Giardini Naxos - 11 June 2018

The small scale magnetic elements on the photosphere: a turbulent story.

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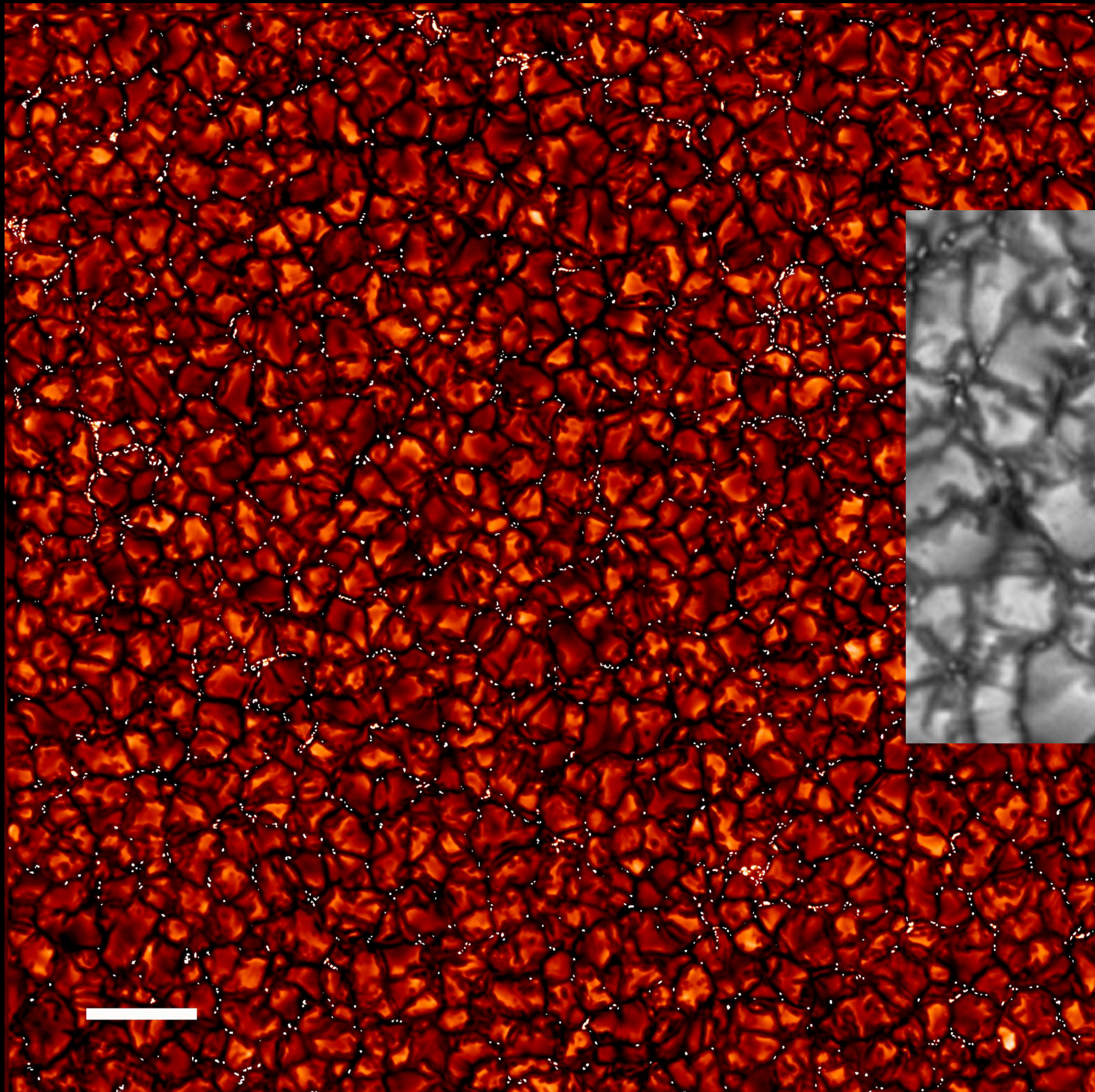

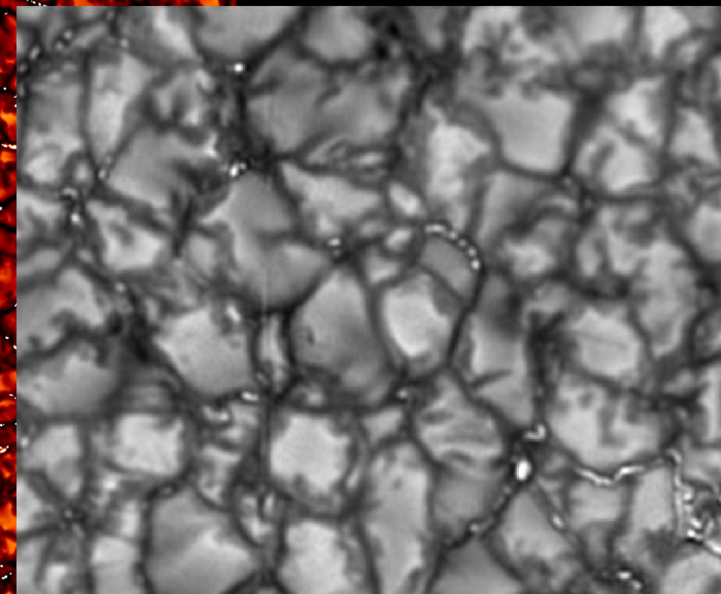

Sanchez-Almeida 2010
The Swedish 1-meter Solar Telescope – La Palma

The large scales

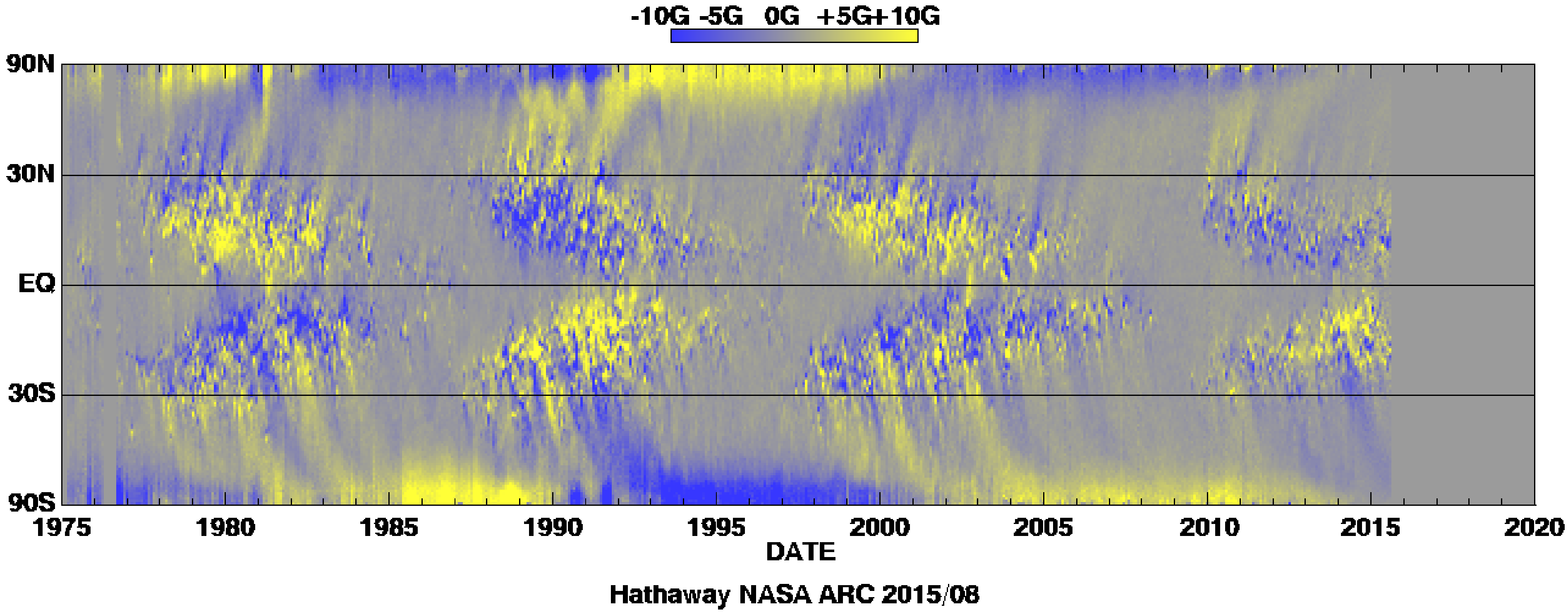

Image by David Hathaway

- Equatorward migration of Active Regions.
- Poleward migration of their decayed diffuse field
- Polar field reversal at the maximum of the cycle.

Diffusion: a key ingredient for kinematic dynamo models

MAIN INGREDIENTS:
Differential rotation
Diffusion
Meridional flow

Case SUN:
prescriptions to match measurements of solar flux emergence and evolution.
Case LIN:
dependence of magnetic feature mobility on flux removed
Case DISP:
same emergence as Case SUN, but dispersal 10 times less efficient.
Case LIN+DISP:
combination of LIN and DISP.

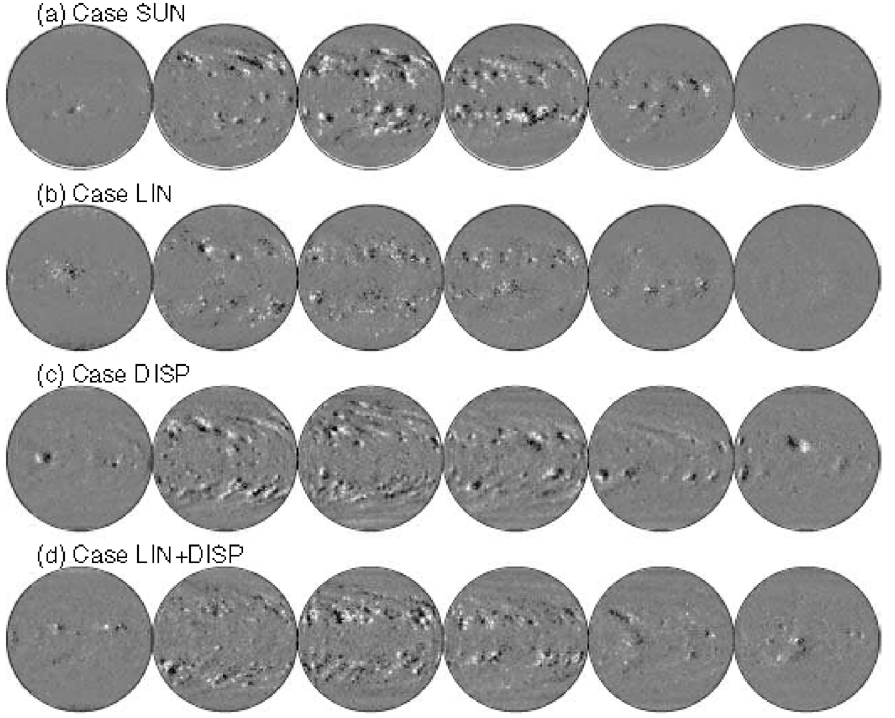

Figure 3. Equatorial views of Cases SUN, LIN, DISP, and LIN+DISP throughout half of a polarity (or a full sunspot) cycle, all scaled to $\pm 4 \times 10^{5}$ Mx cm^{-2}. The first and last images in each row correspond to successive minima in the sunspot cycle.

De Rosa, Proc. IAU, S233, 2, 25, 2006

- Surface B diffusion strongly dependent on turbulent convection properties

The small scales

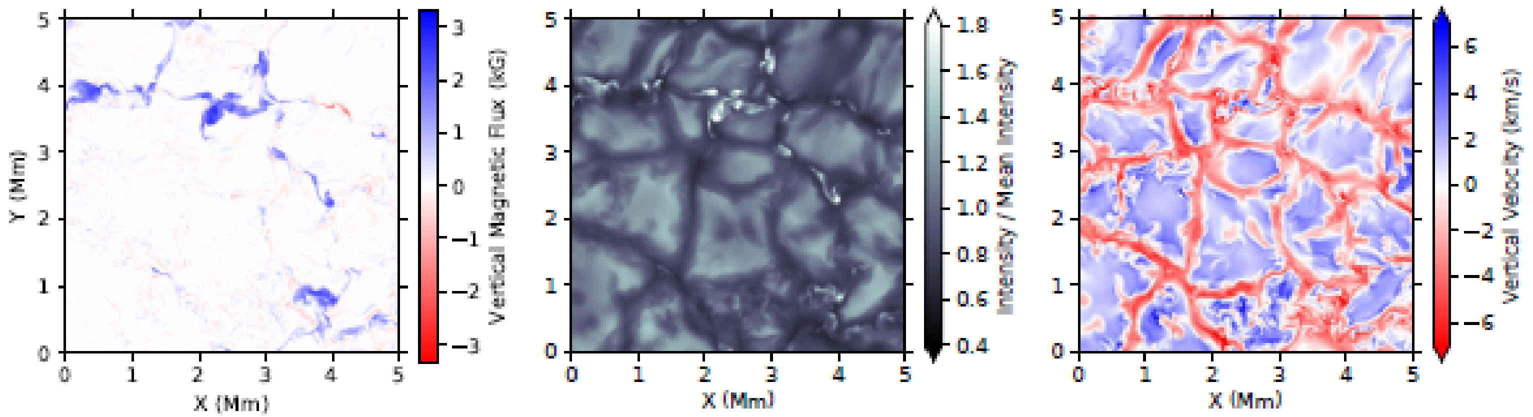

Figure 1. A common 5 × 5 Mm portion of the Rempel (2014) MURaM simulation showing, from left to right, vertical magnetic flux, white-light intensity, and vertical plasma velocity at the beginning of the analyzed time range (time stamp 040000). Over the full frame, peak values for I/I_{mean} are near 2.75, peak values for B_z are near 3.3 kG, and peak values for V_z are near 9.9 km s^{-1} and -11.9 km s^{-1}. (The full 24.5 × 24.5 Mm simulation is used in this paper.)

Magnetic diffusion value: “small”
Otherwise no small scale dynamo

Turbulent diffusion coefficient in use:

~600 km^2/s for kinematic dynamos

<10 km^2/s for MURAM code simulations

Here it begins

THE ASTROPHYSICAL JOURNAL, 743:133 (9pp), 2011 December 20 doi:10.1088/0004-637X/743/2/133

TURBULENT DIFFUSION IN THE PHOTOSPHERE AS DERIVED FROM PHOTOSPHERIC BRIGHT POINT MOTION

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Received 2011 July 11; accepted 2011 September 2; published 2011 November 30

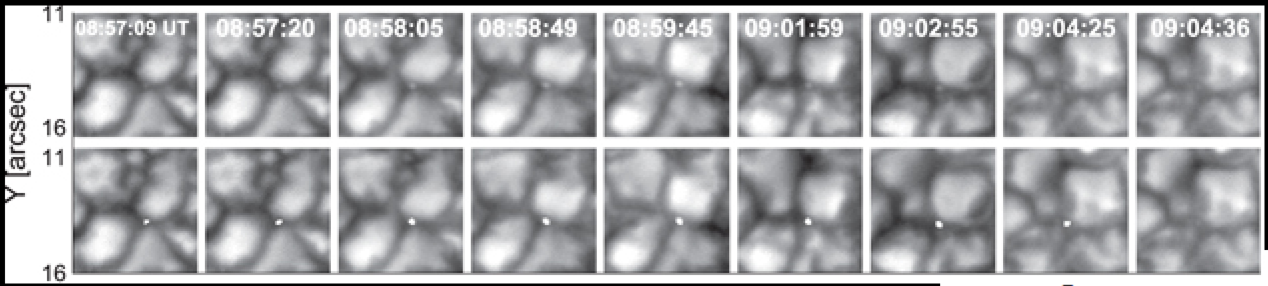
ABSTRACT

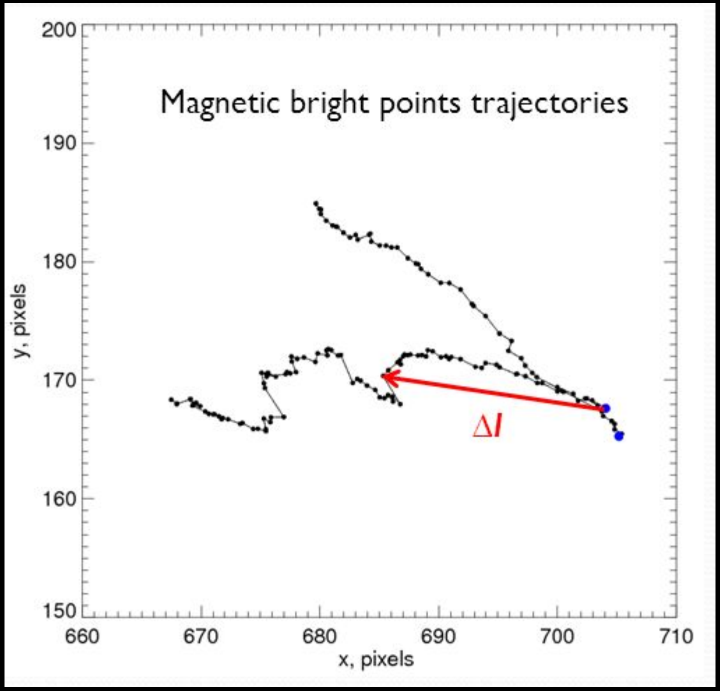
On the basis of observations of solar granulation obtained with the New Solar Telescope of Big Bear Solar Observatory, we explored proper motion of bright points (BPs) in a quiet-sun area, a coronal hole, and an active region plage. We automatically detected and traced BPs and derived their mean-squared displacements as a function of time (starting from the appearance of each BP) for all available time intervals. In all three magnetic environments, we found the presence of a super-diffusion regime, which is the most pronounced inside the time interval of 10–300 s. Super-diffusion, measured via the spectral index, γ, which is the slope of the mean-squared displacement spectrum, increases from the plage area ($\gamma = 1.48$) to the quiet-sun area ($\gamma = 1.53$) to the coronal hole ($\gamma = 1.67$). We also found that the coefficient of turbulent diffusion changes in direct proportion to both temporal and spatial scales. For the minimum spatial scale (22 km) and minimum time scale (10 s), it is 22 and 19 $km^2\ s^{-1}$ for the coronal hole and the quiet-sun area, respectively, whereas for the plage area it is about 12 $km^2\ s^{-1}$ for the minimum time scale of 15 s. We applied our BP tracking code to three-dimensional MHD model data of solar convection and found the super-diffusion with $\gamma = 1.45$. An expression for the turbulent diffusion coefficient as a function of scales and γ is obtained.

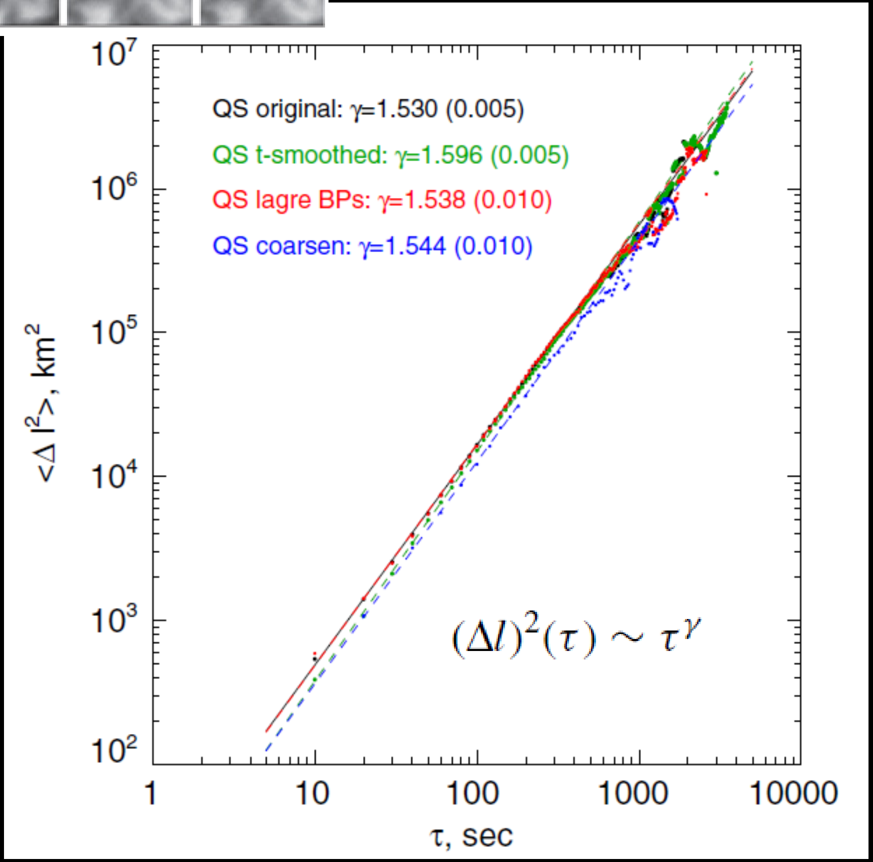
Key words: Sun: photosphere – Sun: surface magnetism – turbulence

Abramenko et al. 2011

Anomalous diffusion!







Abramenko et al. 2011

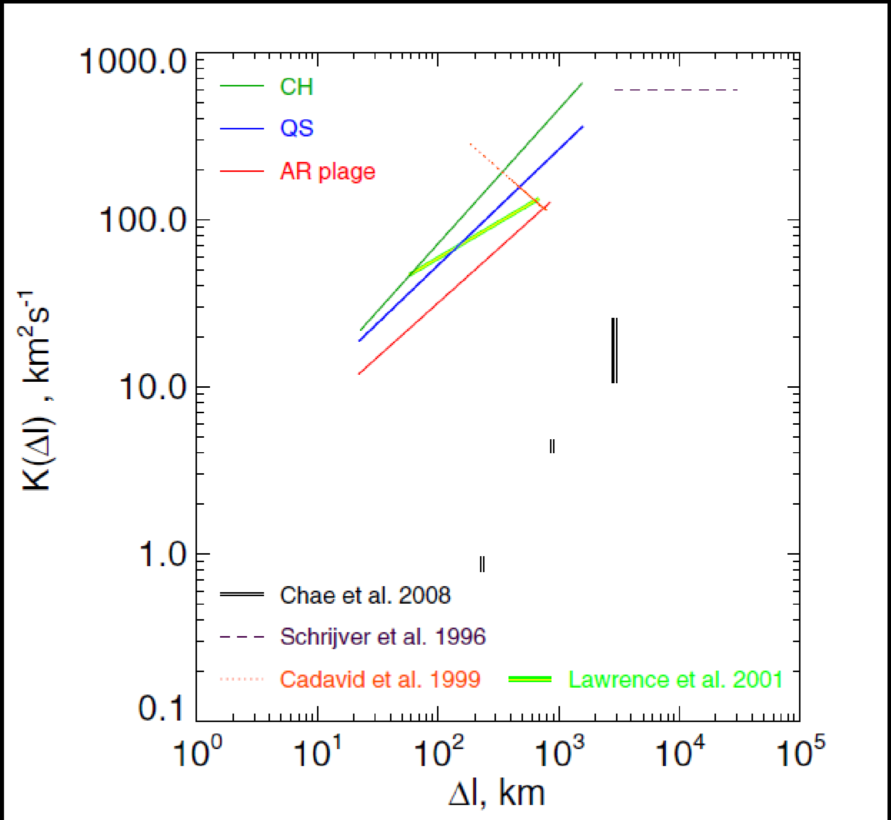
The diffusion coefficient changes from small to large scales

$$K(\tau) = \frac{1}{4}\frac{d}{d\tau}\langle l^2(\tau)\rangle,$$

Table 3. Comparison of the mean values of diffusion index γ and diffusion coefficient D of small magnetic elements obtained in this study with some of those in the literature.

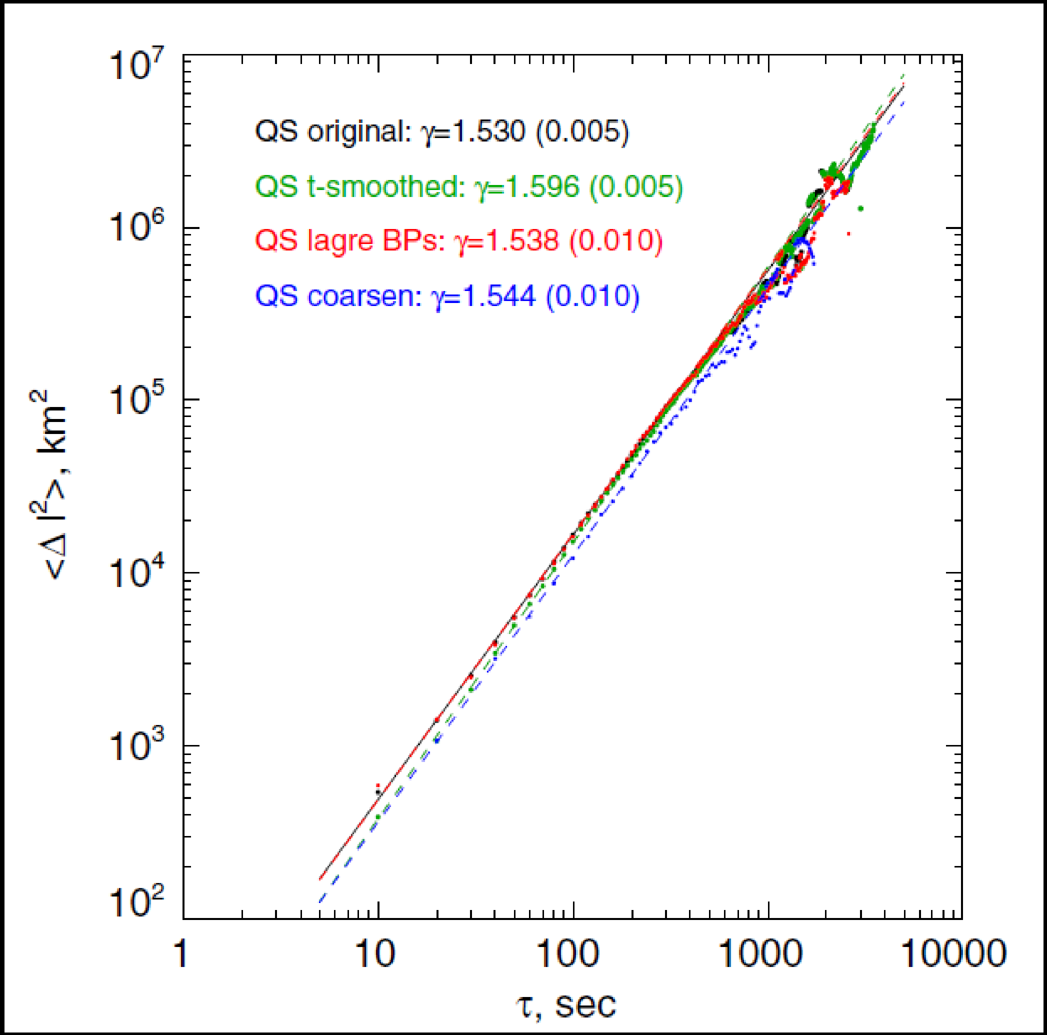
Reference	Origin of data	Telescope/ Spacecraft	Spatial resolution	Feature[a]	Lifetime[b,c] [sec]	γ[c]	D[b,c] [$km^2 s^{-1}$]
This study	Stratospheric balloon	SUNRISE/SuFI	0.″14	IMBP	461	1.69	257
Chitta et al. (2012)	Ground	SST/CRISP	-	IMBP	180 – 240	1.59	(≈ 90)
Abramenko et al. (2011)	Ground	BBSO/NST	0.″11	IMBP[d]	(10 – 2000)	1.48	(19 – 320)
Manso Sainz et al. (2011)	Space	Hinode/SOT	0.″32[e]	IMBP	< 900	0.96	195
Utz et al. (2010)	Space	Hinode/SOT	0.″22[f]	IMBP	150	(≈ 1)	350
Chae et al. (2008)	Space	Hinode/SOT[g]	-	ME[d]	-	-	0.87
Lawrence et al. (2001)	Ground	SVST	0.″23	NMBP	9 – 4260	1.13	-
Cadavid et al. (1999)	Ground	SVST	0.″23[h]	NMBP	18 – 1320	0.76	-
					1500 – 3450	1.10	-
Hagenaar et al. (1999)	Space	SOHO/MDI	2.″3[i]	MFC	$< 1.0 \times 10^4$	(≈ 1)	70 – 90
					$> 3.0 \times 10^4$		220 – 250
Berger et al. (1998)	Ground	SVST	≈0.″2	NMBP[d]	(100 – 3800)	1.34	60
Lawrence & Schrijver (1993)	Ground	BBSO	-	ME[d]	-	0.92	250

Jafarzadeh et al. 2013



Abramenko et al. 2011

Can we do better?



Abramenko et al. 2011

Richardson diffusion?

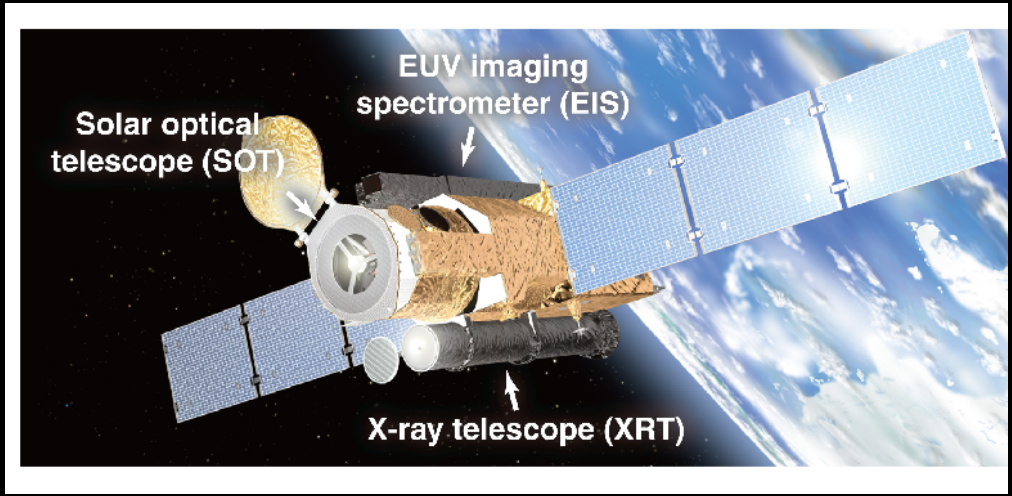
Fully turbulent medium?

Self-similar scaling?

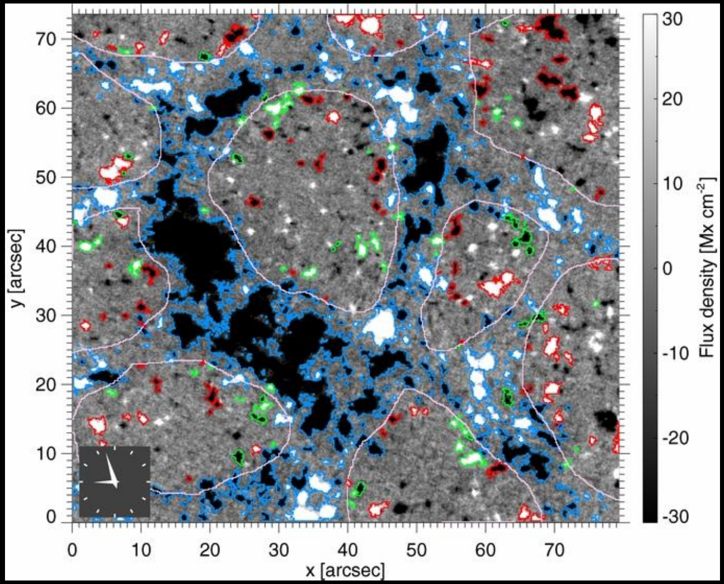
Methods ok?

Ranges explored?

An exceptional dataset



Duration: ~25 hours FoV: ~50x50Mm^2
Cadence: 90 sec Resolution: ~200km



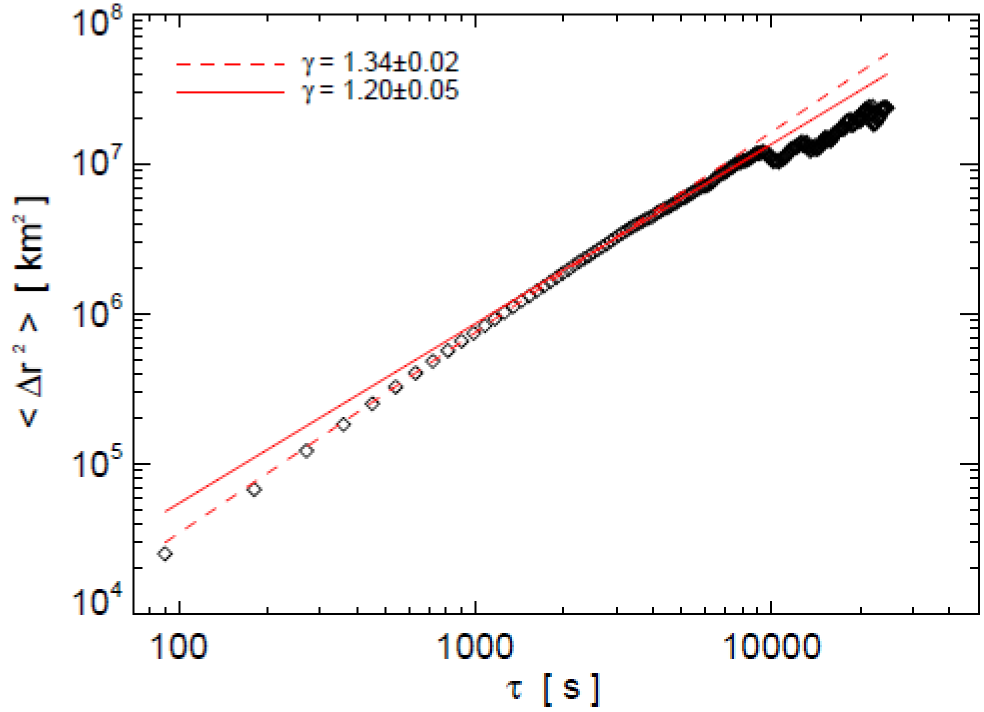
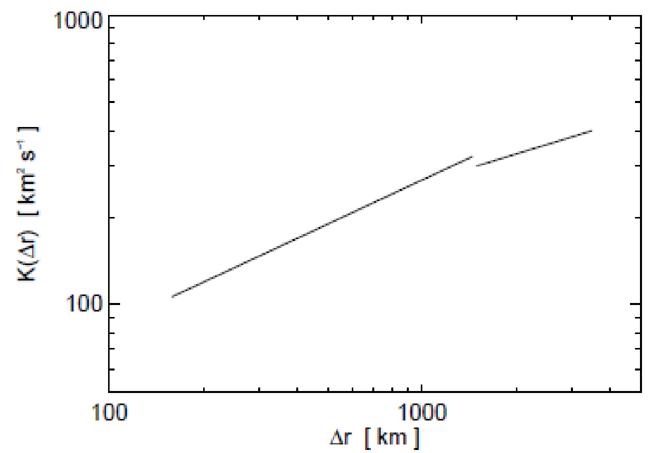


Fig. 4.— Displacement spectrum for all the 16925 magnetic elements far from the boundaries tracked in the field of view. The dashed line fits the data points up to ~ 2000 s; the solid line fits the data points up to ~ 10000 s.



Giannattasio et al. 2013

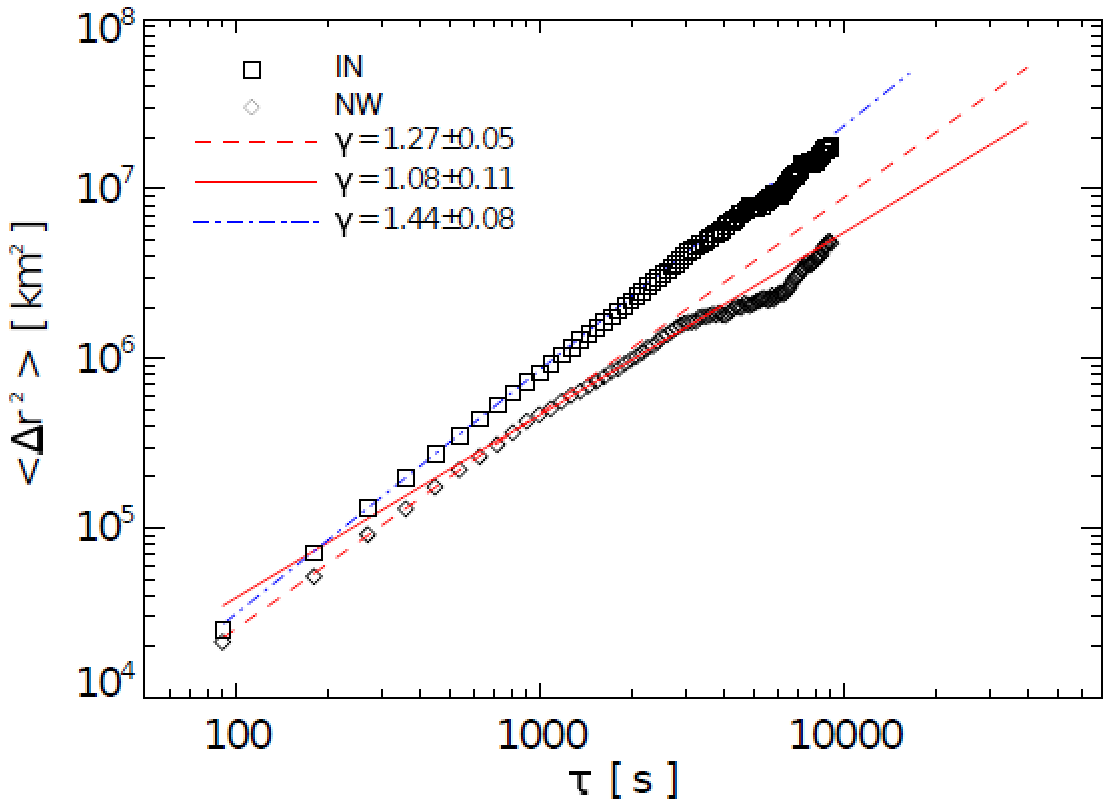
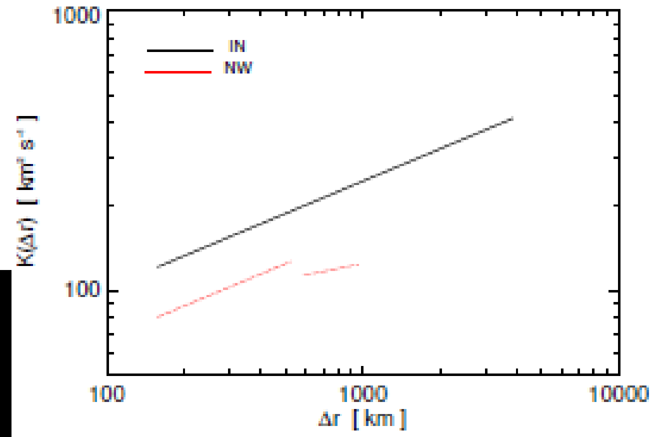


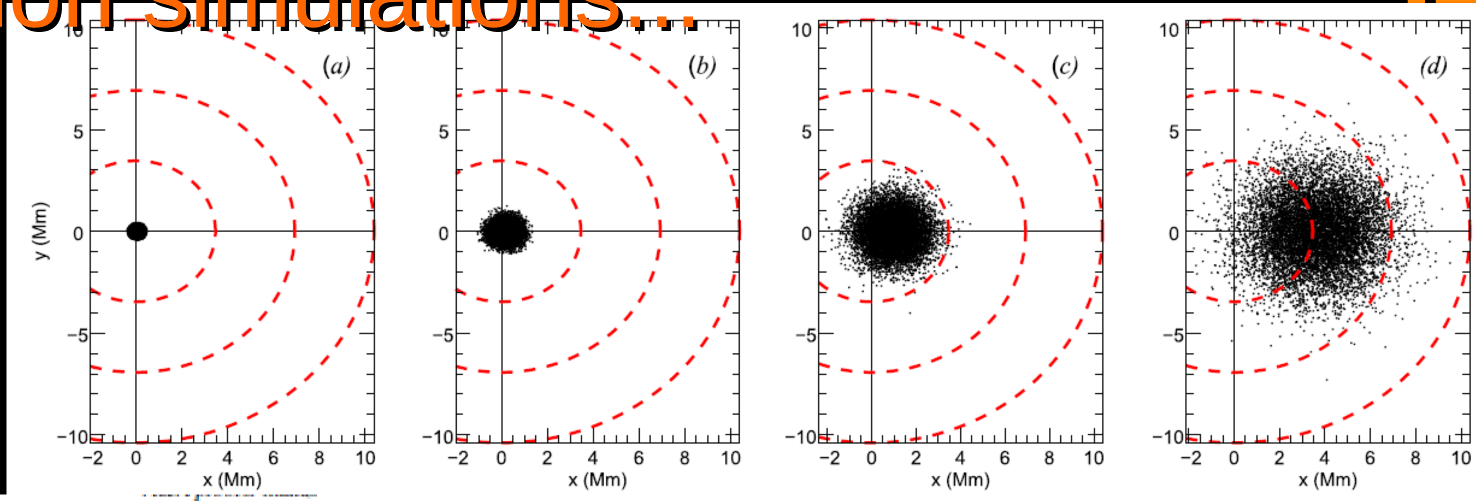
Fig. 2.— Displacement spectrum for IN (black squares) and NW (black diamonds) magnetic elements. The blue dash-dotted line fits the IN data points. The red lines fit the NW data points for $\tau \lesssim 600$ s (dashed line) and $\tau \gtrsim 600$ (solid line).



“the lower diffusivity of magnetic elements in NW regions allows to amplify more easily the magnetic fields therein”

Giannattasio et al. 2014a

Advection simulations...



walkers (black points) at t = (a) 1.5, (b) 6, (c) 45, and (d) 120 minutes. The red (dashed) concentric circles are contours of constant
f walkers along positive *x*-direction, away from the origin. Black solid lines mark the *x* and *y*-axis.

Agrawal et al. 2018

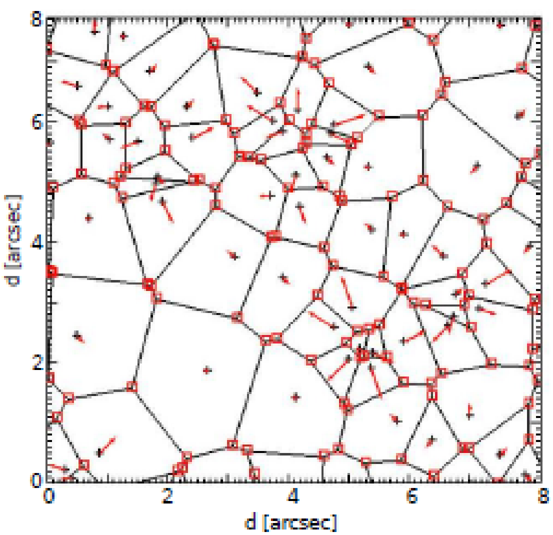
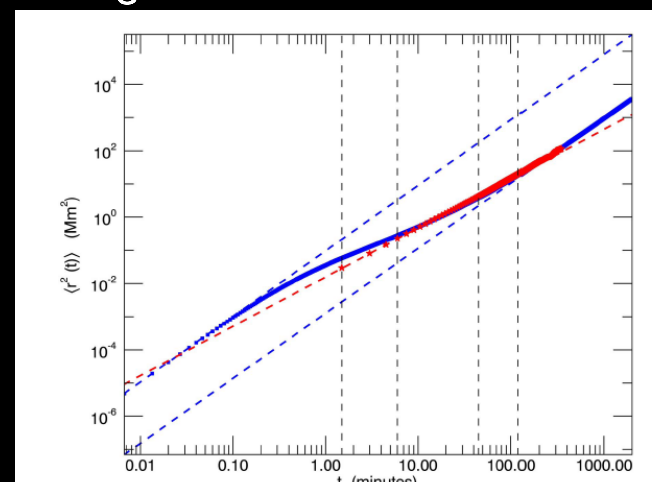


Fig. 3. A snapshot from the simulation. The black crosses represent the advection centres; the red vectors are the displacement (5× exaggeration) to be applied to the centres due to the neighbours' action; the red boxes on the Voronoi tesselation highlight the cell vertexes, which are used as tracers to compute the displacement spectrum. For the sake of visualization, only about a twentieth of the simulation domain is shown.

Del Moro et al. 2015



After all…

No need of Richardson diffusion

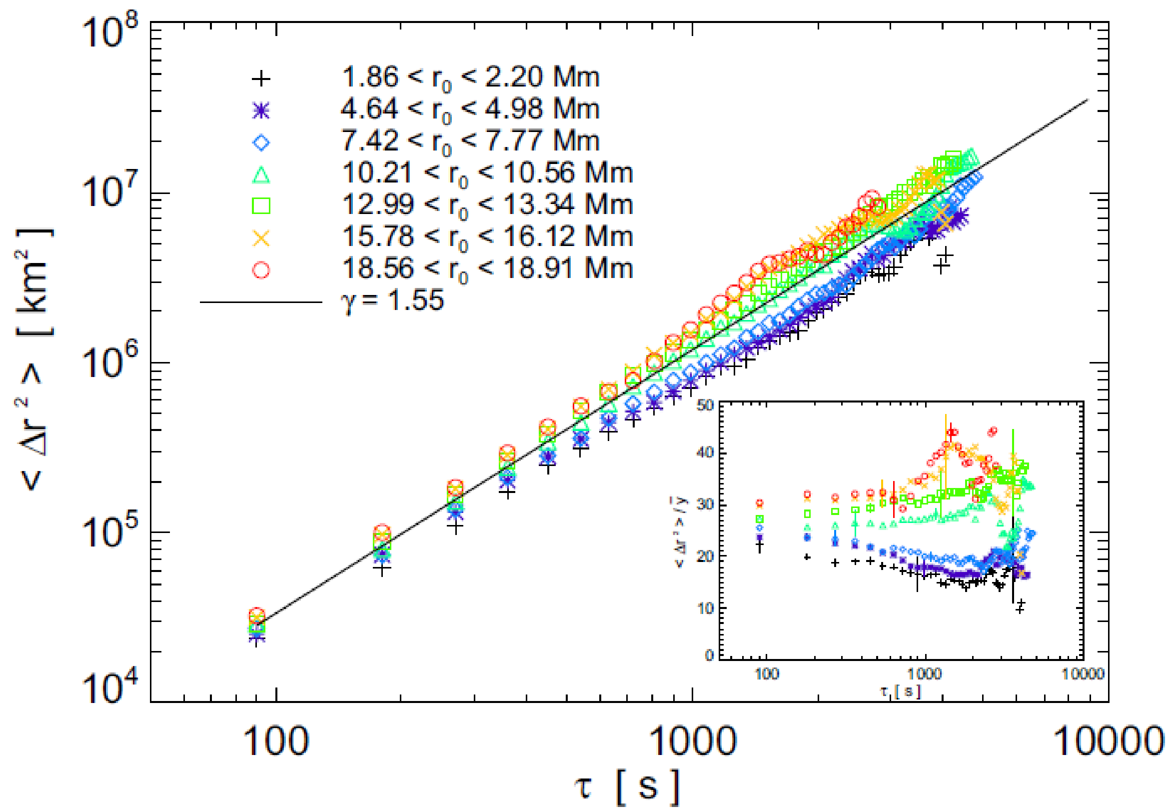


Fig. 4. Mean square separation $\langle \Delta r^2(\tau, r_0) \rangle$ for seven different and equally spaced values of r_0. The black solid line corresponds to the fitting curve $\bar{y}$ of Fig. 2. In the *inset* the compensated mean square separation $\langle \Delta r^2(\tau, r_0) \rangle / \bar{y}$ is shown. The errors (vertical bars) are shown only for a few data points.

Giannattasio et al. 2014b

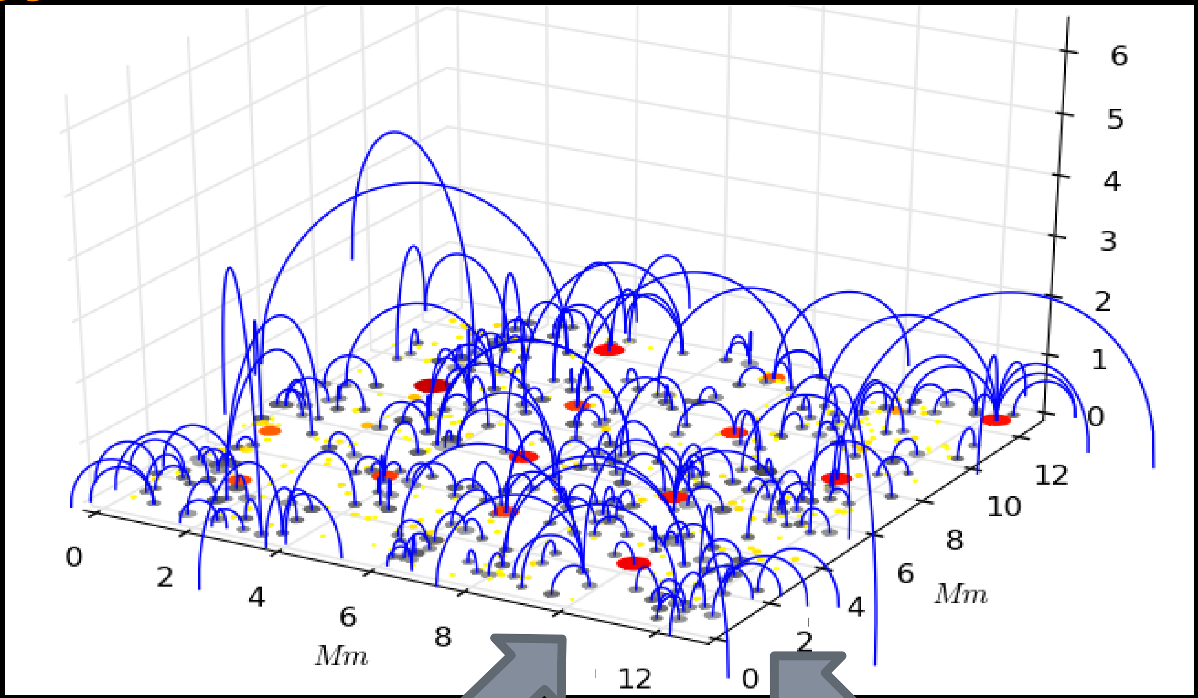
Diffusion coefficients you may use:

~500 km^2/s for large scales (depending on B strength)

<10 km^2/s for small scales

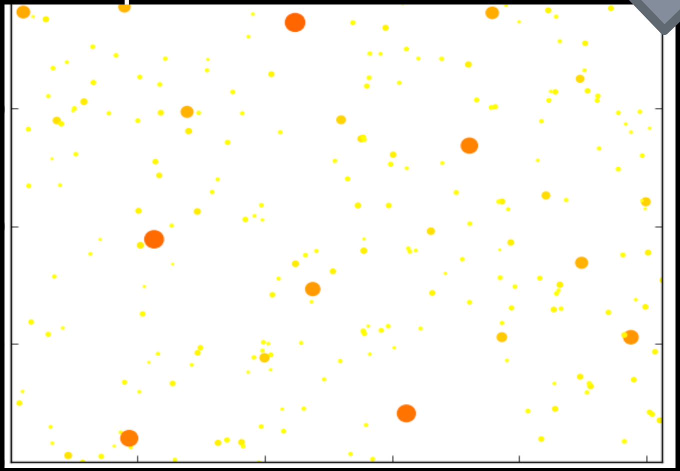
“The diffusion coefficient value depends on the scale and the position”

Energy for the Corona

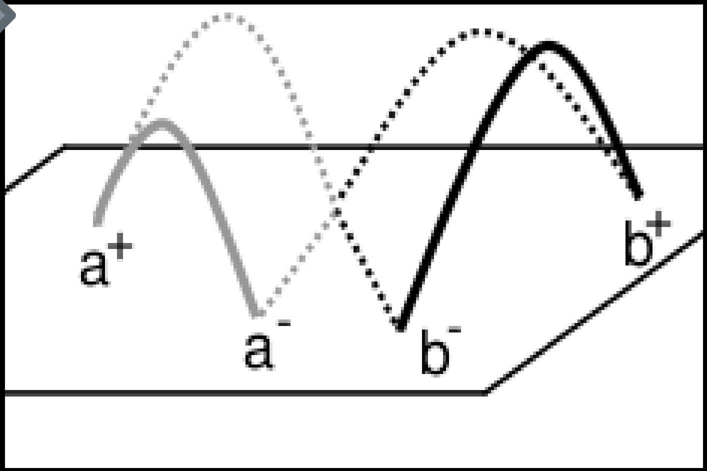


Viticchié et al. 2006, Volpes et al. 2012, Giovannelli et al. 2015

Photospheric advection model



Nano-flare reconnection model



Using the Sun (real or simulated) to study the impact of stellar activity on exo-planet detectability

Stellar activity produces signals that can be observed in photometric light curves and radial velocities.

They are due to:

1. Magnetic activity.
Due to spots and plages.
Varies on day-month time-scales and on year-decade time-scales.

2. Oscillations and pulsations.
They usually have an impact on minute-hour time-scales

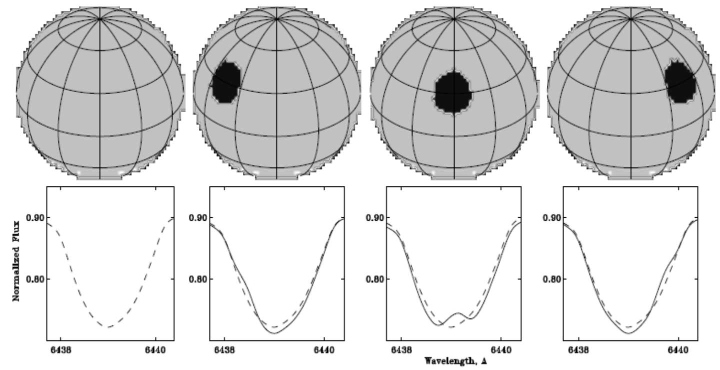


Figure 2: Spectral line profiles for a model fast rotating star with no spots (dashed line) and with a spot moving across the disk as the star rotates (solid line). See also animation at http://www.astro.phys.ethz.ch/staff/berdyugina/private/StellarActivity/StellarAct.html

Use the models as templates to investigate the impact of magnetic activity and turbulent convection diffusion on our ability to detect planetary signals

→ IMPROVE the models!!

Berdyugina, Living Rev. Solar Phys. 2, 8, 2005
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Lanza et al., A&A, 520, A53, 2010
Maheara et al., Nature, 485, 478, 2012
Notsu et al., ArXiv:1304.7361v1, 2013

Miss a EST.

Thank you