OSUG

Observatoire des Sciences de l'Univers de Grenoble

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UNIVERSITÉ Grenoble Alpes

Mitigating stellar signals to reveal other Earths

Review on stellar processes and approaches

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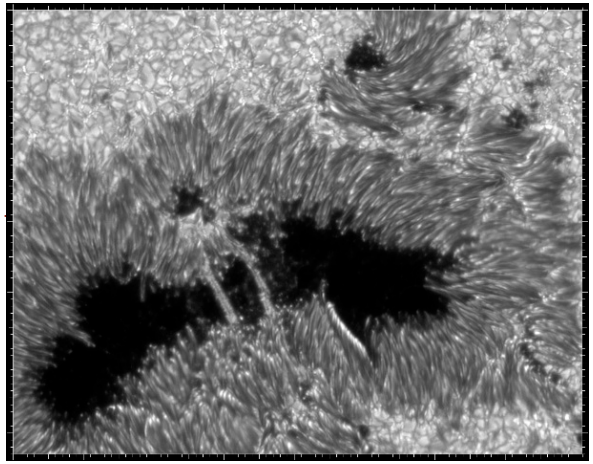
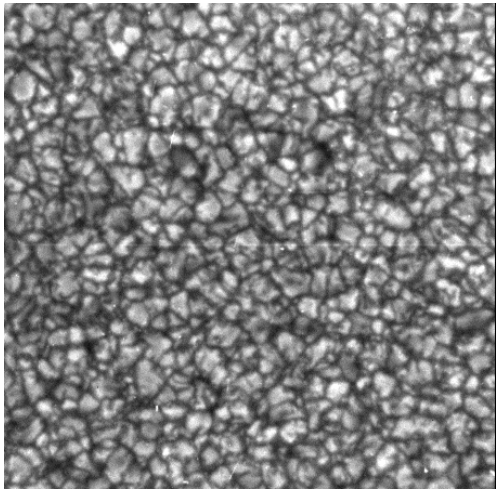
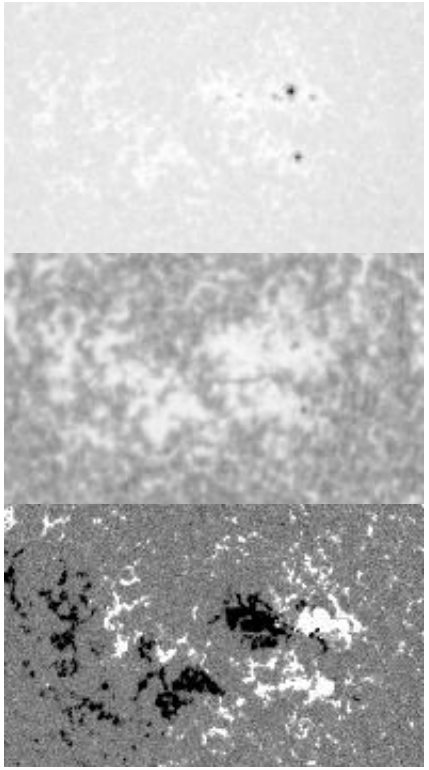
EPRV IV, Grindelwald, March 2019

Outline of the talk



- Stellar signals in RV measurements
  - Impact of magnetic activity and flows on RV
  - Typical amplitudes and scales
  - Dependence on spectral type
- How to mitigate them ?
  - General approaches to test performance
  - Methods





Time scales

Minutes

Hours

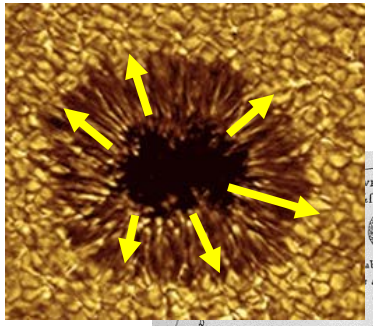
Days

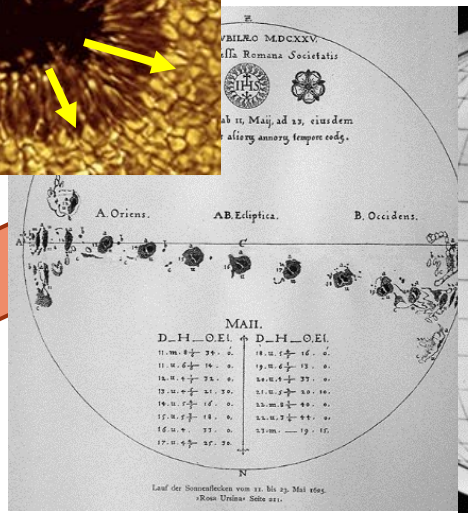
Month

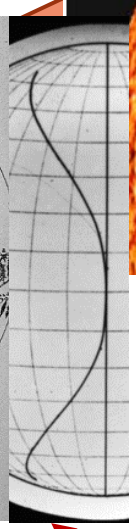
Years

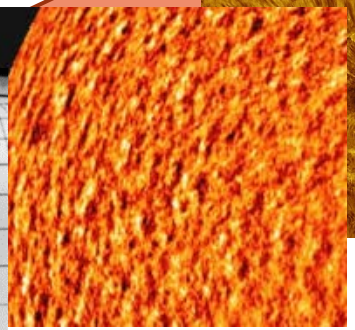
Decades+

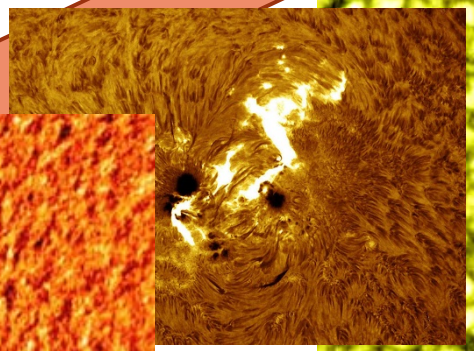
Evershed flows

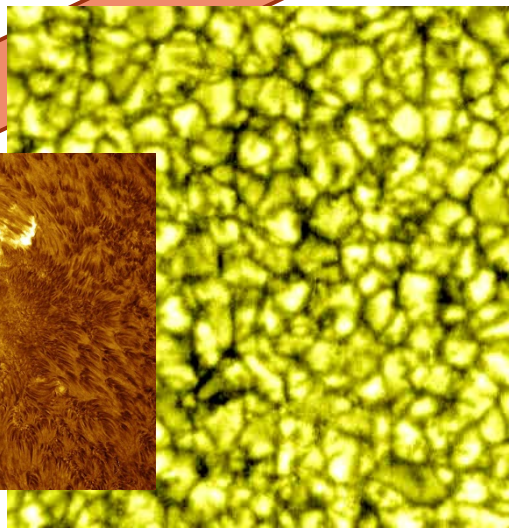










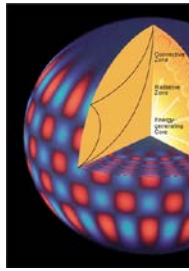


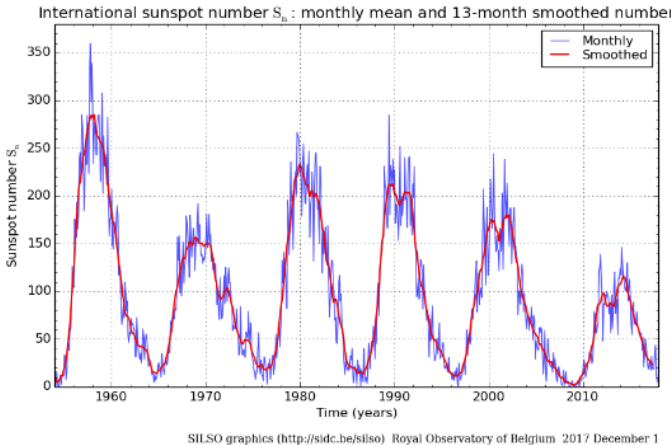
Flares

Supergranulation

Granulation
Oscillations

Convection
inhibition



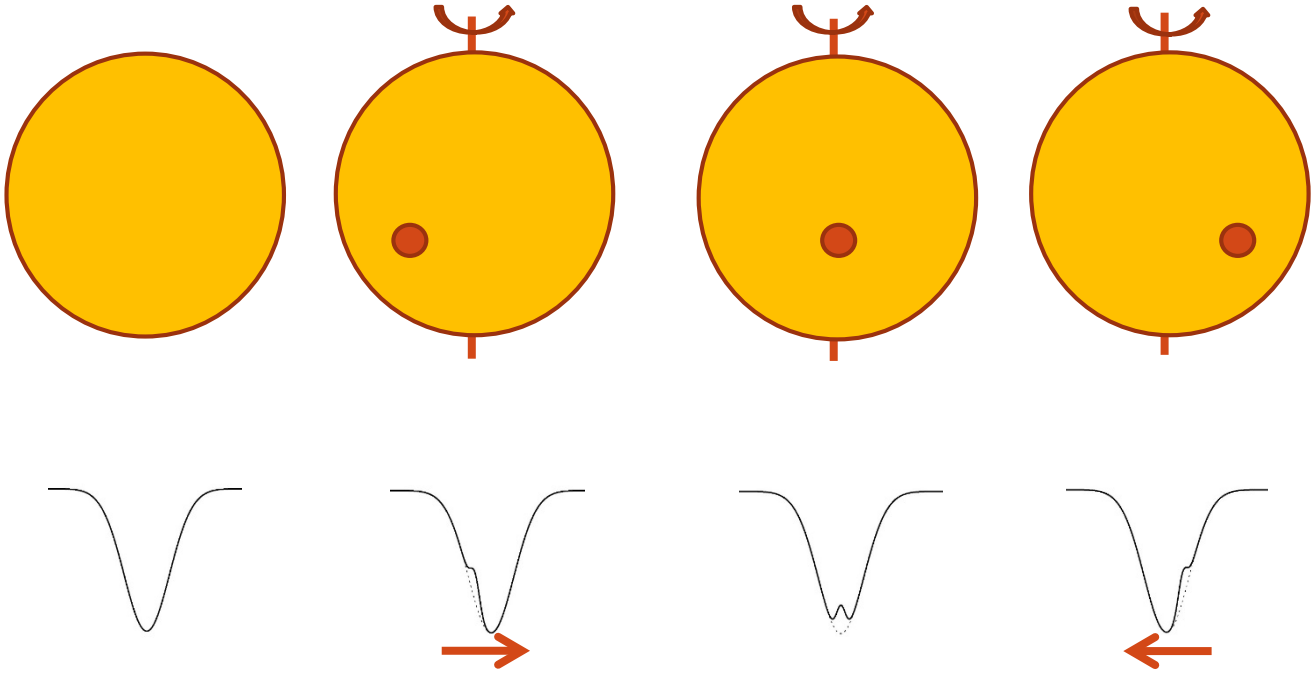


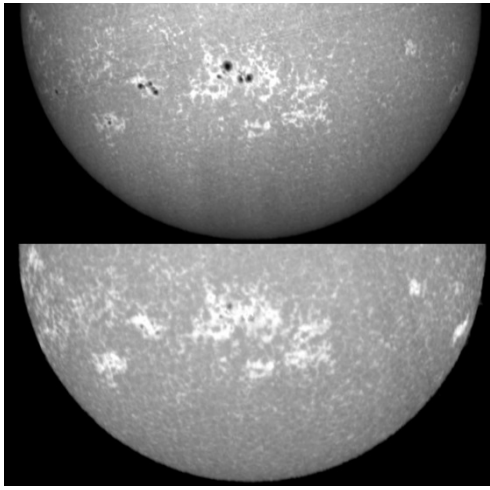
Spots, plages

Rotation Period, cycle
Evolution of structures / lifetime
Large scale flows

Gravitational redshifts (Cegla+12)

Contrast of spots or plages + rotation → spurious RV

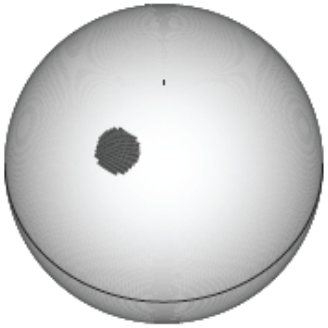


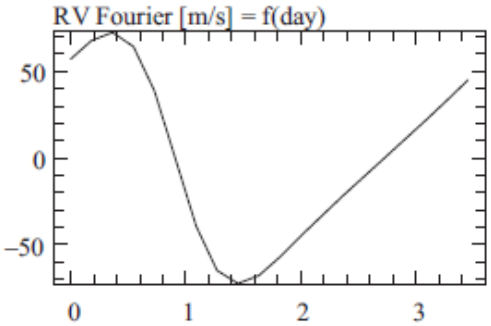


Saar&Donahue97, Hatzes02, Saar+03, Wright05

RV meas. biased >0

RV meas. biased <0

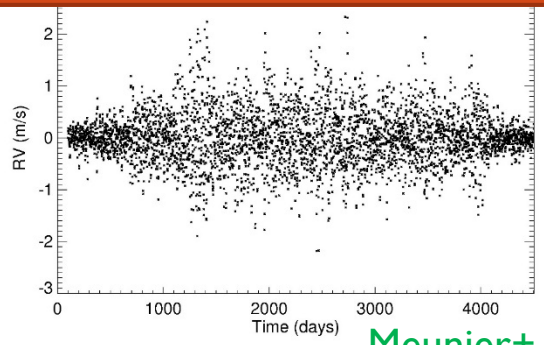




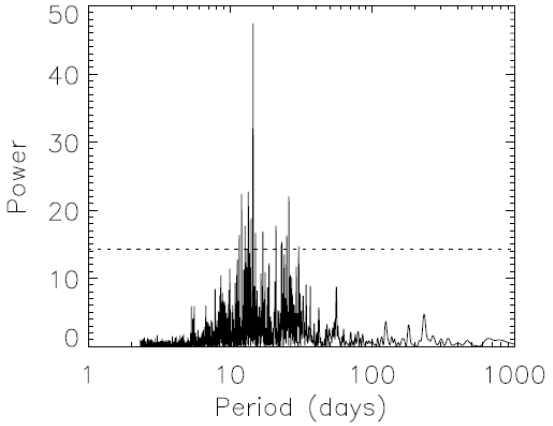
Complex shape
Ex. from Desort+07

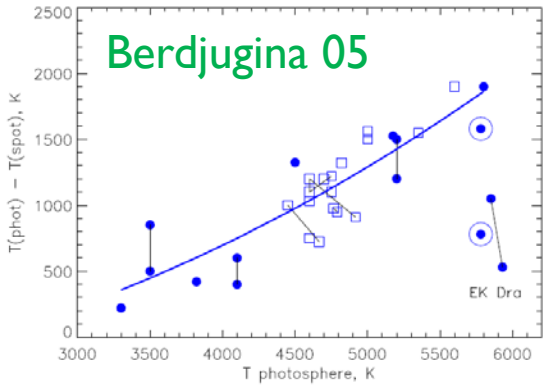
A few properties

- Typical time scales: week-months
  - Finite lifetime + evolution
  - Rotationnal modulation ($\Delta\Omega$, dispersion) + harmonics
- Amplitude in RV
  - RV jitter < 1 m/s for G-K (Sun ~0.3-0.4 m/s)
- Impact of
  - Inclination
  - Wavelength
  - Spectral type, Prot
- Degeneracy spots/plages
- Magnetic fields → Zeeman effect Reiners 13



Meunier+10

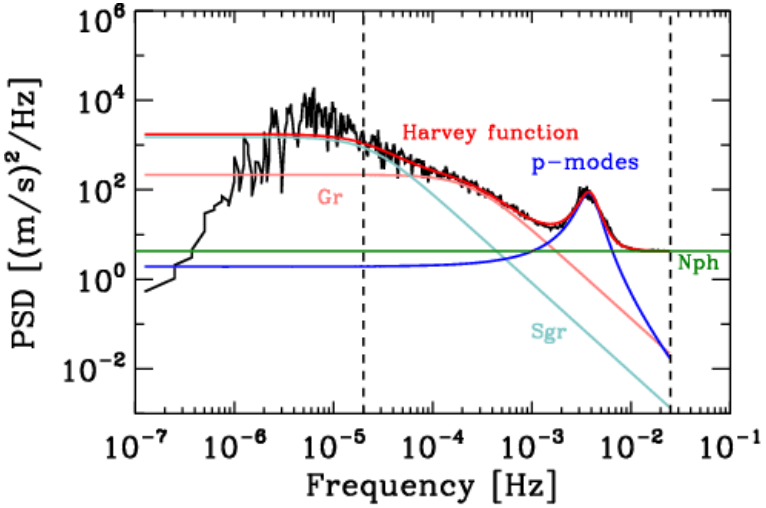




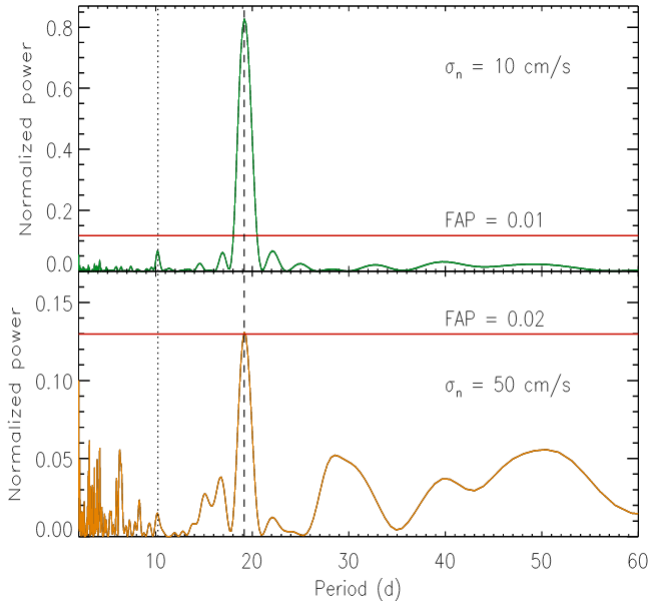
(Norris+18 for plages)

Oscillations

- Typically ~ a few min for solar type stars (p-modes), ~1 m/s
  - Many peaks in the power spectrum with well-defined envelope (Kjeldsen95, …)
  - Easily averaged Dumusque+11, Chaplin+19
- Amplitude and frequency increases slightly with Teff
- New: impact of sectoral r-modes, Lanza+19
  - Main mode for the Sun = 0.44 cm/s; 19.16d

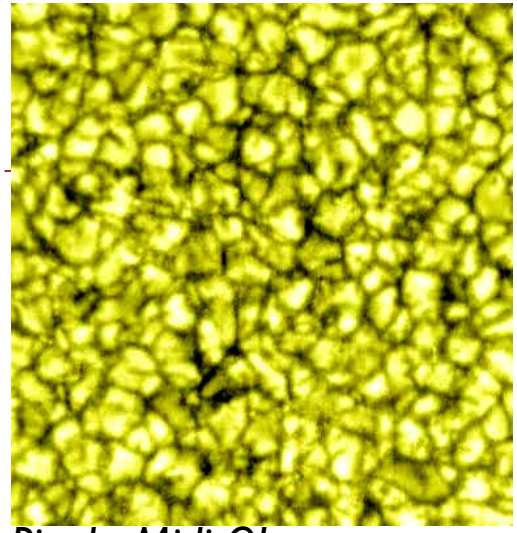


Lanza+19



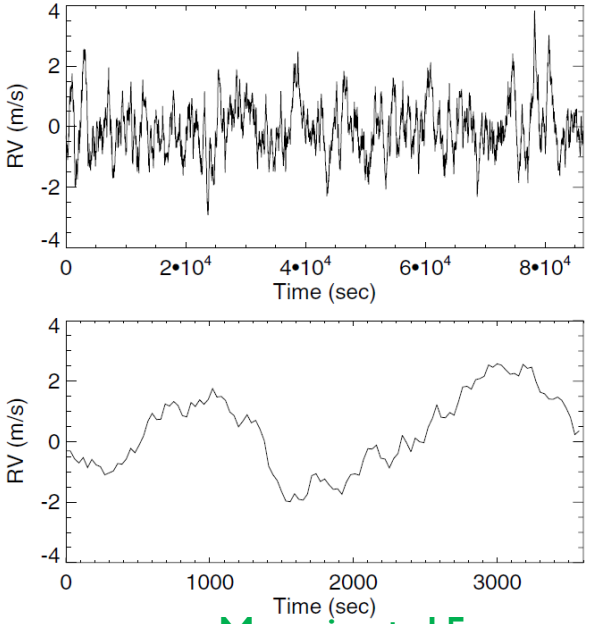
Lefebvre+08 + many other papers Harvey85

Granulation



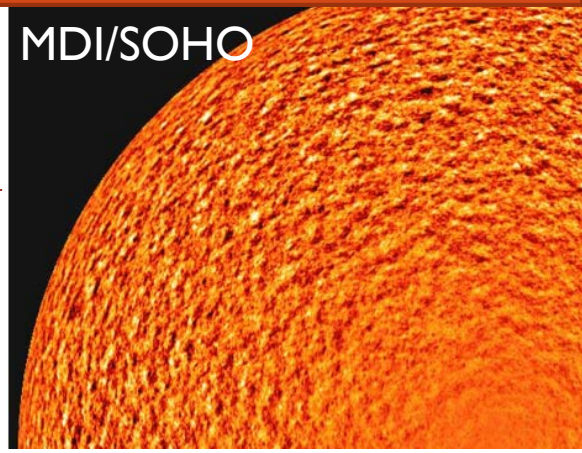
Pic du Midi Observatory

- Typical scales for the Sun
  - Lifetime ~10 minutes (but large distribution)
  - Size ~1000 km
  - ~10^6 cells
  - Flows ~km/s
- RV jitter due to solar granulation ~0.8 m/s (Meunier+15)
  - Different realisations of the 10^6 granules over time
  - MHD numerical simulations Cegla+18
  - Increases with Teff: numerical simulations Magic+, Beeck+, … observation Gray 09, Dumusque+11, Meunier+17,18
- Strong distorsion of the line shape
  - Complex bisector shapes
  - + the convective blueshift
- Possible to average (Dumusque+11) but difficult to reach a very low level



Meunier+ 15

Supergranulation

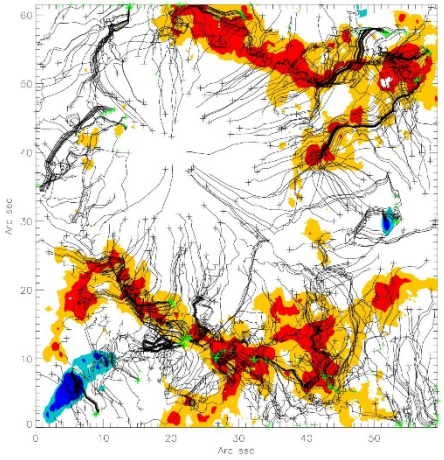


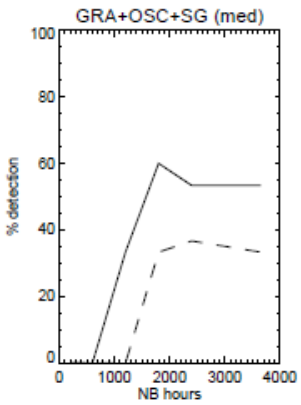
- Large cells outlined by the magnetic network
  - Solar lifetimes ~24-48h
  - Size ~30000 km
  - Flows ~200-300 m/s

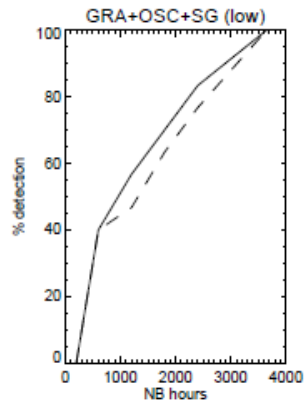
See reviews
Rieutord+10
Rincon+18

- RV jitter not well constrained
  - Slower flows but less cells on the surface → Jitter remains strong !
  - Solar : estimation median value 0.7 m/s (low estimate 0.3 m/s Meunier+15)
  - Observed in other stars (Dumusque+11)
- Probably a more important problem than expected!
  - More difficult to average out
  - Power at long periods
  - No intensity counterpart
  - →Low detection rates Meunier+19 subm. →

Roudier+16



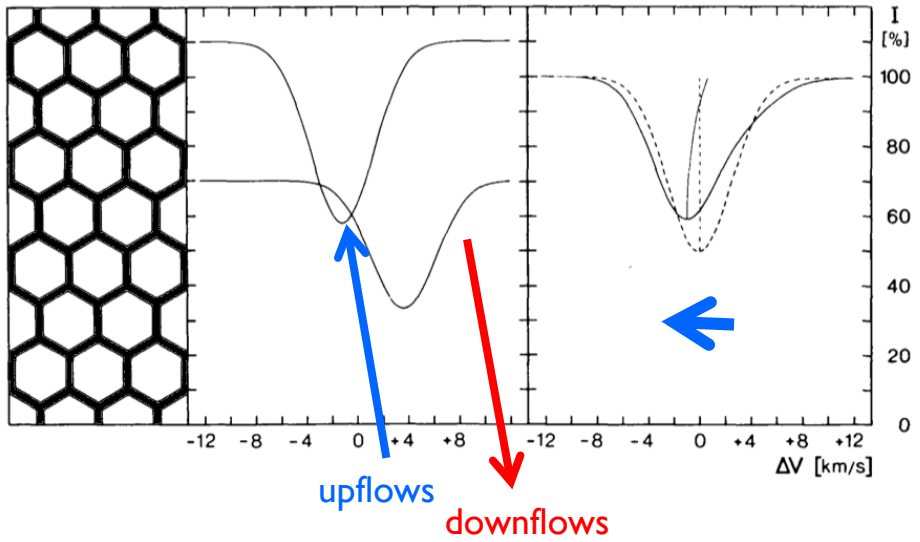




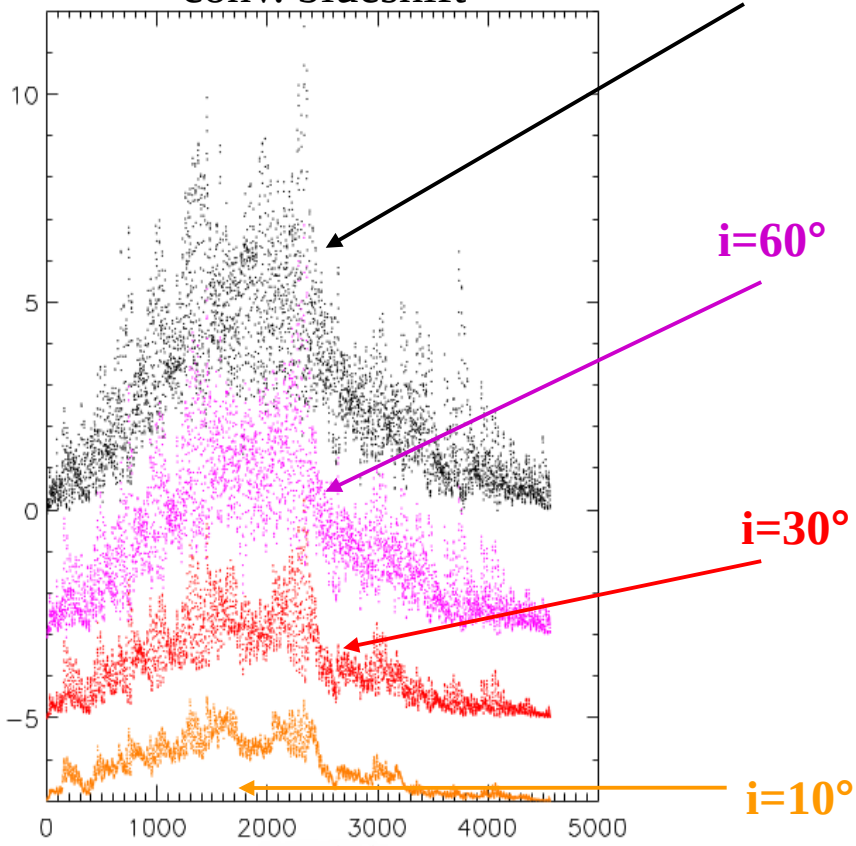
Attenuation of the convective blueshift in plages → related to flows and magnetic fields

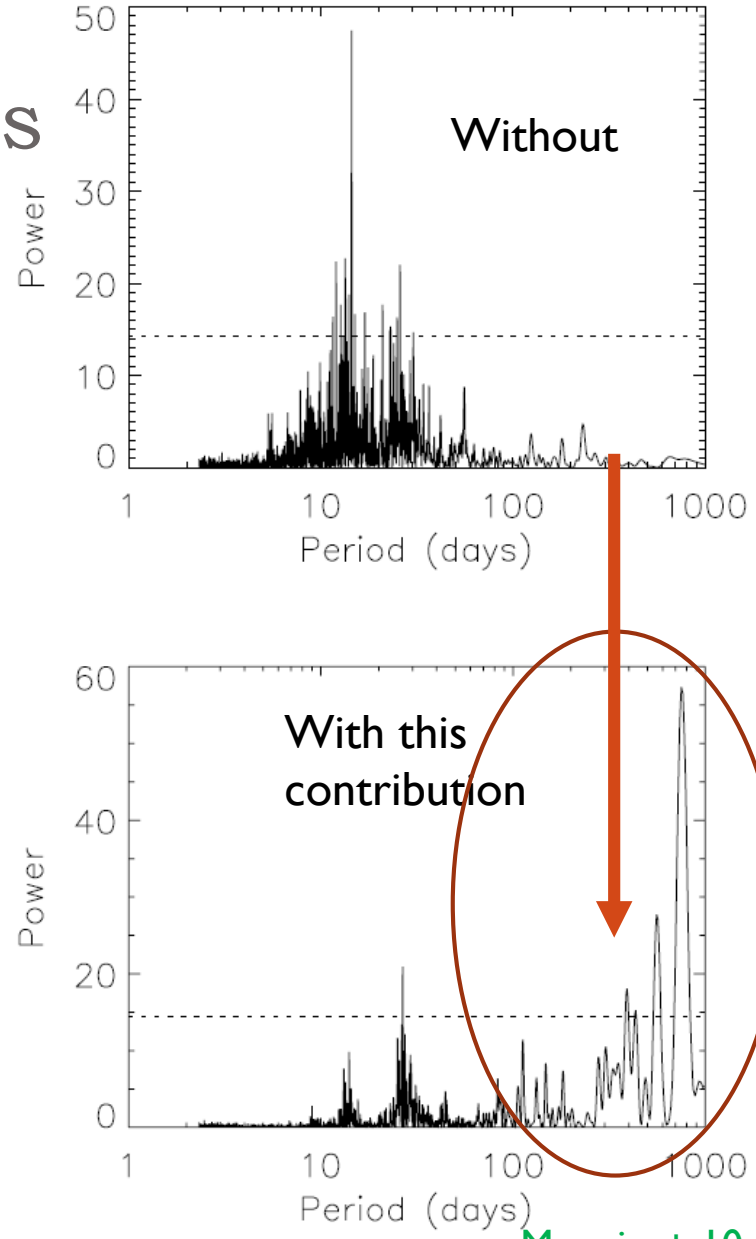
- Net redshift, depending on the activity level
  - All structures contribute
  - Stronger for large active regions
- Signal both at short timescales (Prot) and cycle
- Solar case = dominant RV component
- (in spots = very small signal)

Dravins 81, …



Impact for solar-type stars



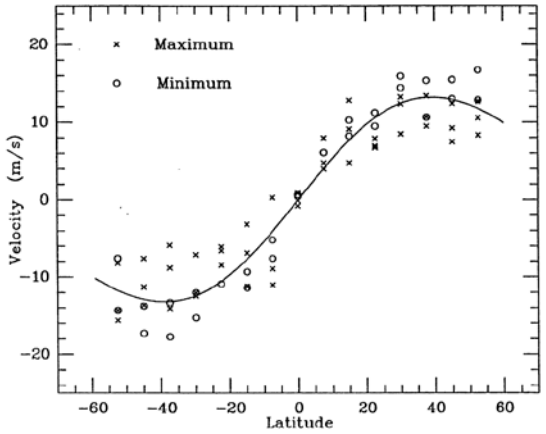


Meunier+ 10

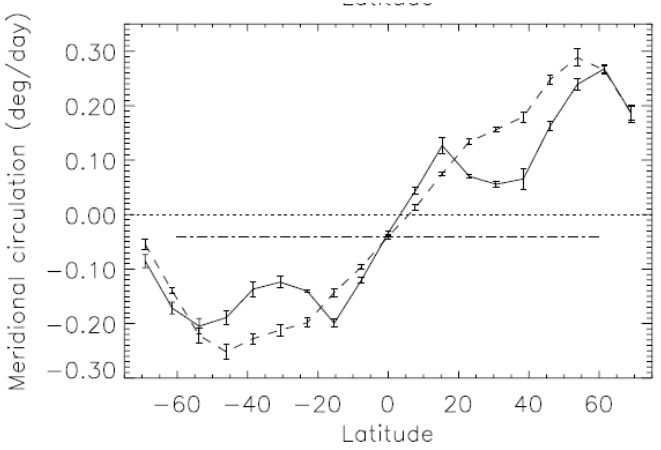
Borgniet+ 15

Large-scale flows

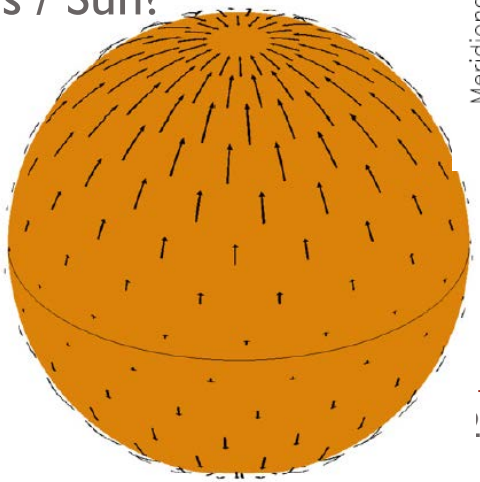
- Impact of meridional circulation Makarov 10
  - Inclination
  - Expected impact on long timescales (cycle)
- Solar meridional circulation
  - Toward the pole, amplitude max ~10-20 m/s
  - Possibly with complex pattern in latitude
  - Small variation over the cycle
- On other stars?
  - Decreases for fast rotators (Ballot+07) and with decreasing mass (Matt+11, Ωfixed)
  - Lower mass - slower rotators / Sun?



Komm+ 93 (and many other papers)



Meunier 99



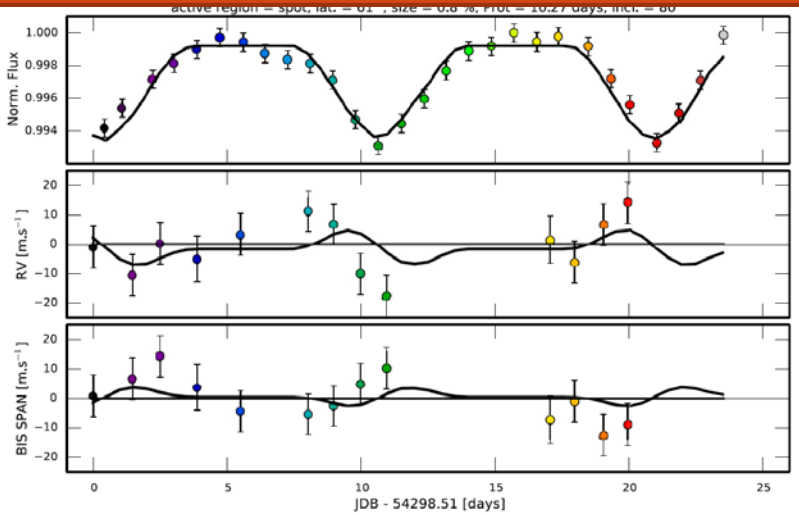
Approaches at our disposal

- Simulations: solar and stellar
  - Simulation of simple or complex configurations
  - Fitting challenge (Dumusque+16,17)
- Solar observations
  - Solar - integrated RV + many other variables
  - To be compared with disk observations
  - **Indirect**: Meunier+10 (MDI), Lanza+16 (asteroids, …), Haywood+16 (SDO)
  - **Direct**: HARPS-North and South Dumusque+15, Phillips+16, Collier-Cameron+19, …
- In addition to tests on actual stellar observations
  - RV jitters Saar+98, Santos00, Wright05, Isaacson & Fischer10
  - Cyclic variations Lovis+11


Credit: X. Dumusque

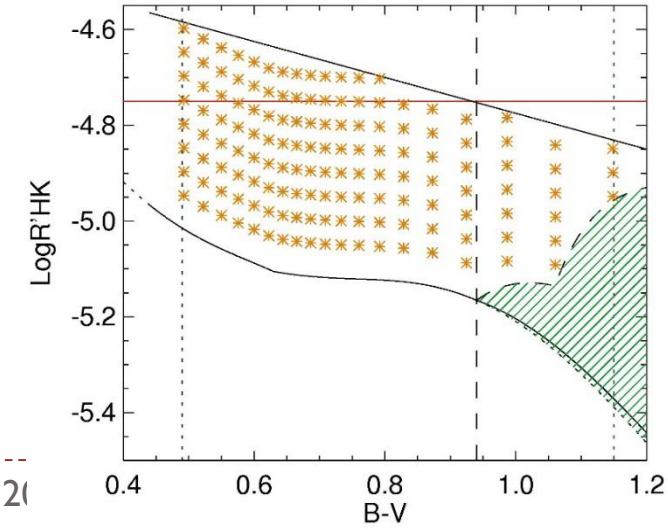
Activity simulations

- One / a few spot(s)
  - SAFIR Desort+ 07
  - SOAP/SOAP2 Boisse+ 12 Dumusque+ 14
  - Starsim Herrero+ 16
  - … (many references / tools !!!)
  - **To derive typical RV amplitudes and shapes for simple activity configuration**
  - **To study fine effects**
  - **To model observations**
- Complex & realistic activity pattern of spots and plages / solar like stars
  - Observed Sun (Lagrange+ 10, Meunier+ 10,12,13) ➔ Simulated Sun (Borgniet+ 15) ➔ Simulated stars F-G-K (Meunier+19 acc., 19b, 19c subm.)
  - Dumusque+16 (fitting challenge)
  - See also Santos+15 for spots only
  - **To derive detection limits**
  - **To test samplings, correction methods**



Dumusque+ 14

Meunier+19



Methods

Based on RV time series

SPOTS/PLAGES

Fits of sinusoids / harmonics Boisse+11

Prewhitening at Prot Queloz 09, Hatzes+ 10

Spot modeling Moulds+ 13 Dumusque+ 14 Herrero+ 16

OSCILLATIONS/GRANULATION

Averaging (for oscillation/granulation) Dumusque+ 11 Meunier+ 15

Correction with periodograms (for granulation) Sulis+17

Using other indicators from the spectra

Correlation with line bisector span Desort+ 07, Boisse+ 09

Doppler imaging Hebrard+16

Chromospheric emission Boisse+09, Pont+10,Dumusque+12, Meunier+ 13 Robertson+14,Rajpaul+15,Lanza+16, Borgniet+17

With the use of Bayesian analysis (Gaussian processes…) & activity indicators Dumusque+17: Rajpaul+ 15, Tuomi+, Damasso+, Gregory, …

Using different sets of RVs

Using selected sets of lines (depth) Meunier+ 17

Combining different line properties Dumusque+18

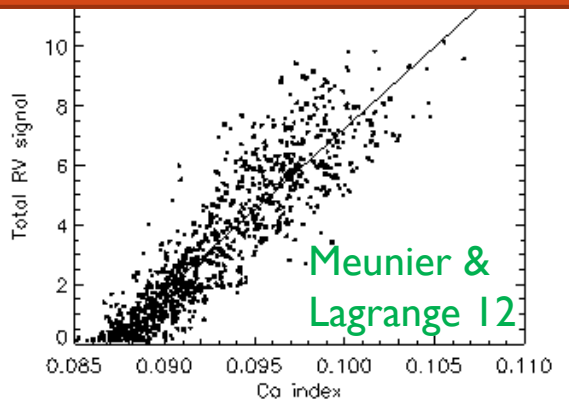
Wavelength dependence/chromatic index Tal-Or+ 18

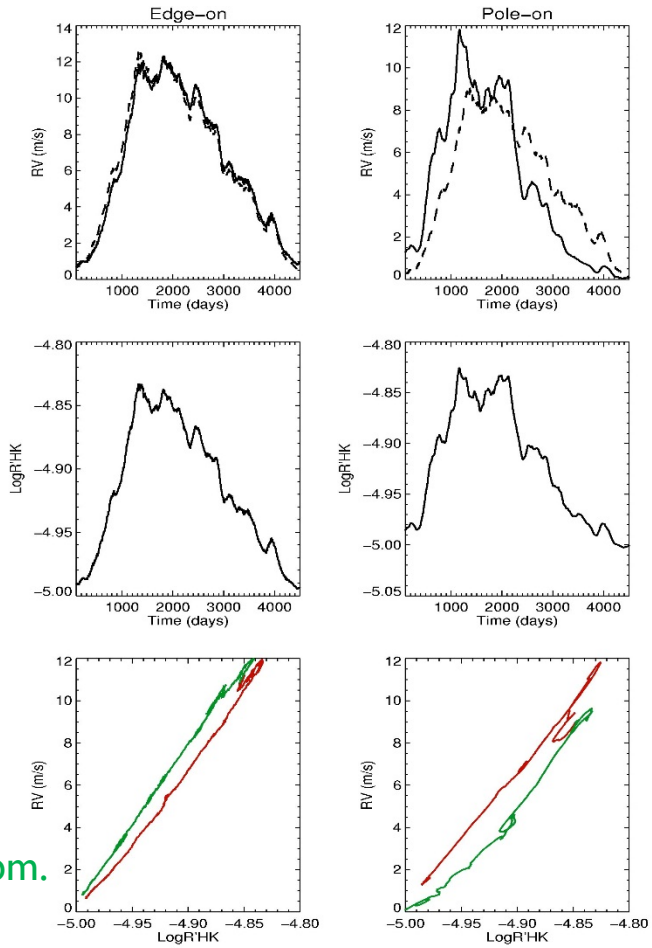
Some limitations

- **All these techniques reduce** the RV jitter due to the stellar signal to some level
  - Reliability of the residuals?
  - Do we introduce spurious « planetary » signal? Remove the planetary signal?
- Residual jitter still **too high to allow the detection of a one Mearth planet in the habitable zone** of a solar type star
  - See results of the fitting challenge Dumusque+17
- Causes
  - **Observing conditions**: sparse temporal sampling, noise…
  - **Stellar activity**: degeneracies between contributions, very stochastic processes, complex frequency behavior
  - **Incomplete models**: lack of knowledge, Prot not well known / not unique, missing processes?

Example: correction using chromospheric emission

- Widely used
  - Leads to significant improvment
- Correlated with plage filling factor
  - More complex at short times scales
- Performance from simulations
  - Solar case need excellent S/N and sampling Meunier&Lagrange12
  - Departure from correlation during cycle, depends on inclination, spectral type, amplitude
  - Impact correction based on direct correlation
  - On-going work to improve the correction





Meunier &
Lagrange 19 subm.

Conclusion

- Stellar activity: complex processes, always there
  - Lots of degeneracies
  - Huge diversity, poorly constrained (and still a lot to understand about the Sun!)
  - Lots to learn about stellar activity on the way
- Other factors
  - Usually sparse sampling in RV, bad phase coverage (Prot)
  - Superposed on other contributions (other planets, instrumental…)
- Future progresses
  - Data analysis: combine many indicators, and different approaches
  - Wavelength coverage (Visible/IR)
  - **Instrumental noise/stability: allow to use more sophisticated techniques**
  - **Need for a lot of telescope time**