# Analysis of Pseudo-Lyapunov Exponents of Solar Convection Using State-of-the-Art Observations

G. Viavattene[1], M. Murabito[1], S. L. Guglielmino[2], I. Ermolli[1], G. Consolini[3], F. Giorgi[1] and S. Jafarzadeh[4,5]

[1]INAF – Osservatorio Astronomico di Roma

[2]INAF – Osservatorio Astrofisico di Catania

[3]INAF – Istituto di Astrofisica e Planetologia Spaziali

[4]Rosseland Center for Solar Physics, University of Oslo

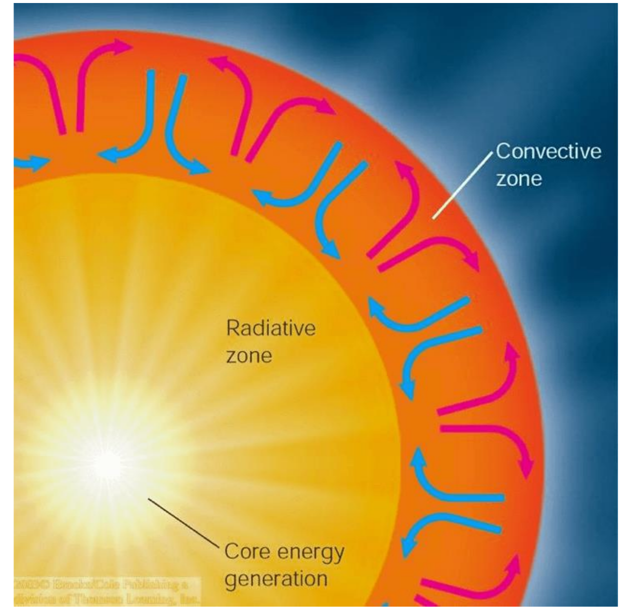
[5]Institute of Theoretical Astrophysics, University of Oslo

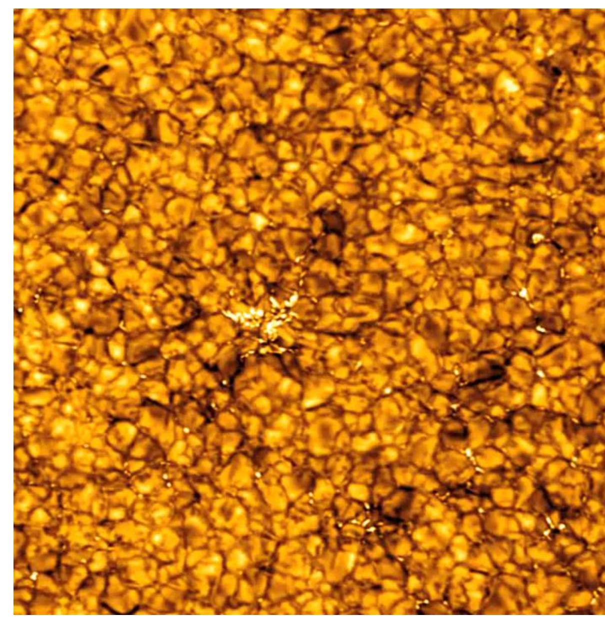
**More details and information in *Viavattene G. el al. (2021), Entropy, 23, 413, doi 10.3390/e23040413***

# Introduction: the solar convection and the Lyapunov exponent

- The thermal convection is a nonequilibrium process ubiquitous in nature which displays a chaotic and turbulent character
- Clear manifestation of the solar convection: granulation pattern
- We characterize the solar convection using the **Lyapunov exponents:** $\boldsymbol{\epsilon(n) \sim \epsilon e^{\Lambda n}}$ (if $\Lambda > 0$: *chaotic* system, if $\Lambda < 0$: *dissipative* system)
- Previous works in the literature:

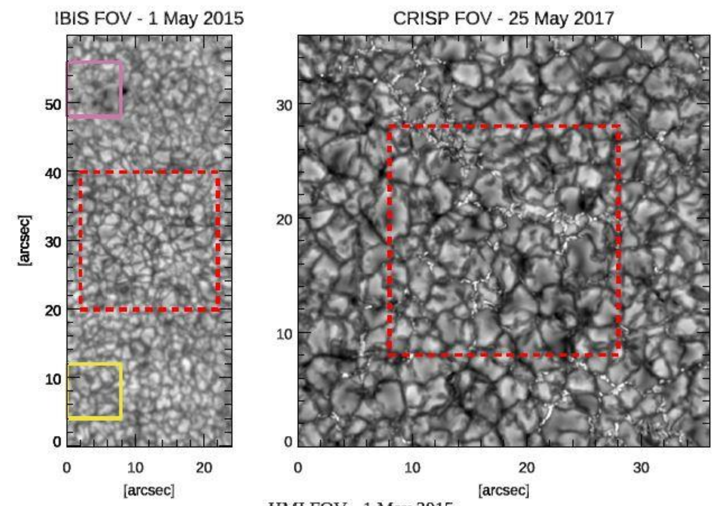
- numerical MHD simulations by e.g. *Steffen et al. 1995*
- evaluation of Lyapunov-like exponents λ in spectroscopic observations (from residuals of four spectral line parameters: $\delta I_c$, $\delta v_c$, $\delta F$, $\delta A$) by *Hanslmeier et al. 1994*

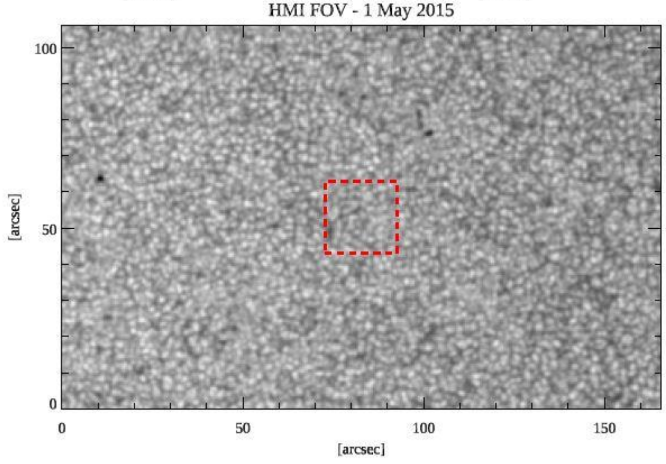


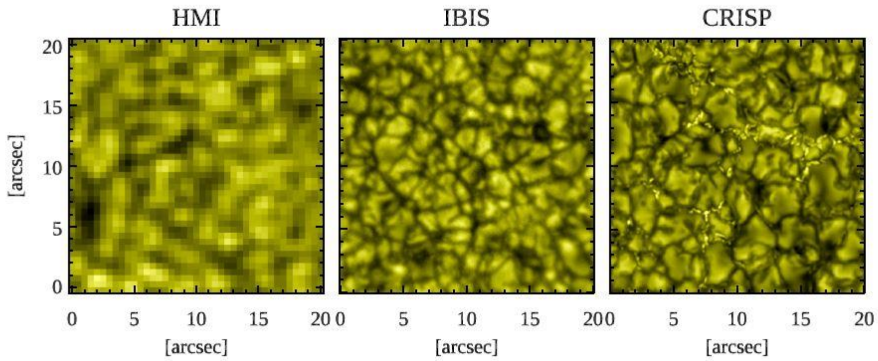



# Datasets of our analysis: IBIS, CRISP and HMI

- Multi-dataset analysis of state-of-the-art ground- and space-based spectropolarimetric observations
- Observations with different spatial resolution, spectral sampling, post-facto processing
- Modern observation techniques (CCD detectors, Adaptive Optics systems) with respect to previous works
- Random sampling of the pixels (to avoid contamination of coherent spatial features)



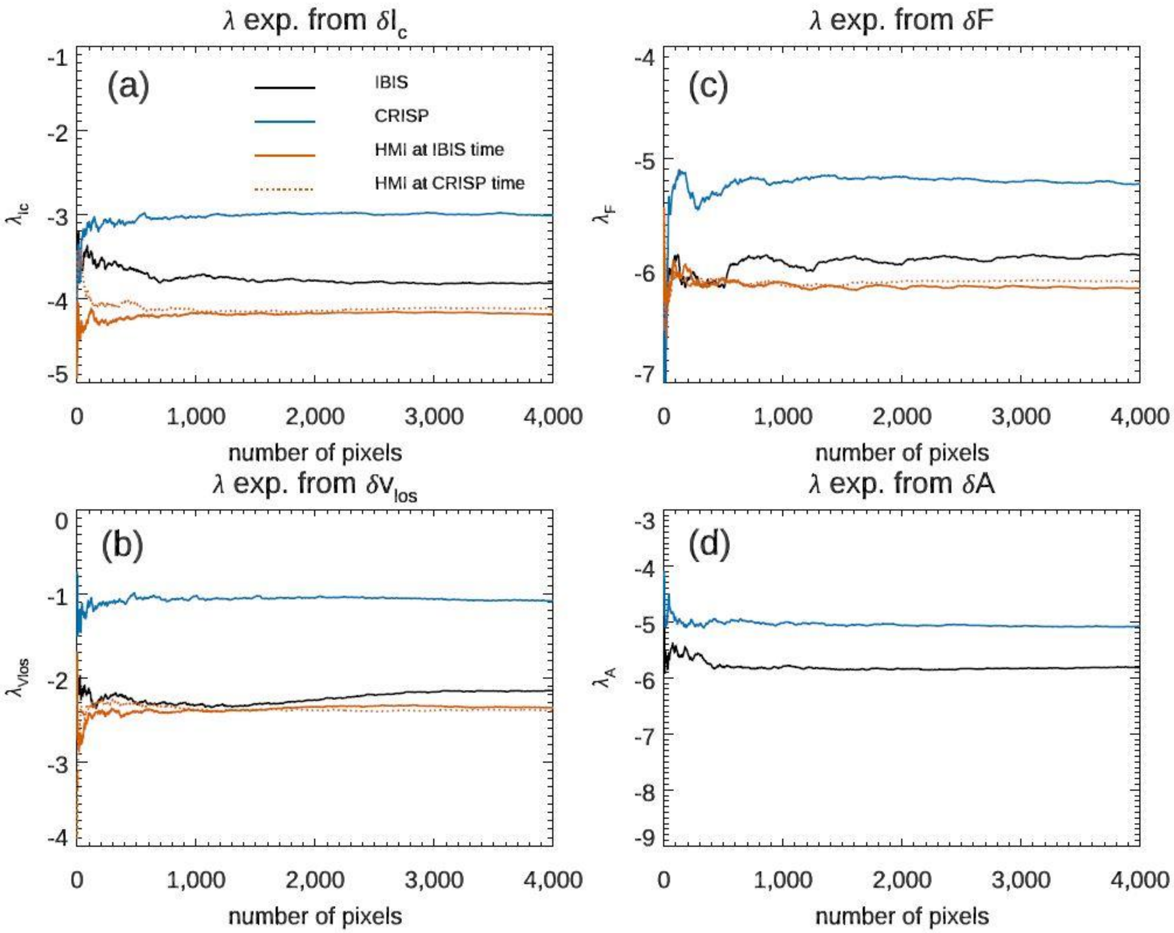




| Telescope | Instrument | Spectral Coverage | Time Coverage | Time Cadence | Spatial Resolution | Formation Height of Line Cores |
|---|---|---|---|---|---|---|
| DST | IBIS | Fe I 617.3 nm | 1 May 2015<br>14:18–15:03 UT | 48 s | 0.16″ | ~150 km |
| SST | CRISP | Fe I 630.15 nm | 25 May 2017<br>09:30–09:40 UT | - | 0.13″ | ~180 km |
| SDO | HMI | Fe I 617.3 nm | 1 May 2015 14:24 UT<br>25 May 2017 09:36 UT | - | 1″ | - |

# Results

*Estimation of Pseudo-Lyapunov exponents (proxy of Λ) following Hanslmeier et al. 1994*

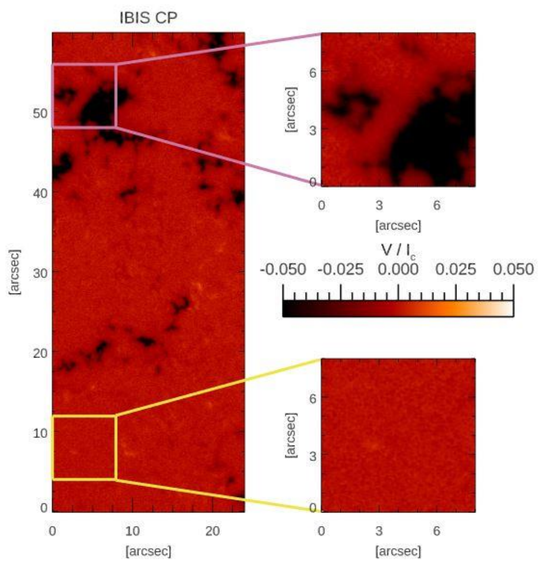
- Negative values (dissipative regime) from all parameters in contrast to previous results in the literature
- Strong dependence on spatial resolution (less dissipative regime at small spatial scales)
- Less noisy behaviour at the smallest spatial scales and more stable convergence wrt previous results in the literature

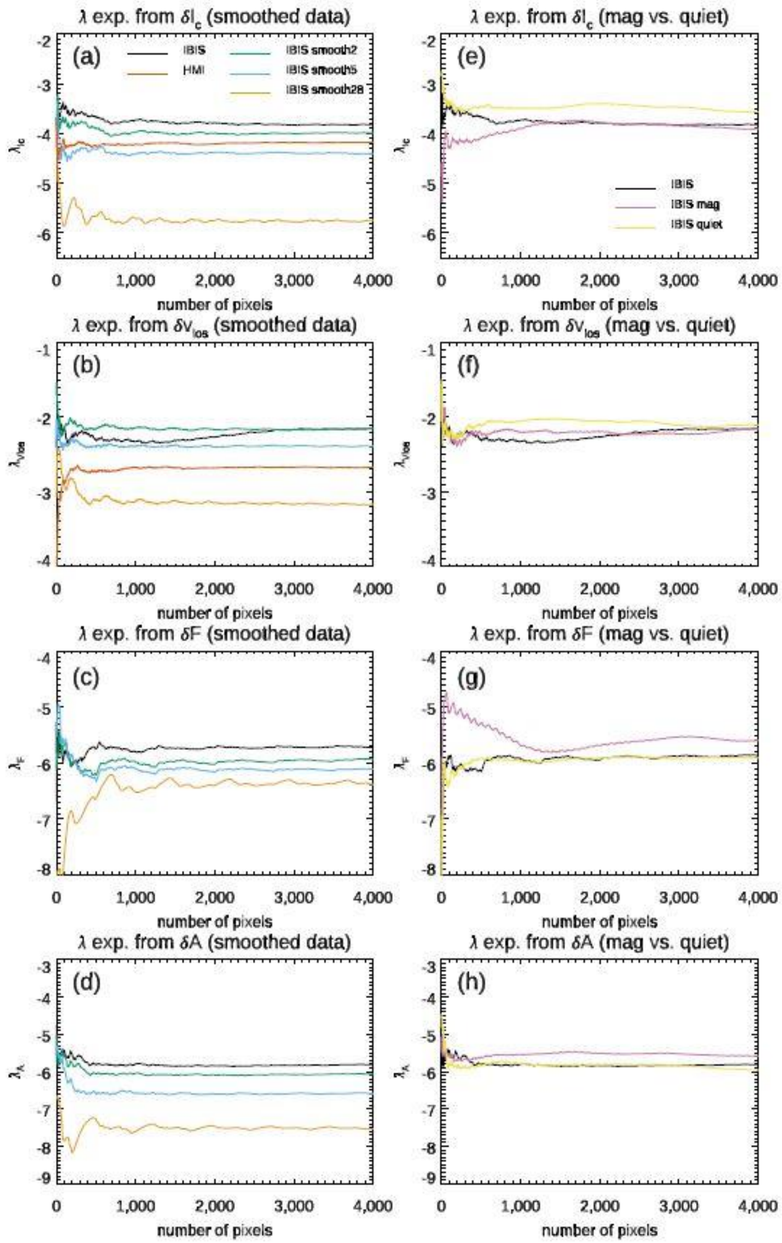


# Results

Analysis of the dependence on spatial degradation with gaussian filtering

- Confirmed dependence of λ exponents on spatial resolution



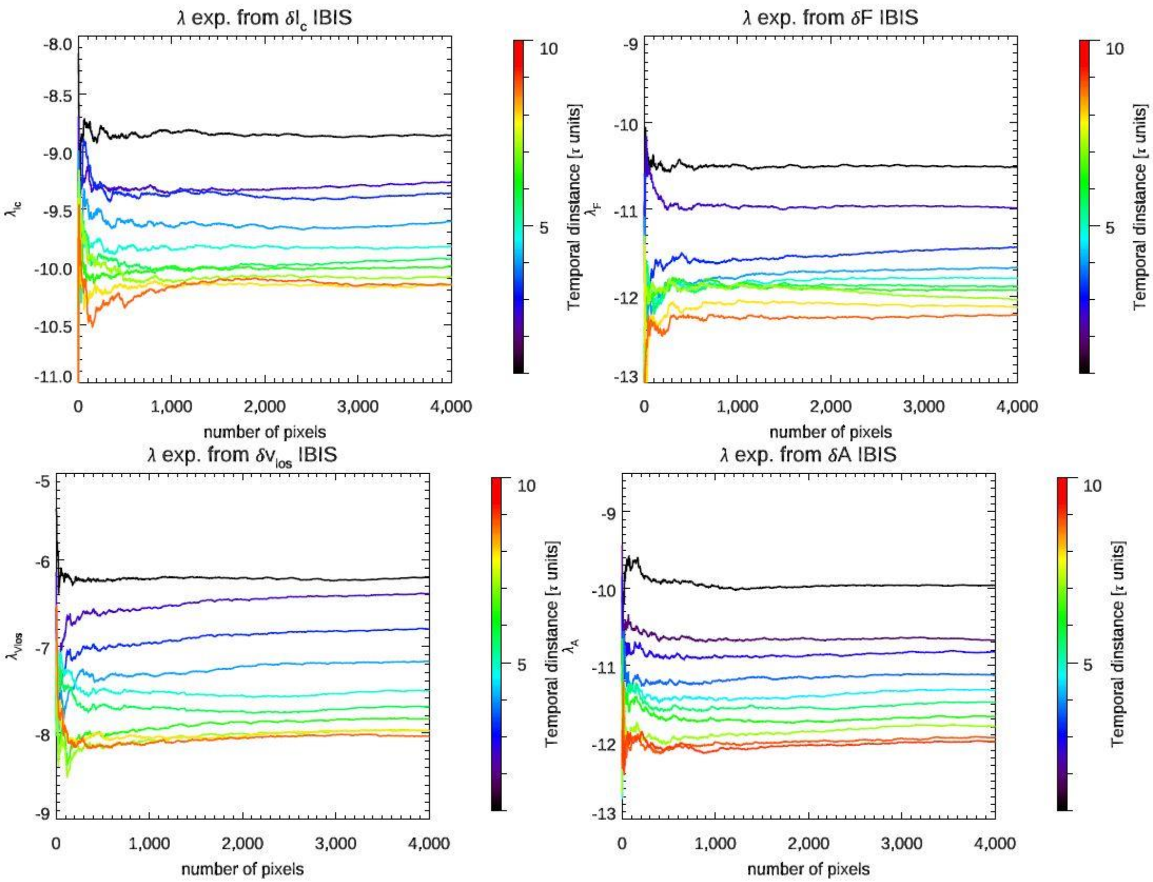

Analysis of the effects of weak magnetic fields (magnetic and quiet sub-FoVs selected using CP circular polarization maps)

- λ exponents mostly unaffected by weak magnetic fields

# Results

Further estimation based on a more accurate definition of the Λ exponents, which accounts for the time evolution of the quantities analysed at each image pixel

- Confirmation of the negative values from all considered quantities
- Clear trend towards smaller values when increasing the time elapsed between the compared observations



# Conclusions

- New estimates of the pseudo-Lyapunov Exponents of the solar convection based on state-of the-art observations of the photosphere acquired with DST/IBIS, SST/CRISP and SDO/HMI
- Analysis of the effect of spatial degradation and of weak magnetic field concentrations
- Strong dependence on spatial resolution
- Small dependence on weak magnetic fields concentrations
- Further new estimates based on a more accurate definition of λ exponents wrt previous works

***See Viavattene et al. 2021 Entropy, 23, 413, doi 10.3390/e23040413 for more details***

This research received funding from the European Union's Horizon 2020 Research and Innovation 531 program under grant agreements No 824135 (SOLARNET) and No 729500 (PRE-EST). This work was supported by the Italian MIUR-PRIN (grant 2017 APKP7T) and by the Istituto Nazionale di AstroFisica (INAF).

SOLARNET

*Thanks for your attention*