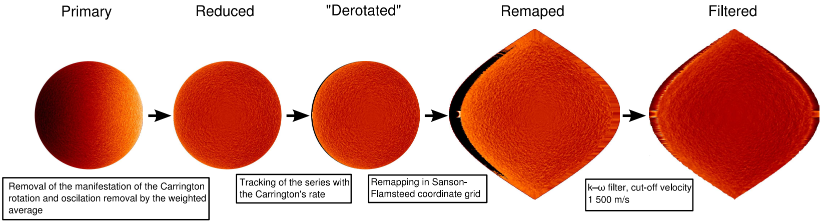
SISOID code


Start from a regular grid
After 1 step
After 1000 steps
Final synthetic dopplergram
Properties of individual supergranules are chosen randomly according to their measured distribution function
First 1000 steps are "dummy" to stabilise the supergranular pattern
Points where the new synthetic supergranule will be formed in the next step
Neighbouring supergranules do not influence each other, they simply overlap; final line-of-sight velocity is given by the sum of individual line-of-sight velocities

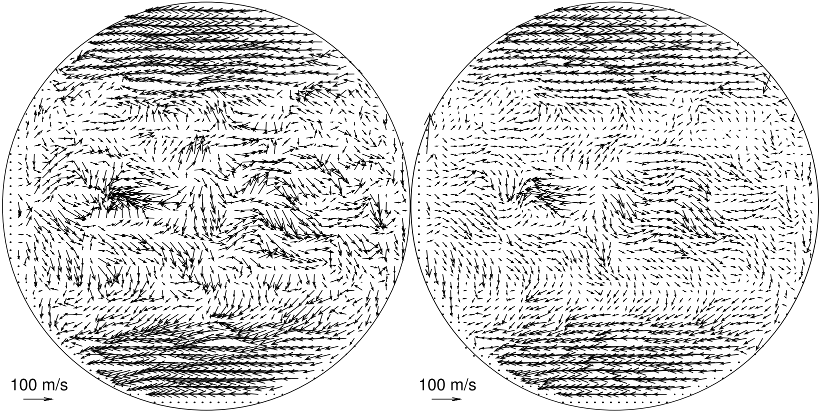
SISOID results



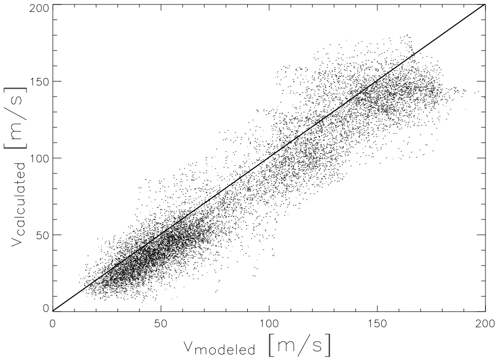
Method of data processing



Model vs. calculated flows



Calibration



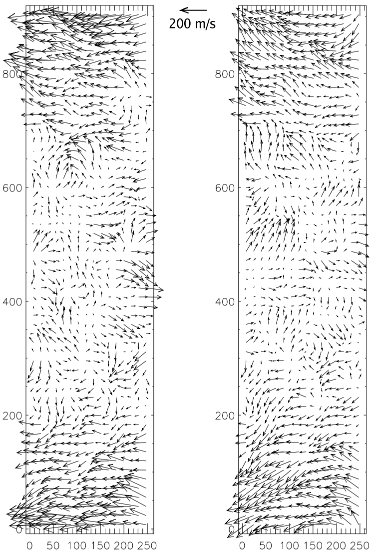
$$v_{\mathrm{cor}} = 1.13\, v_{\mathrm{calc}} + 15\ \mathrm{m\,s^{-1}}$$

ŠVANDA ET AL.: 2006, A&A 458, 301–306

Comparison to time-distance helioseismology

- It works on synthetic data, but what is the reality?
- ŠVANDA ET AL.: 2007, SOL. PHYS. 241, 27–37: comparison study of both methods using the same data-set
- Quite good agreement, magnitudes underestimated by factor of 1.12
- Correlation coefficients $\sim$ 0.8 for components, 0.86 for directions
- Encouraging for both methods

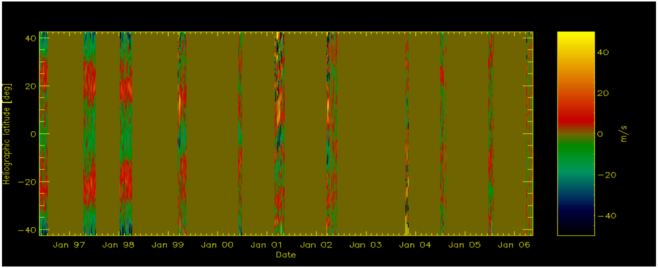
LCT vs. time-distance



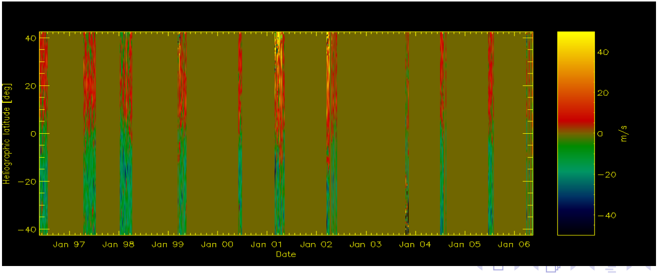
Real data series

- *Dynamics campaigns* approximately two months per year continously from 1996 to 2006
- 806 days, 502 days useful, 1004 full-disc horizontal velocity fields, almost 3 TB of primary data
- Computation took several months using Solar Oscillation Investigation group (Stanford University) fast network resources

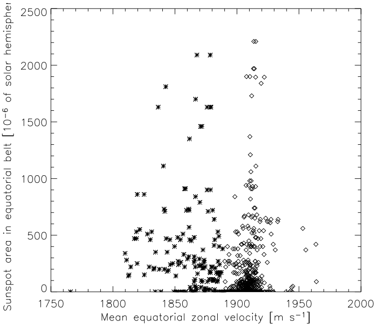
Integral properties



Torsional oscillations ⇑ ⇓ Meridional flow



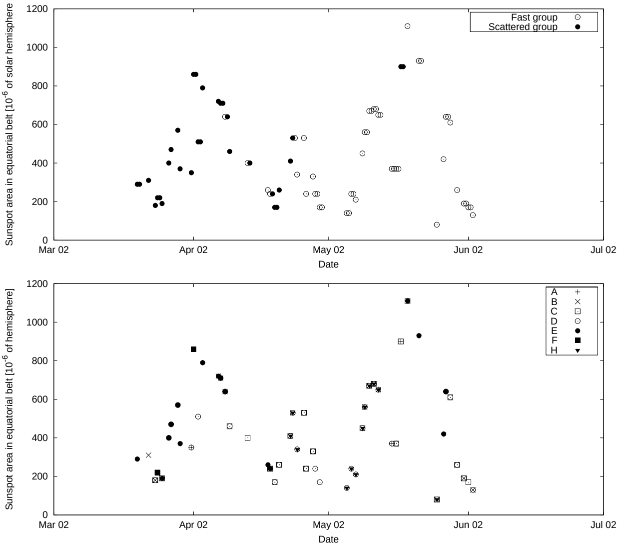
Two types of sunspots?



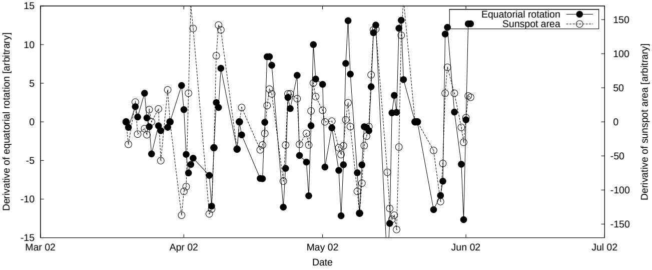
- Used the zonal patches (10 ° wide, averaged, (mean equatorial rotation)

- Total sunspot area derived from SEC NOAA daily reports
- "Fast group" and "scattered group"
- Dynamical disconnection of sunspots from their magnetic roots (SCHÜSSLER & REMPEL: 2005, A&A 441, 337)

Fast vs. scattered in 2002



Changes 2002



$$\Delta v \sim 0.2\,\Delta A_{\mathrm{sunspots}}\ \mathrm{m\,s^{-1}}$$

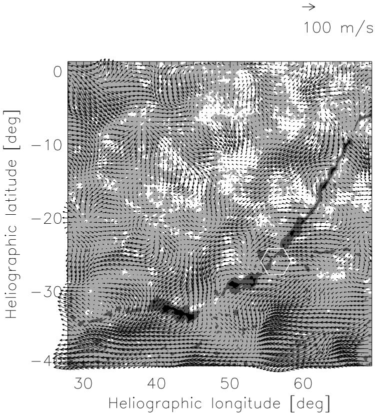
Behaviour for 2001 is very similar

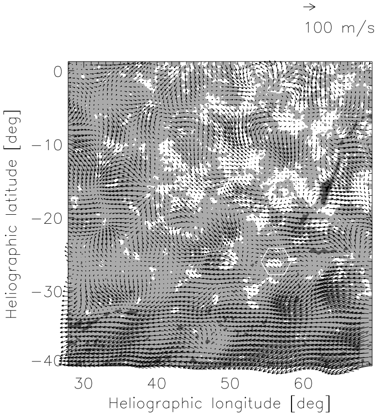
ŠVANDA ET AL.: 2007, A&A, SUBMITTED

Flows around the filaments

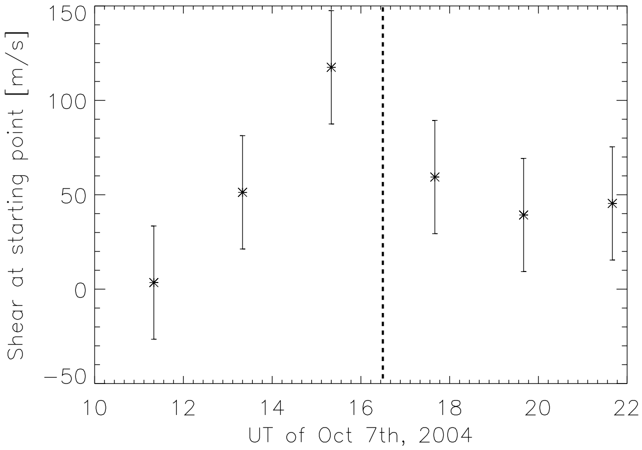
- JOP 178 with 11 instruments (including SoHO/MDI and ISSON)
- Study of the large-scale flows in the area of the eruptive filament
- The aim is to find any evidence of the motion supporting the destabilization of the magnetic field in corona
- ROUDIER ET AL.: 2007, A&A, JUST BEFORE THE SUBMISSION

Before and after eruption





Zonal shear around the starting-point



Importance of the influence

- Is the current and the shear important to the destabilization of the filament?
- How did the topology of the coronal magnetic field change? – *the aim of further study*
- Can we observe such a behaviour also in other cases of eruptive filaments or even in cases of regular solar flares?

What's next?

- Detailed study of the "sunspot's magnetic roots disconnection"
- Detailed study of the meridional flow (have important consequences for the dynamo models, some preliminary results obtained by *butterfly tracking* – maybe in discussion?)
- What about giant cells?
- Large-scale motions in and around active regions (including the extrapolation of the magnetic field)

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Can we go further?

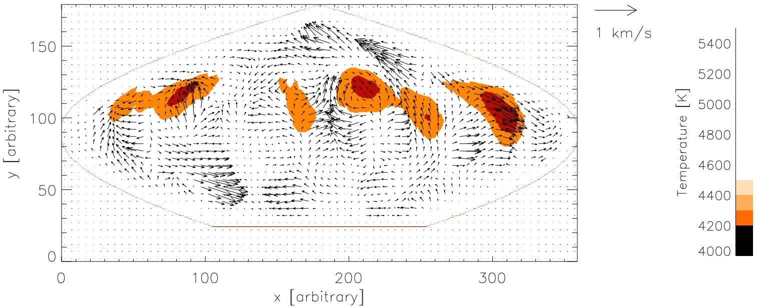
- Sun is just one star of many
- Can we apply the same method to stellar data?
- Doppler imaging series seem promissing

Pilot study

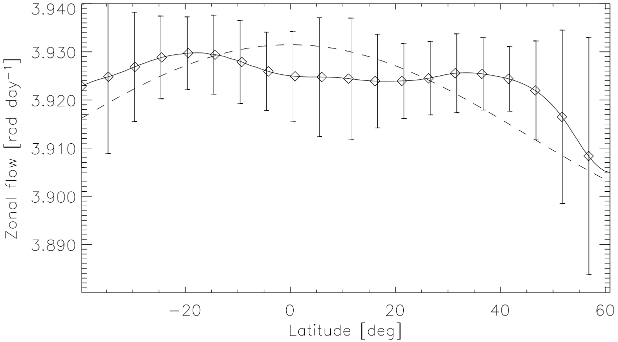
LQ Hydrae

- K2V subdwarf, $R = 0.97\ R_\odot$, $T_{\text{eff}} = 5070$ K, $P_{\text{rot}} = 1.6007$ days, age ~ 100 Myr, $M = 0.8\ M_\odot$
- 28 consecutive temperature maps obtained by inversion code *TempMap* by group of K. G. Strassmeier, AIP, from the set of 52 high-resolution spectral profiles of line Fe I 643.0 nm taken during 57 nights at NSO in November–December 1996
- ŠVANDA ET AL.: 2007, A&A, SUBMITTED

LQ Hya flow map

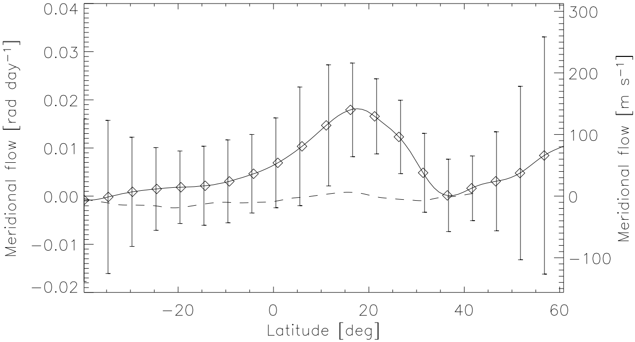


LQ Hya differential rotation



$$\Omega = 3.928(0.001) - 0.019(0.002)\sin^2\varphi \text{ rad day}^{-1}$$

LQ Hya meridional circulation



Other targets

- New results of mean flows are consistent with previous or with recent (i.e. not yet published) studies obtained with different methods
- Other targets already processed: UZ Lib, σ Gem – both are tidaly locked close binaries *(⇒solar physicist studying close binaries???)* – results consistent with previous studies, both depict anti-solar differential rotation
- Other target of further studies are forming
- Flow maps (we need to be sure that they are real) could be an important clue for the stellar dynamo theory