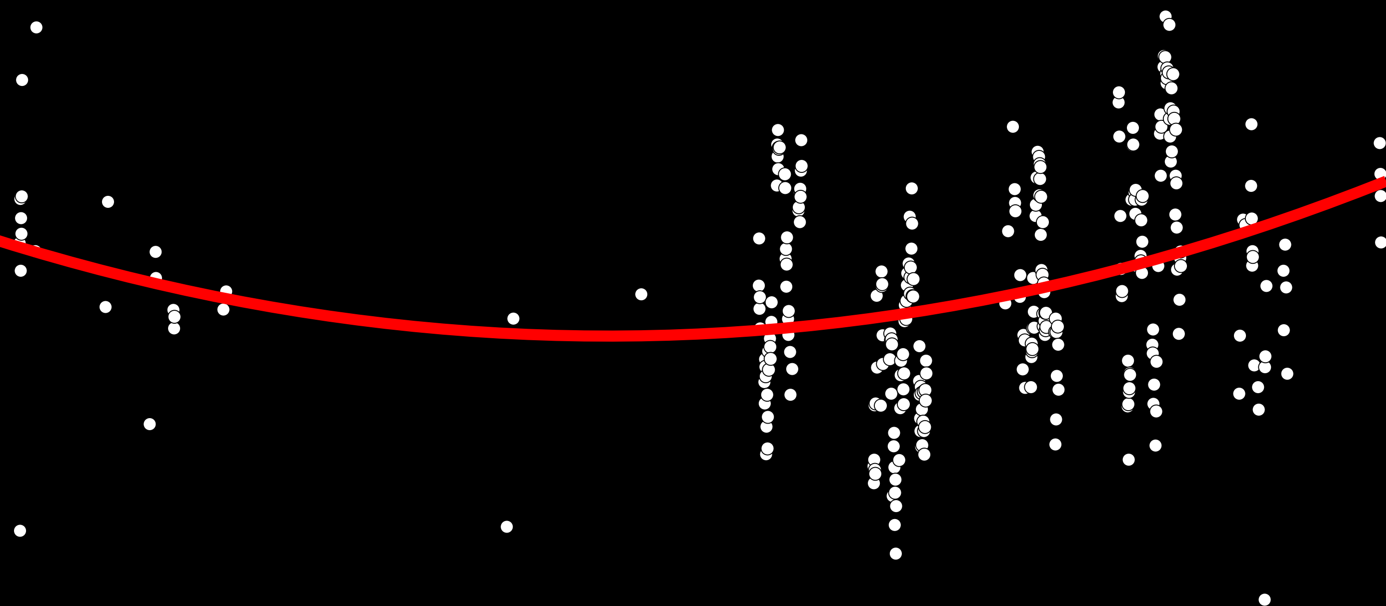
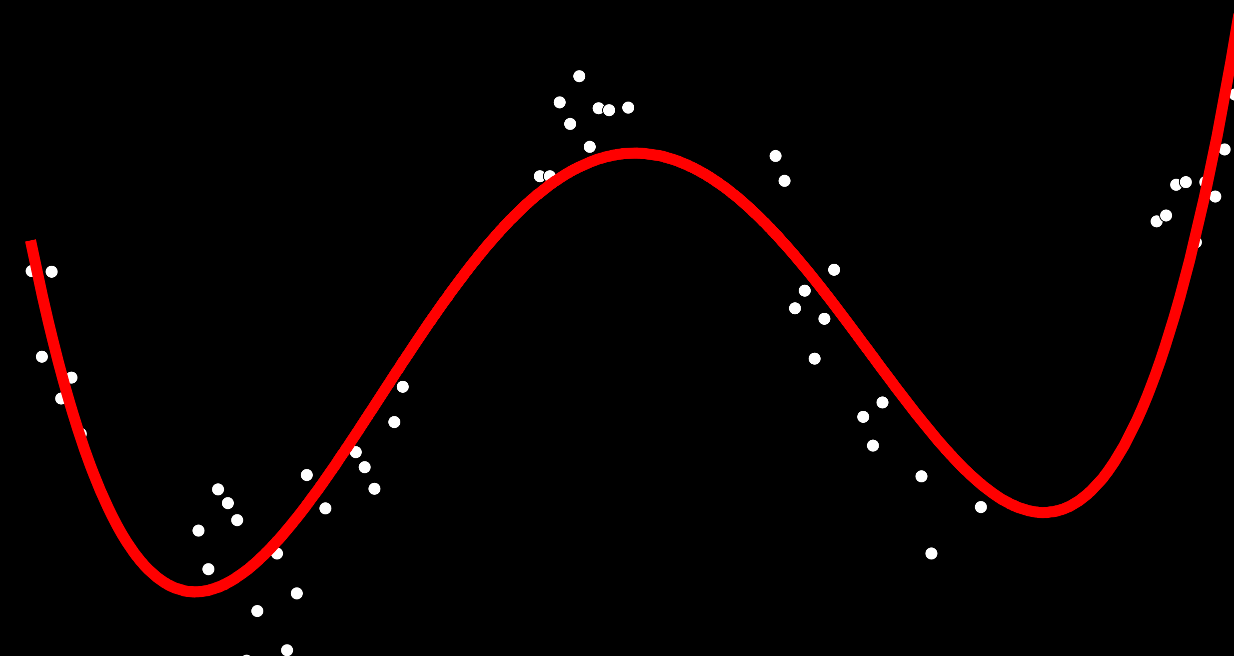
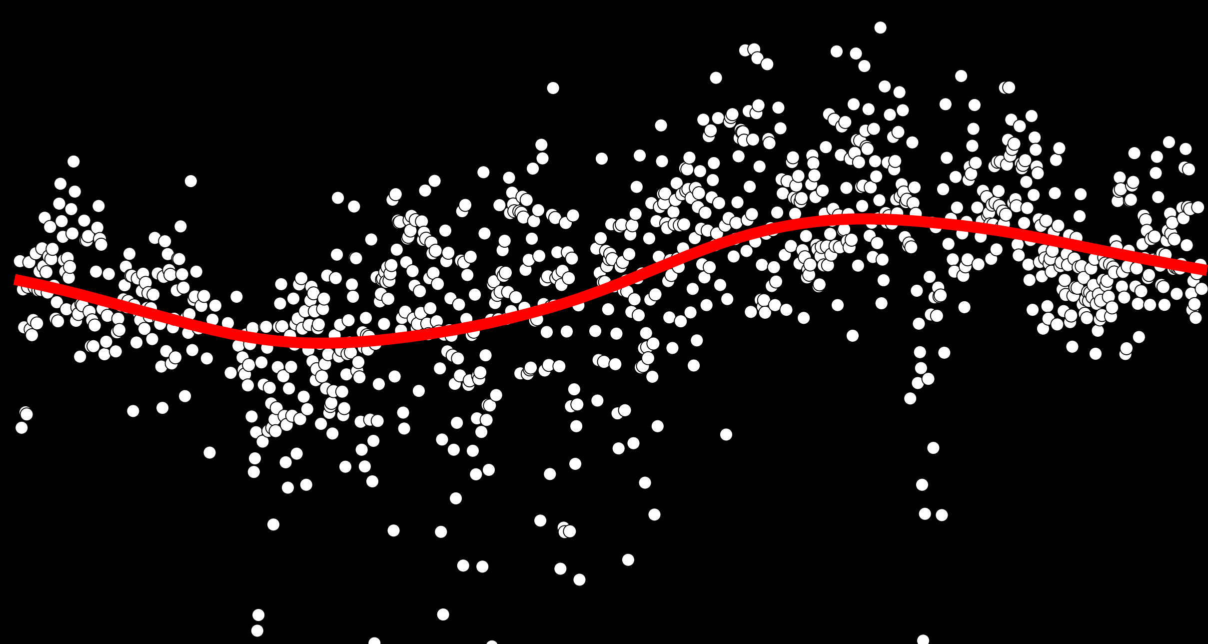
Stellar Signals in Radial Velocity Measurements

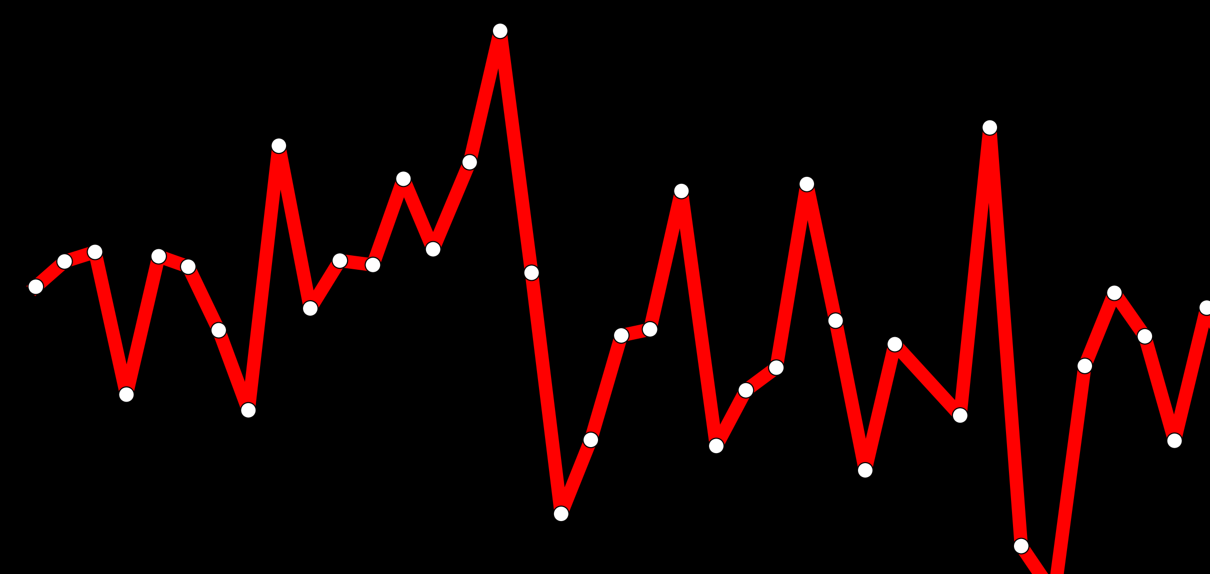




CfA

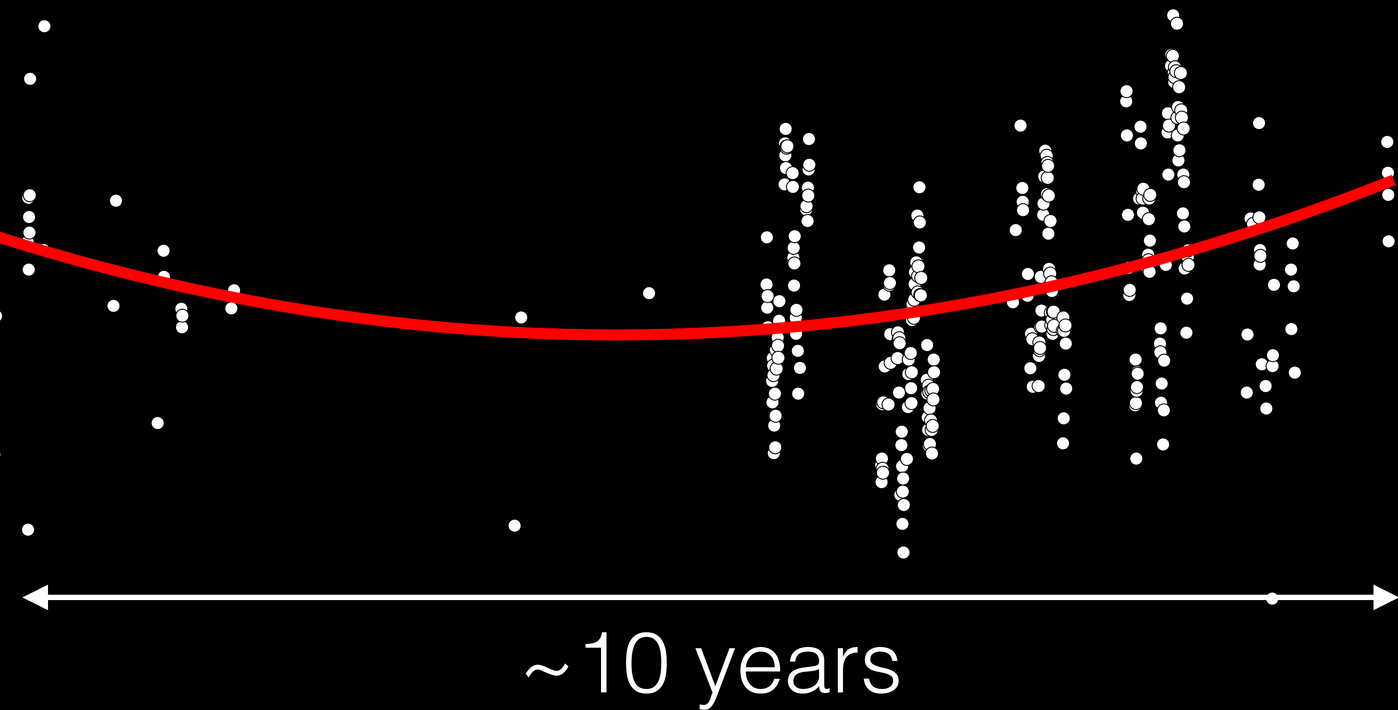


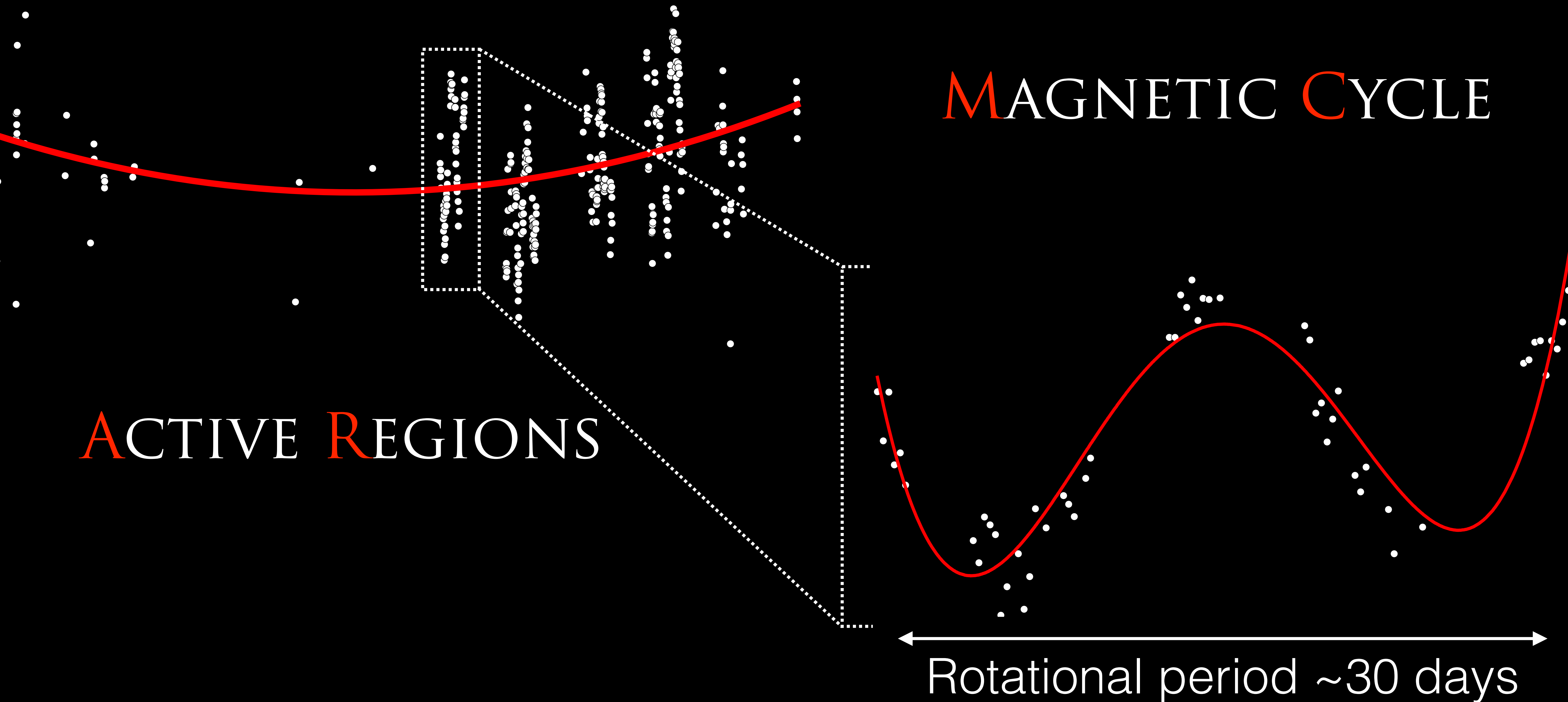
ToE Porto 2014

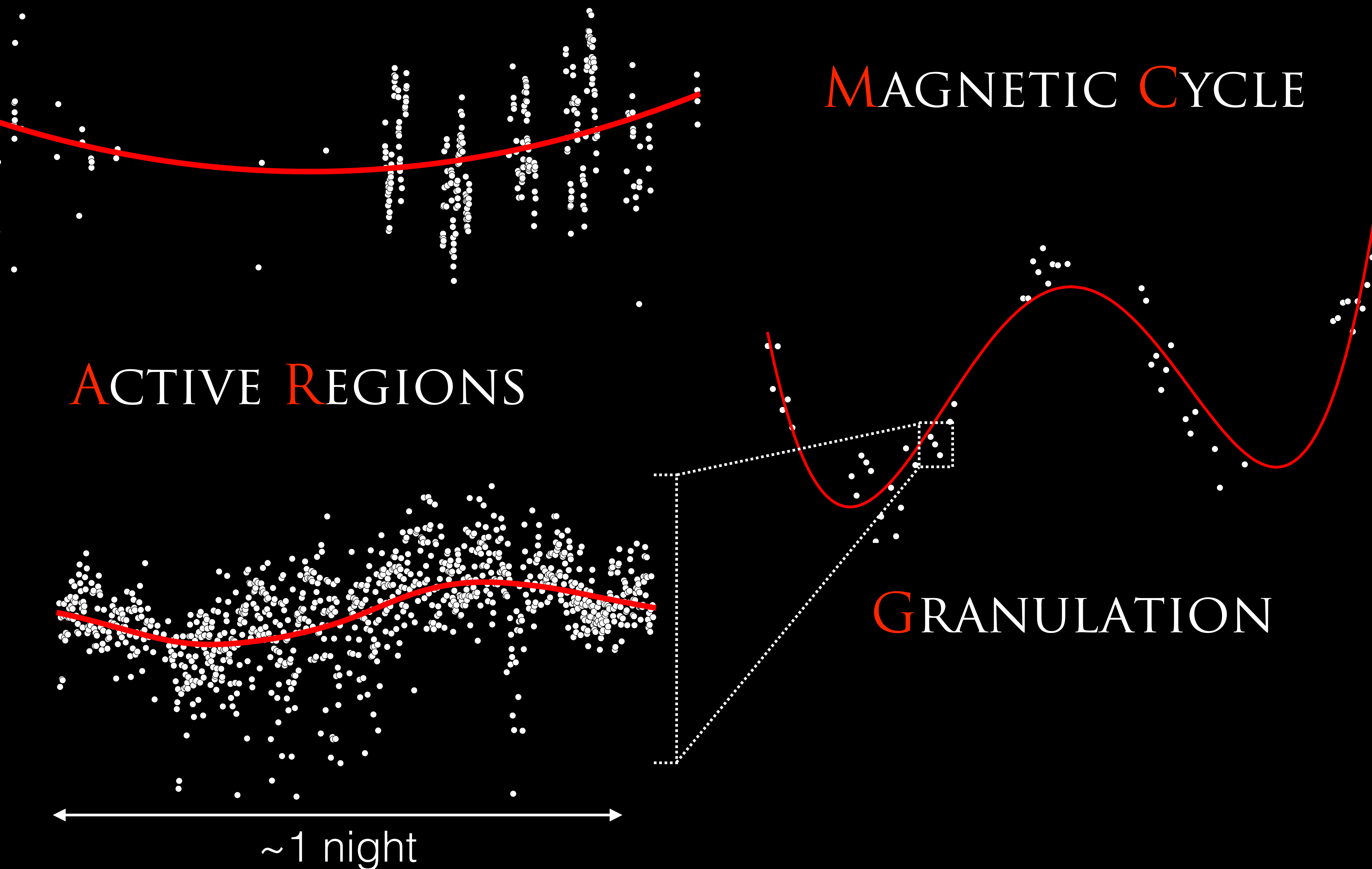


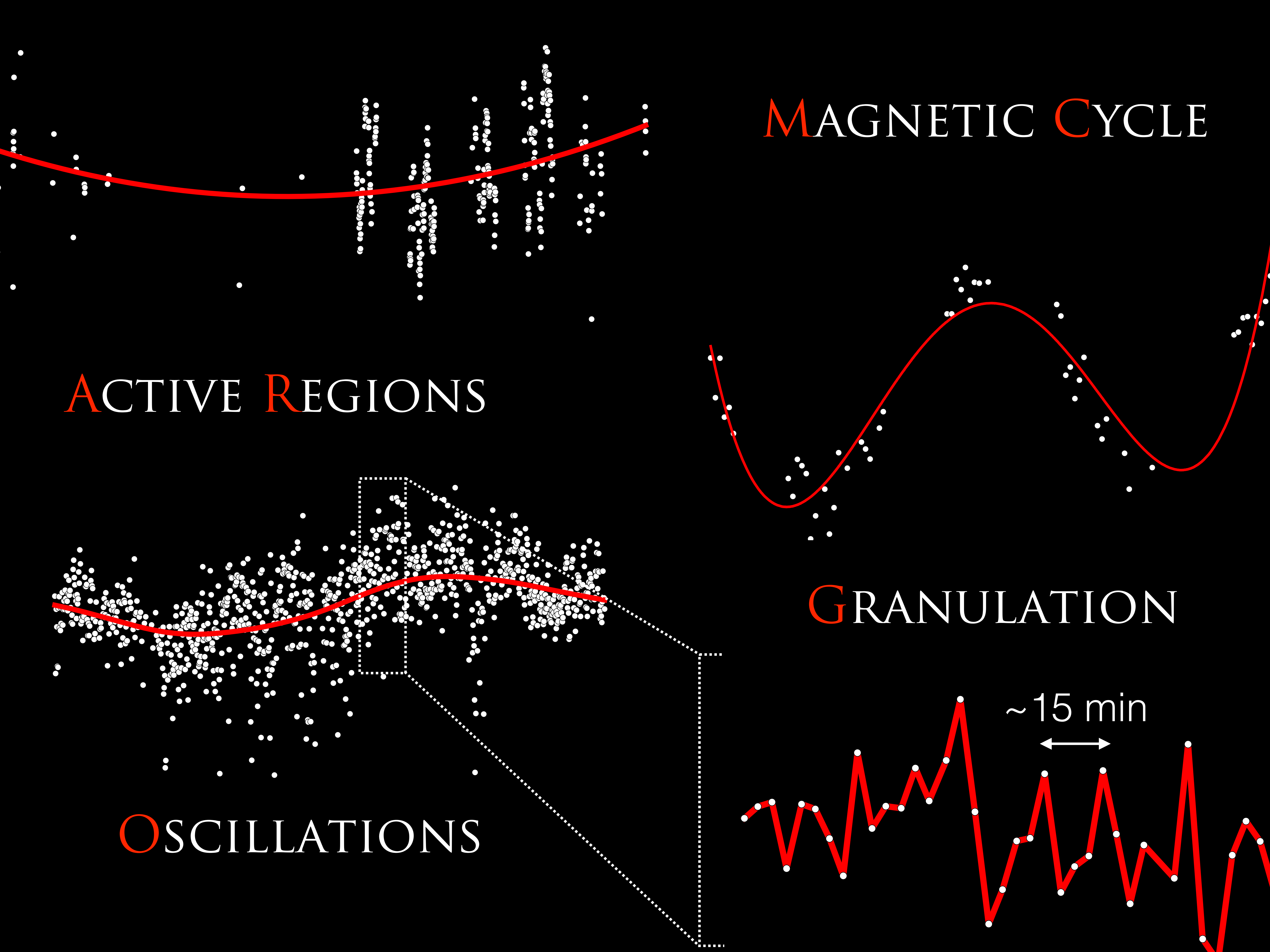
Xavier Dumusque

Magnetic Cycle




MAGNETIC CYCLE
ACTIVE REGIONS
Rotational period ~30 days

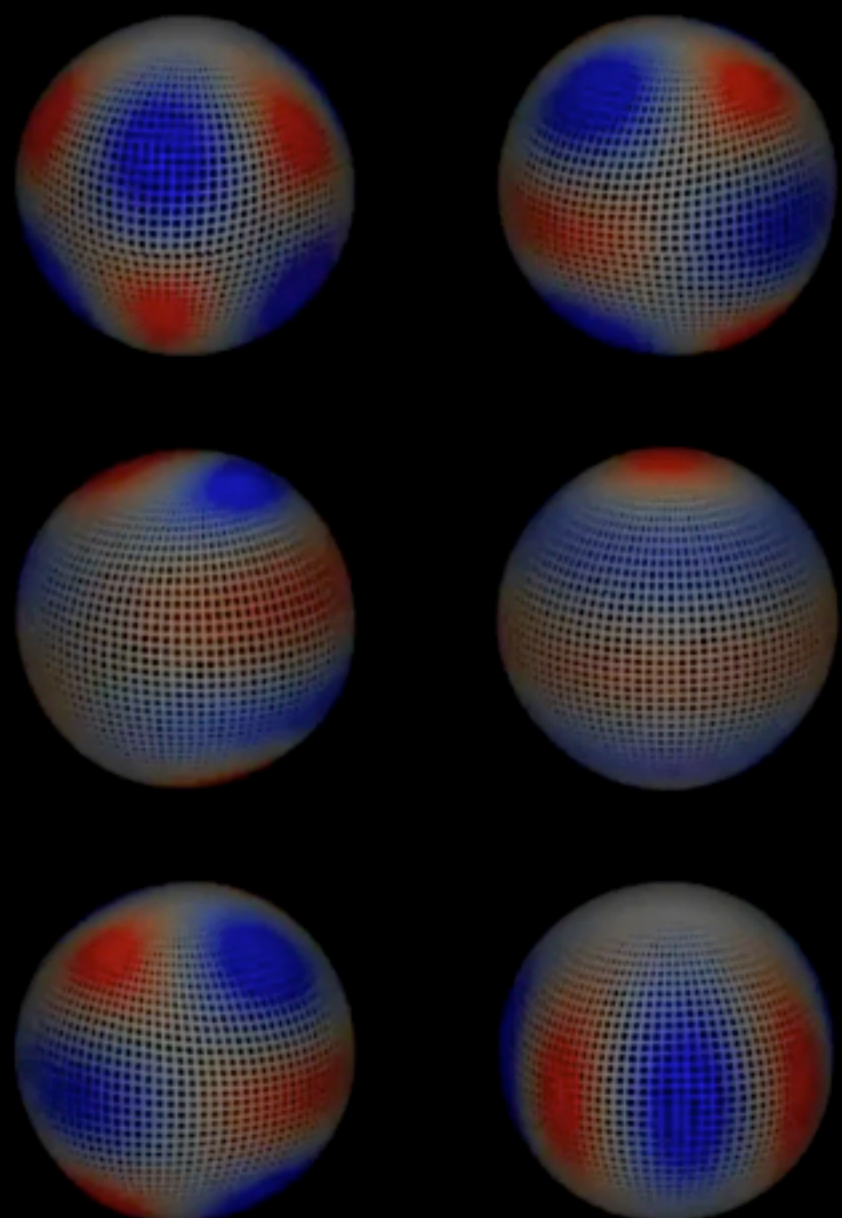

Magnetic Cycle
Active Regions
Granulation
~1 night

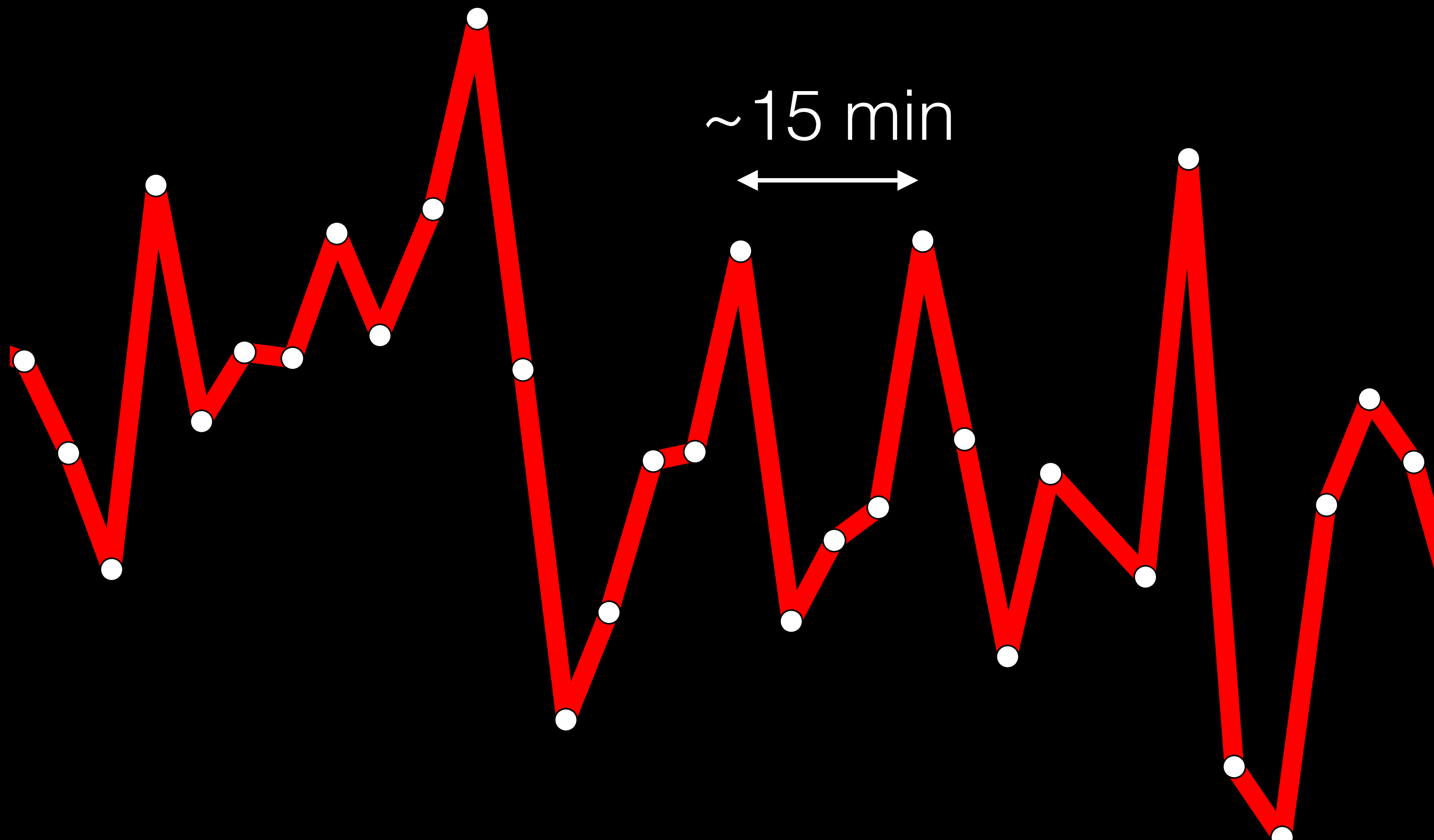

MAGNETIC CYCLE
ACTIVE REGIONS
GRANULATION
OSCILLATIONS
~15 min

Oscillations

Oscillations

a few m/s (Dumusque+ 11)





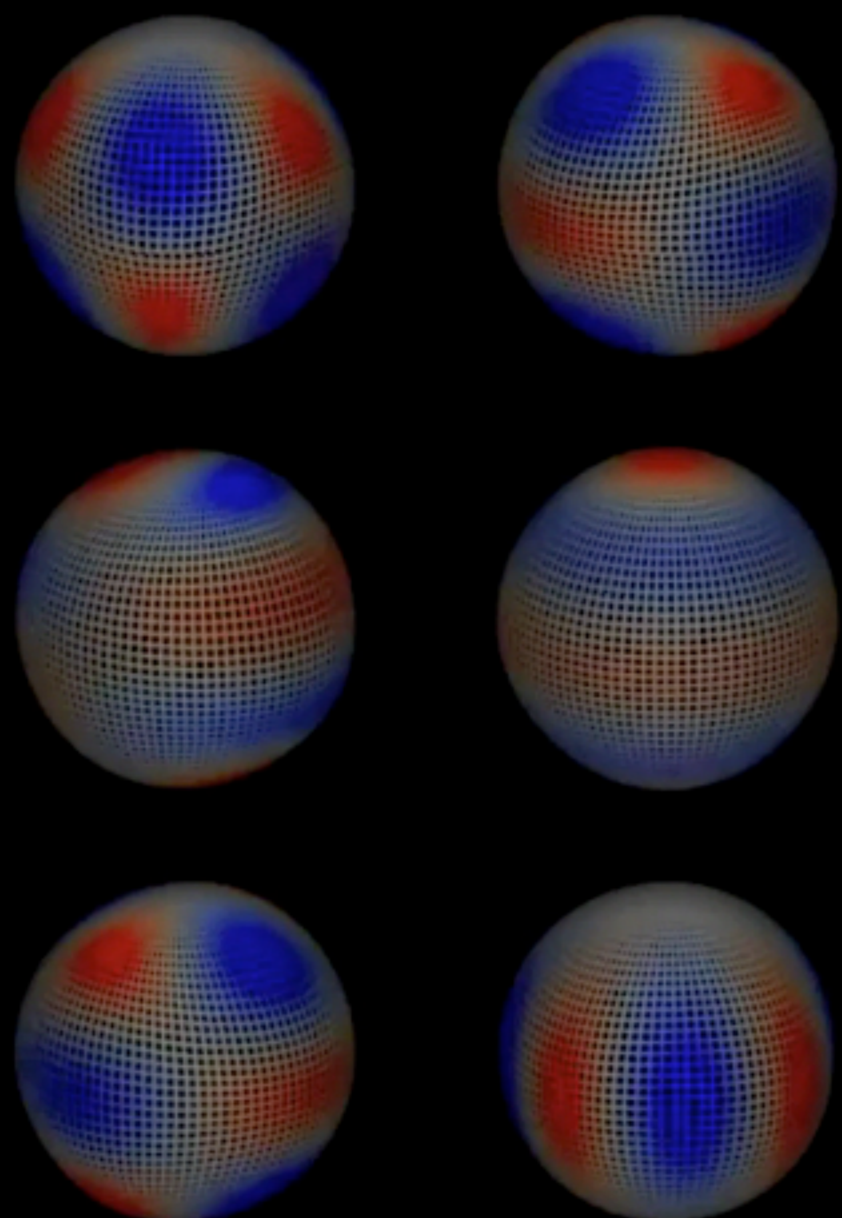
Credit: Charpinet

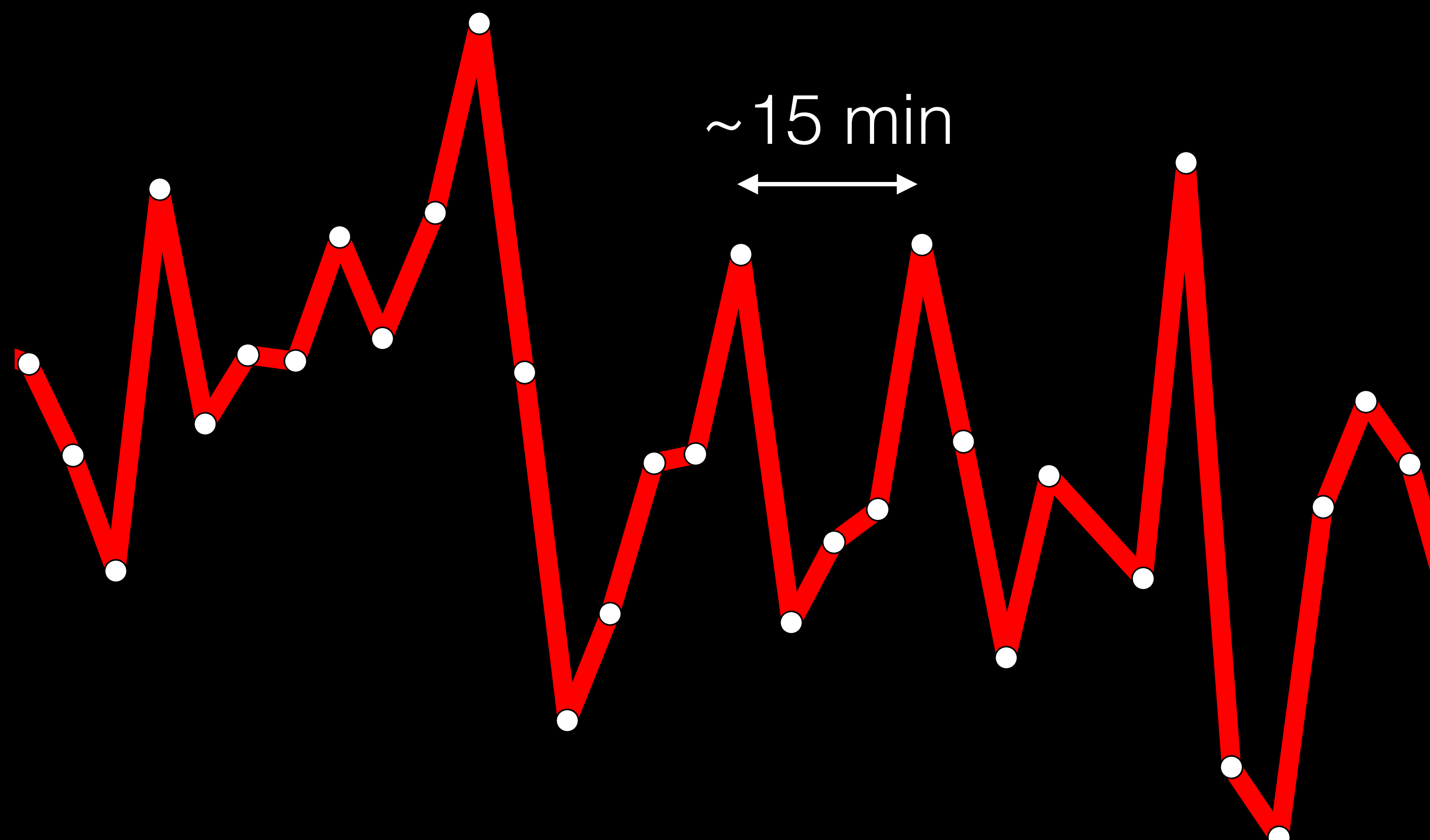
Kjeldsen+ 95, Bouchy & Carrier 01, Butler+ 04, Bedding & Kjeldsen 07

Oscillations

Oscillations

a few m/s (Dumusque+ 11)



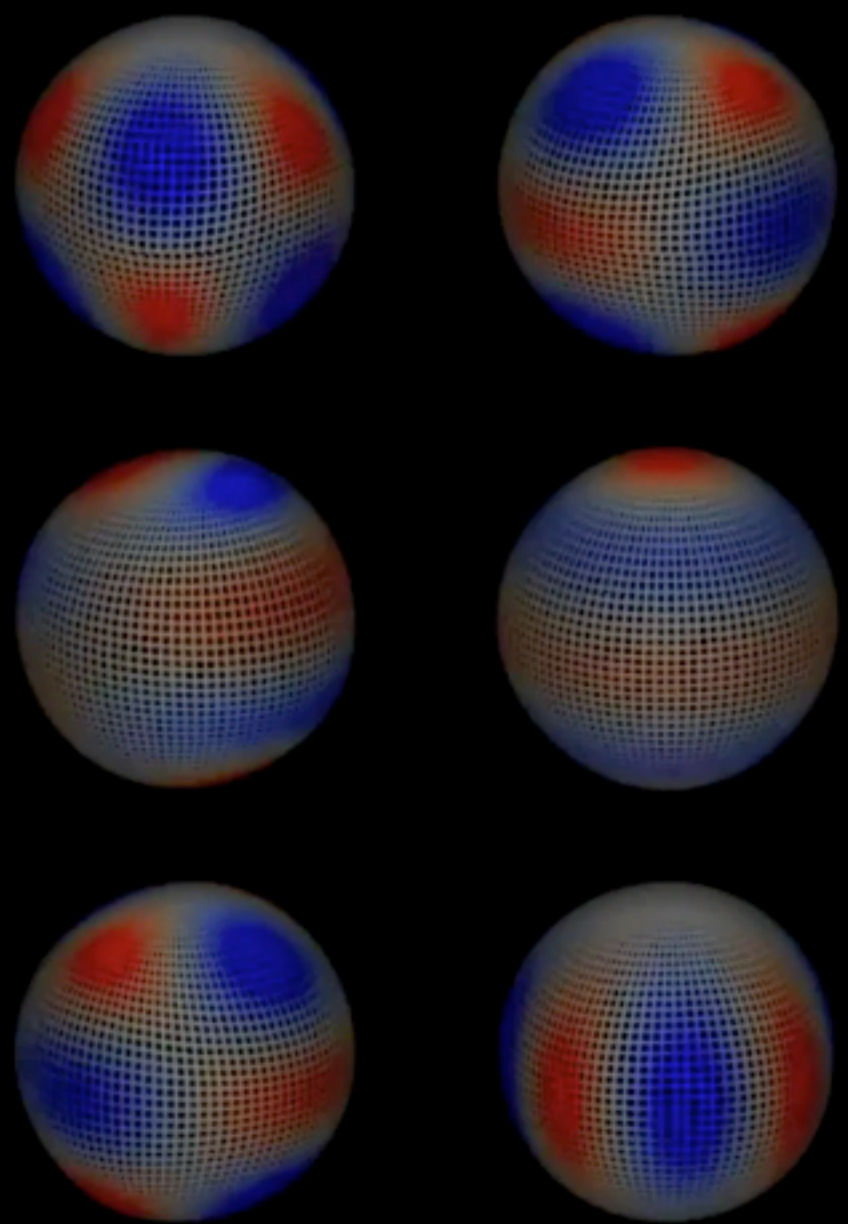


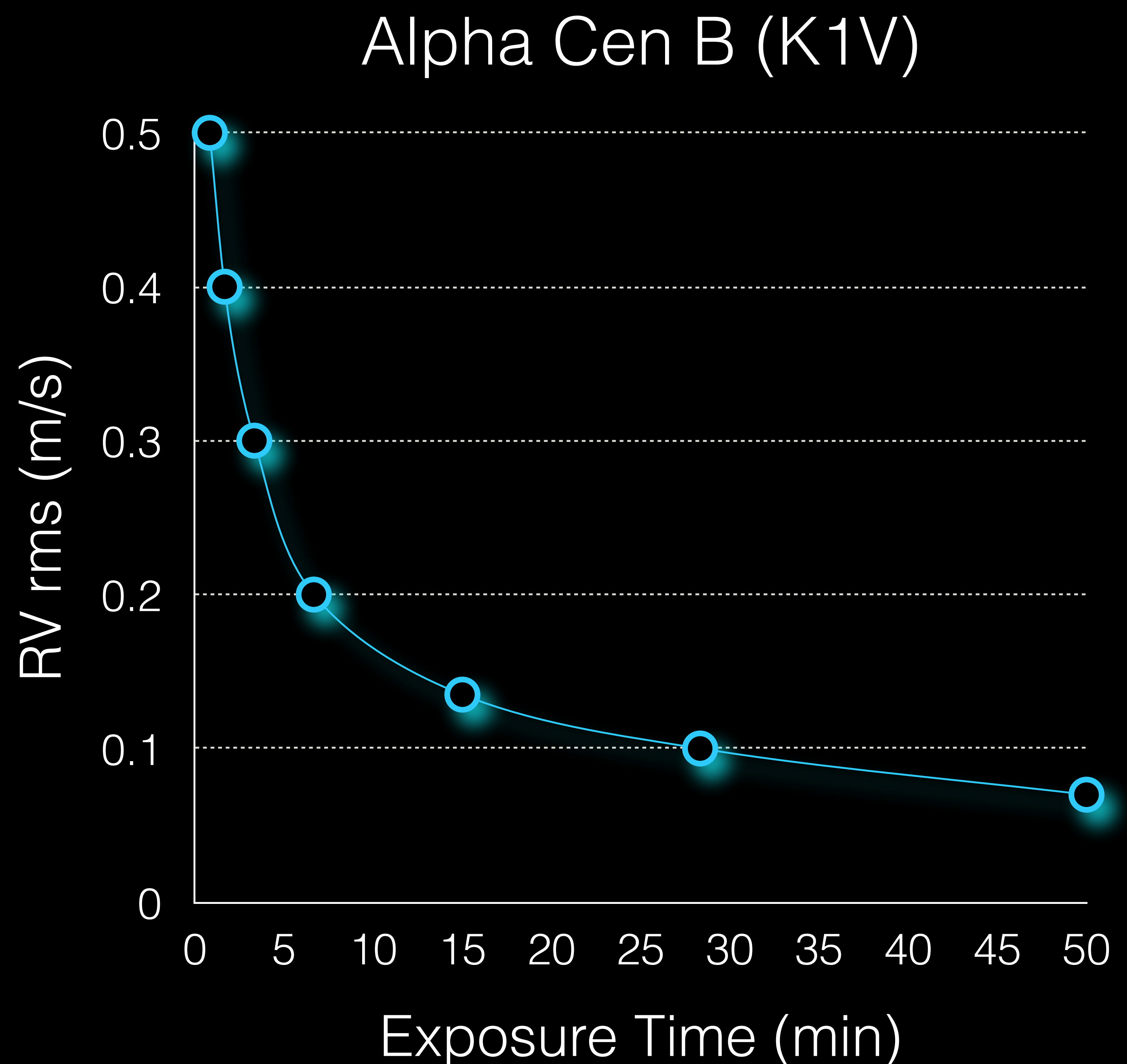
Credit: Charpinet

Kjeldsen+ 95, Bouchy & Carrier 01, Butler+ 04, Bedding & Kjeldsen 07

Oscillations

Oscillations

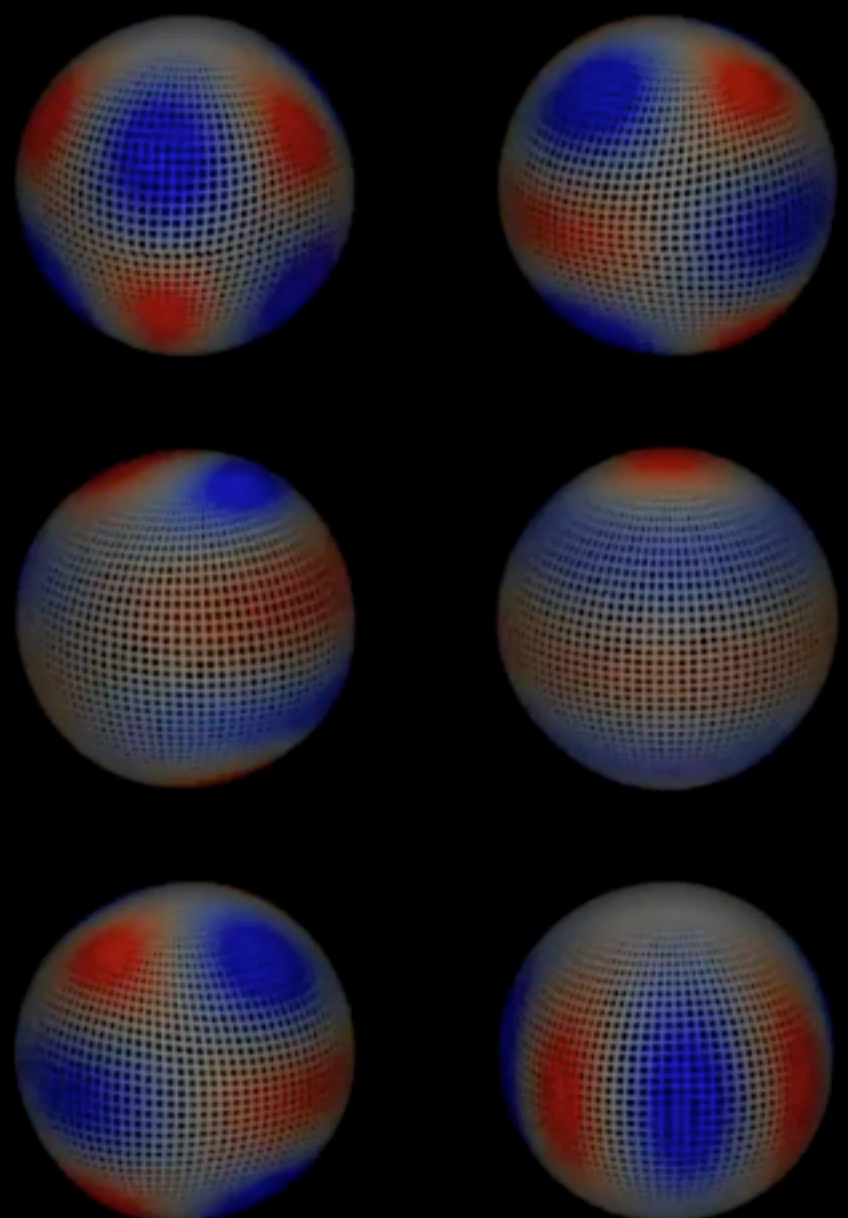


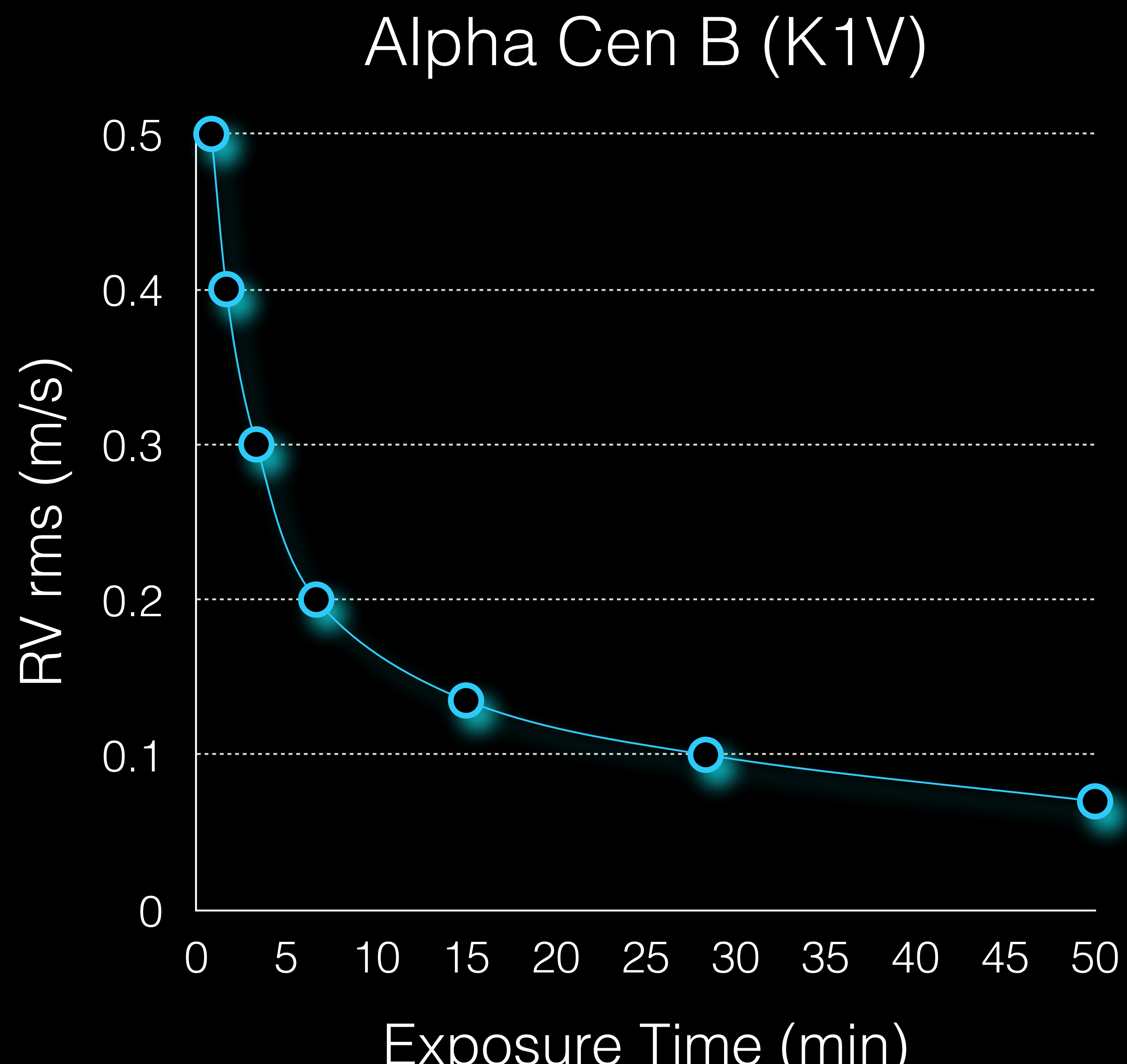


Credit: Charpinet

Oscillations

Oscillations

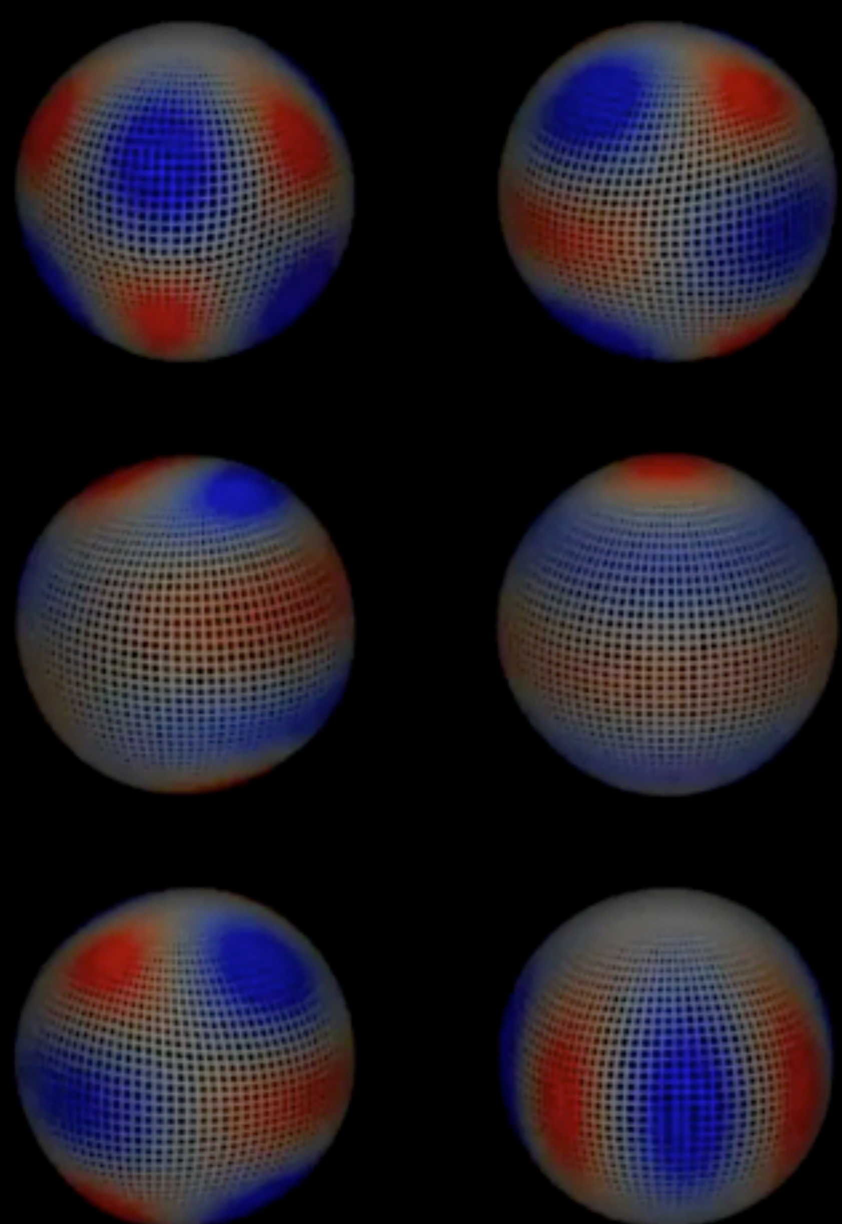


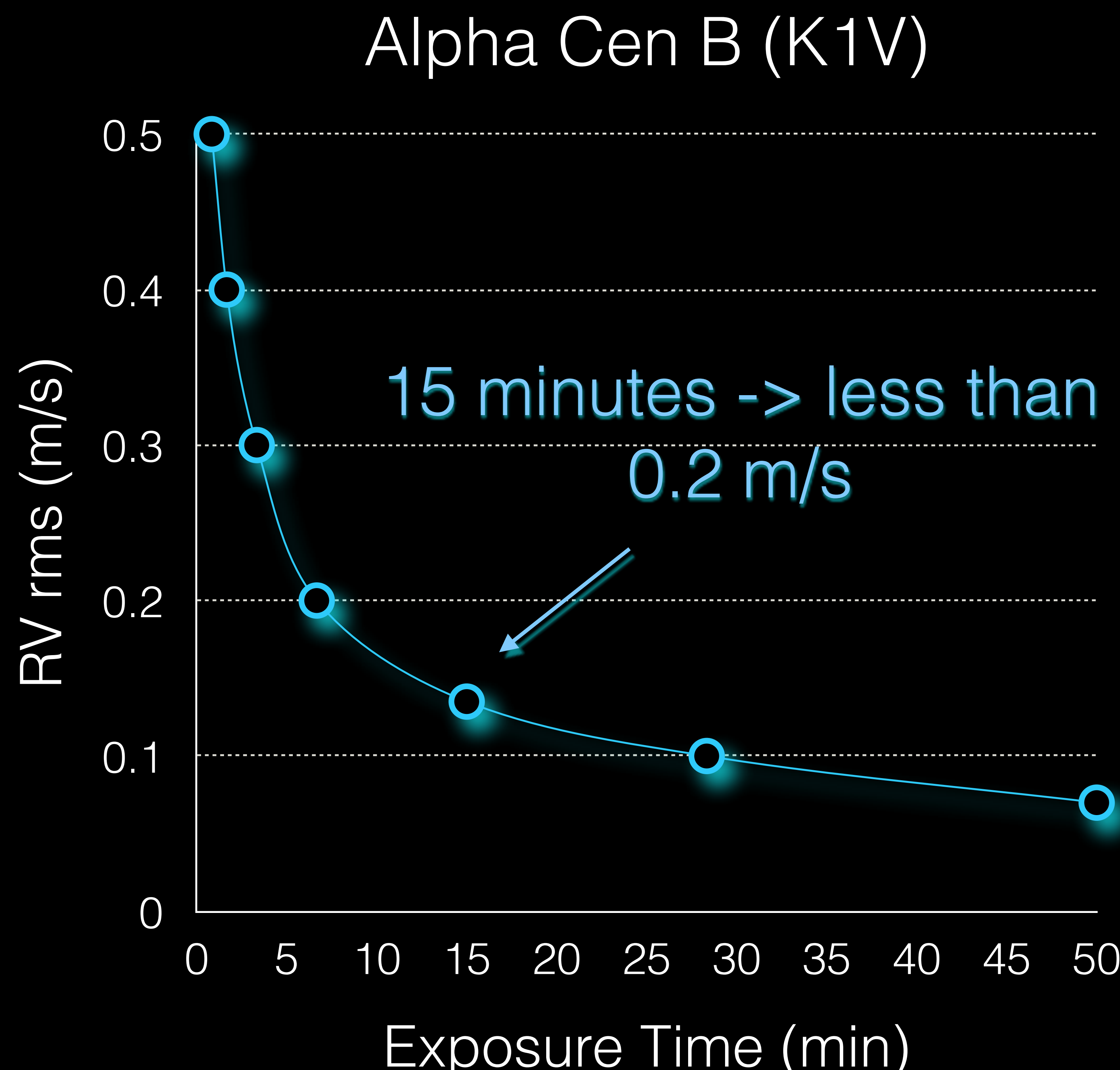


Credit: Charpinet

Oscillations

Oscillations

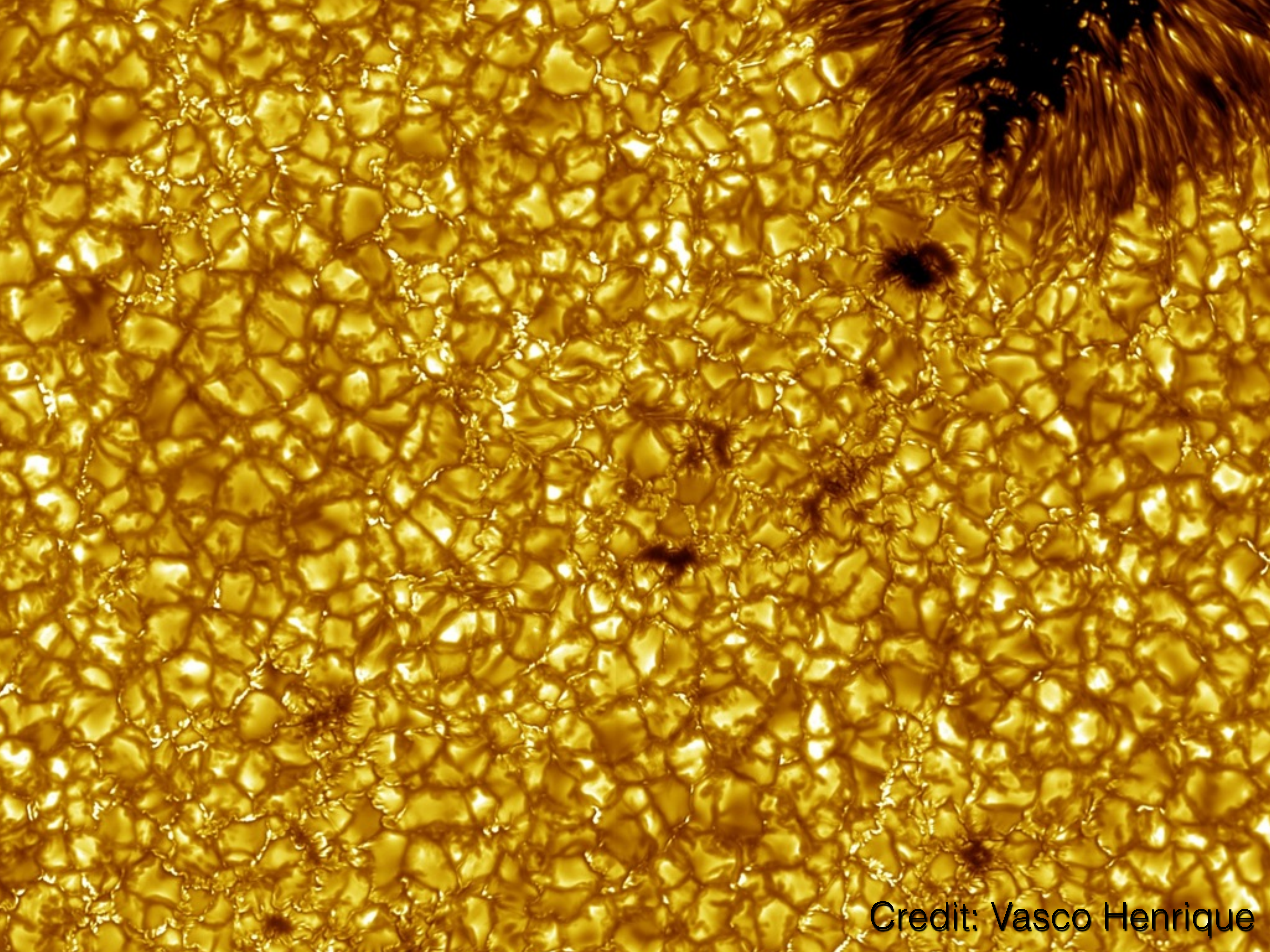




Credit: Charpinet

Granulation

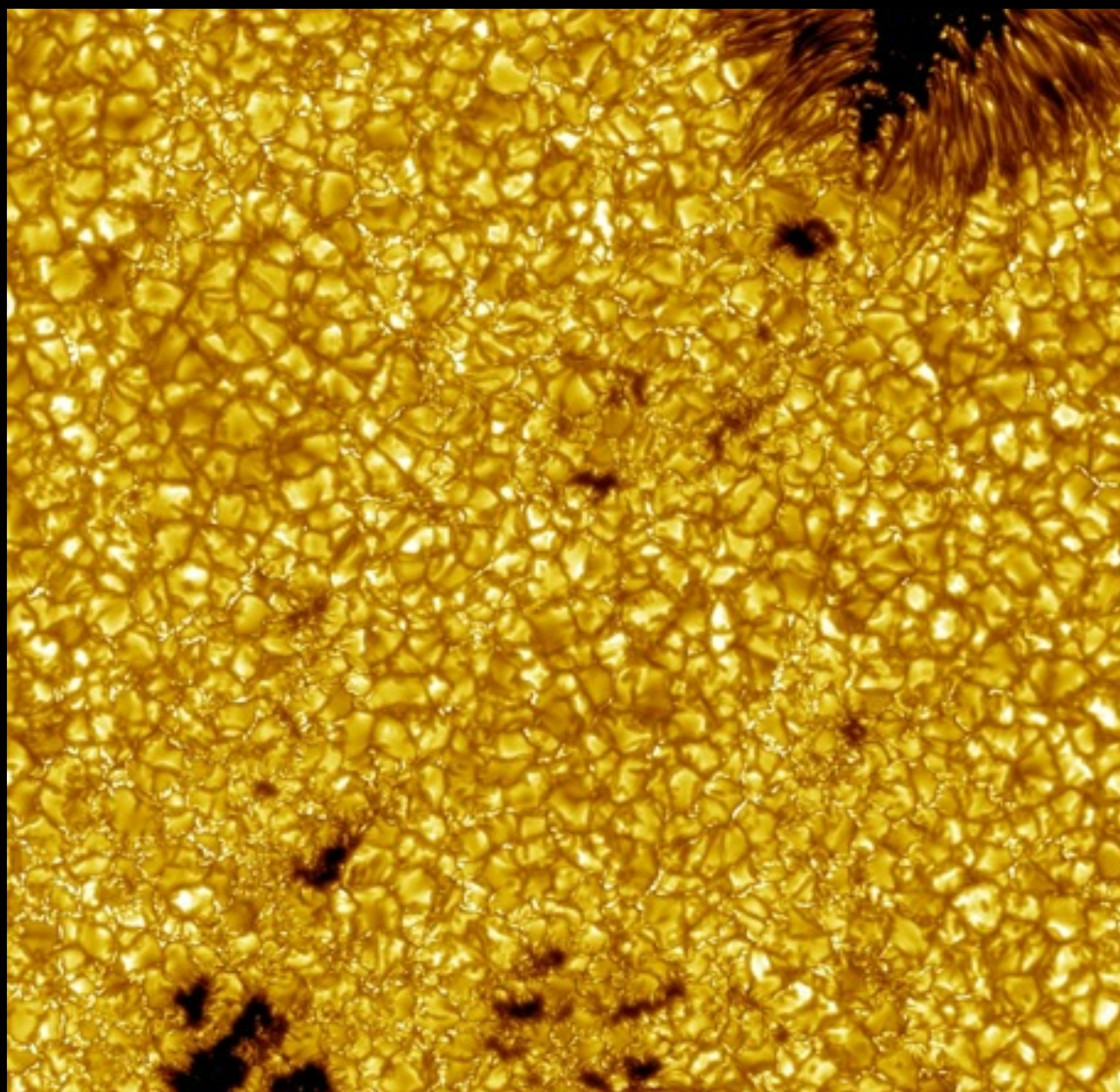
Granulation


Credit: Vasco Henrique

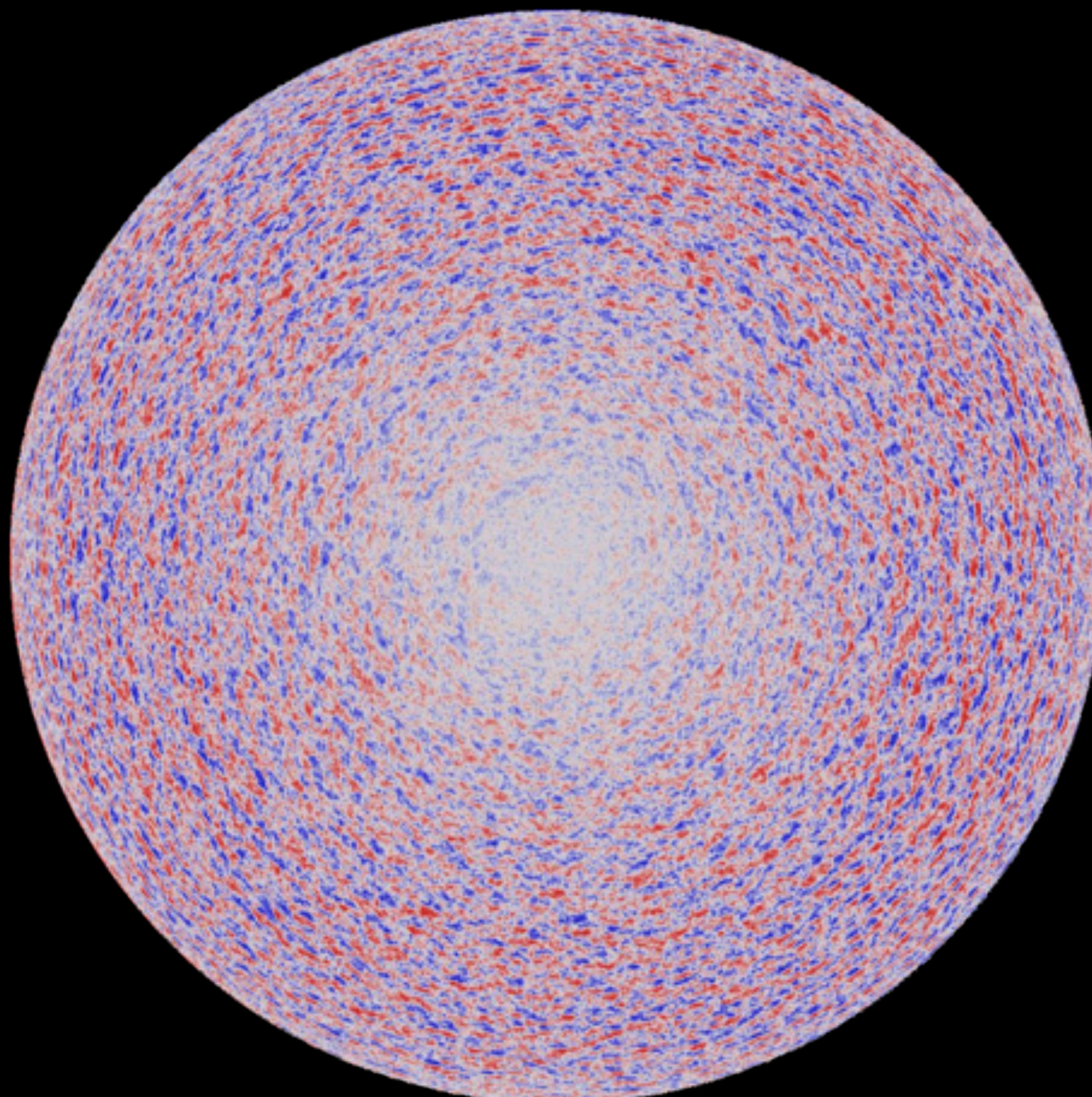
GRANULATION

GRANULATION

a few m/s (Dumusque+ 11)



1000 km - 10^{3} m.s^{-1} - > 10 min

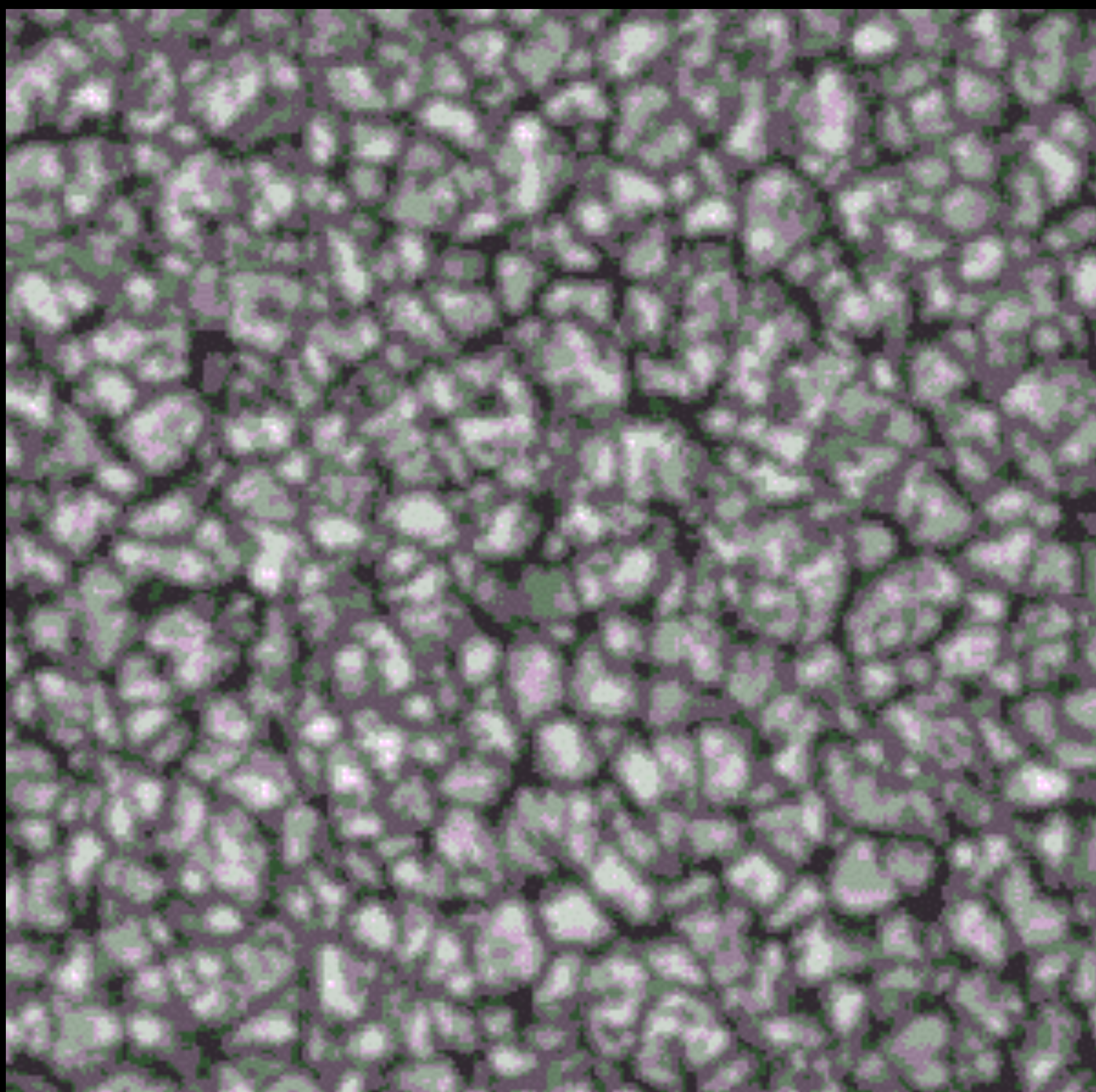


30000 km - 10^{2} m/s - < 2 days

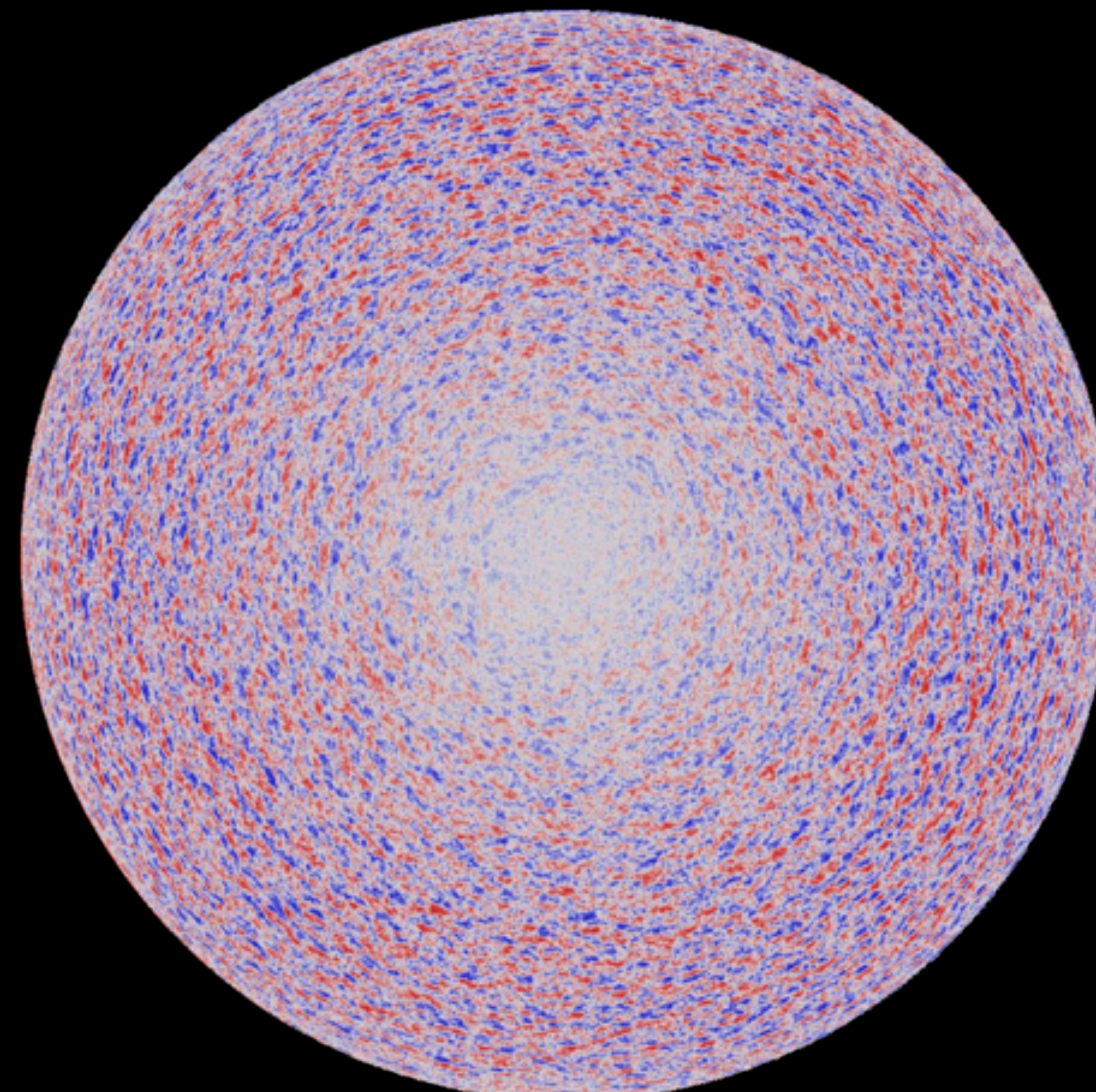
Granulation

Granulation

a few m/s (Dumusque+ 11)



1000 km - 10^{3} m.s^{-1} - > 10 min

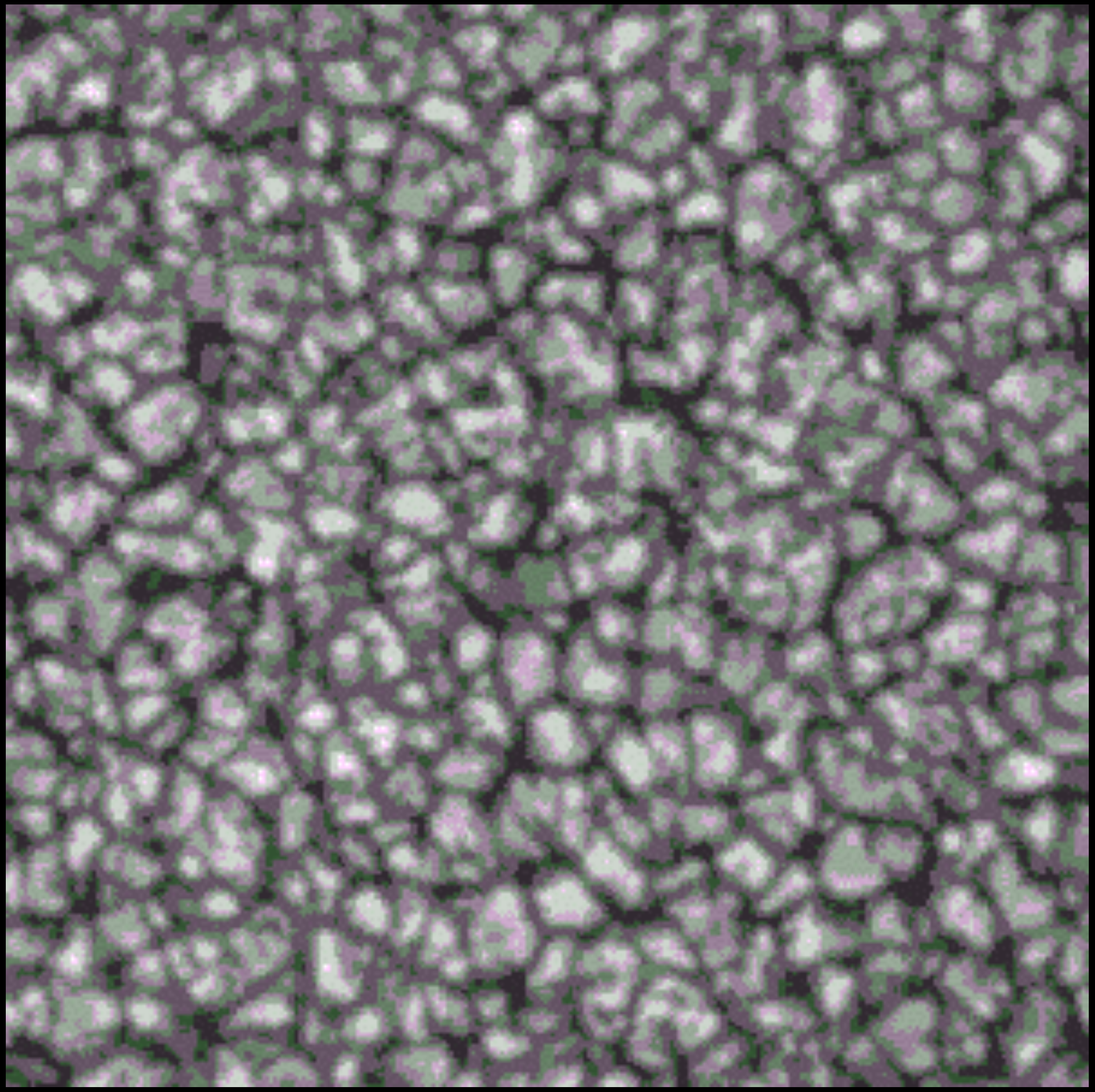


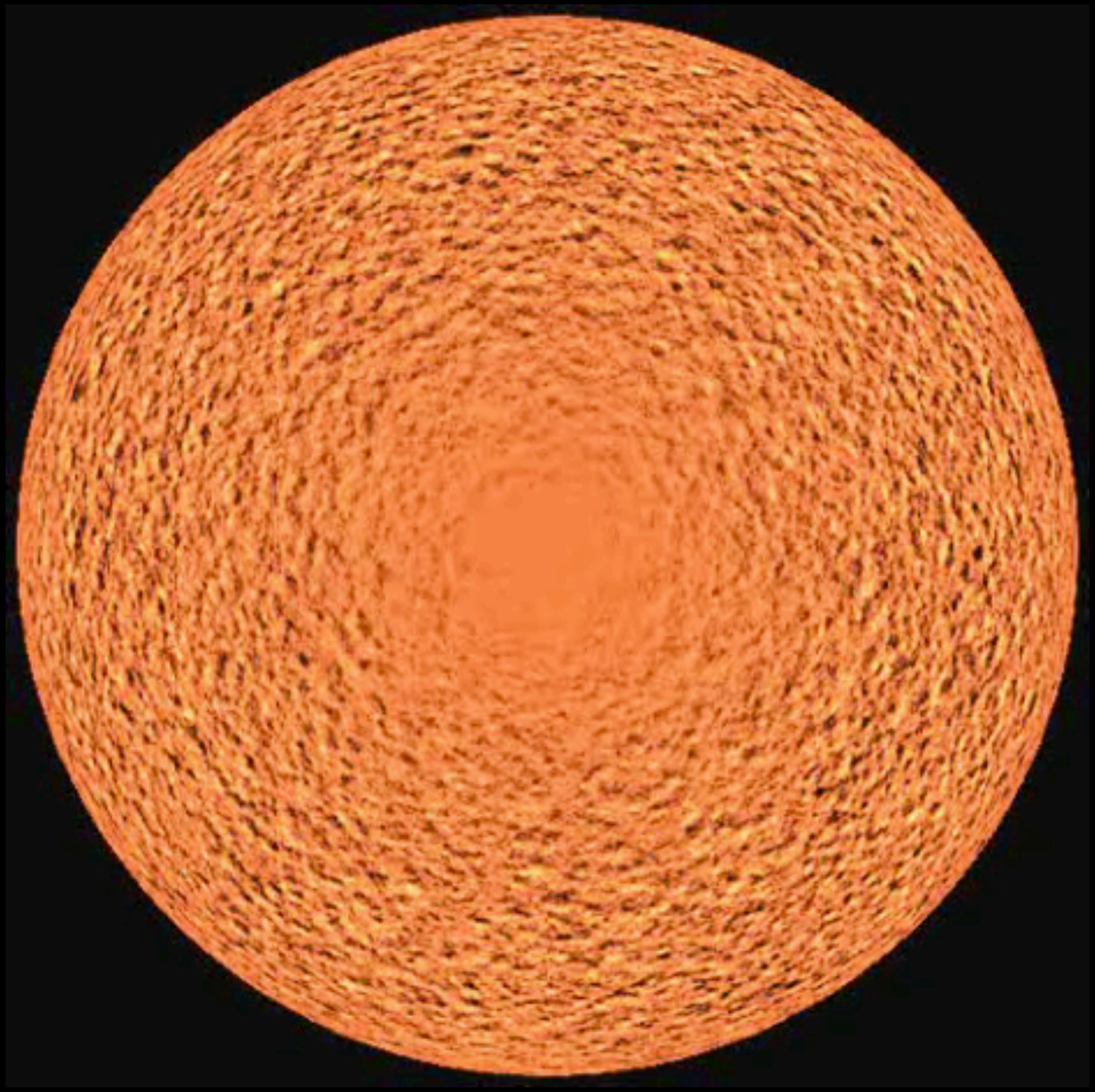
30000 km - 10^{2} m/s - < 2 days

GRANULATION

GRANULATION

a few m/s (Dumusque+ 11)





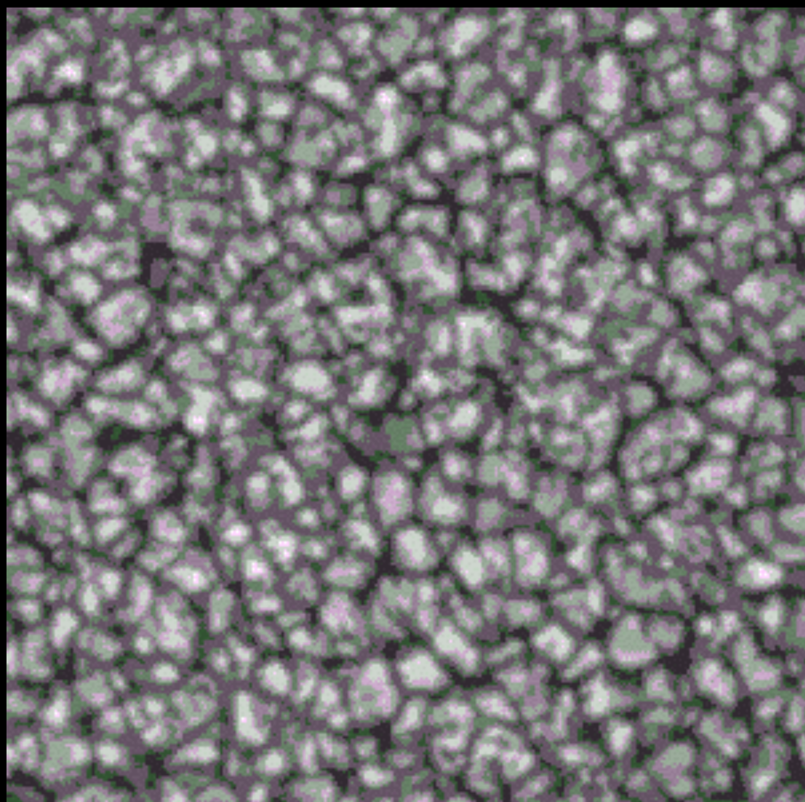
1000 km - 10^3 m.s^{-1} - > 10 min

30000 km - 10^2 m/s - < 2 days

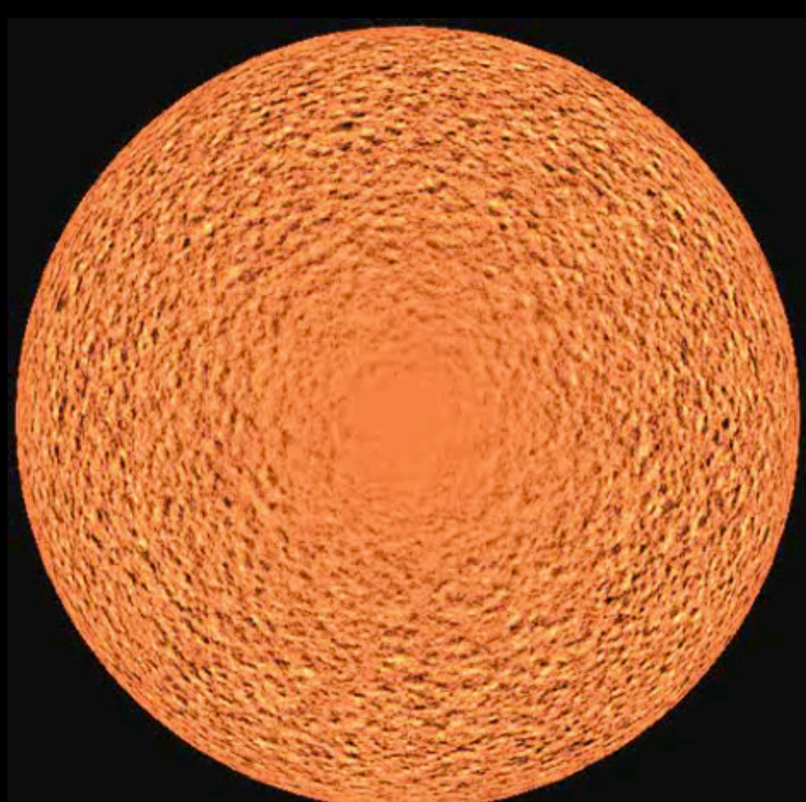
GRANULATION

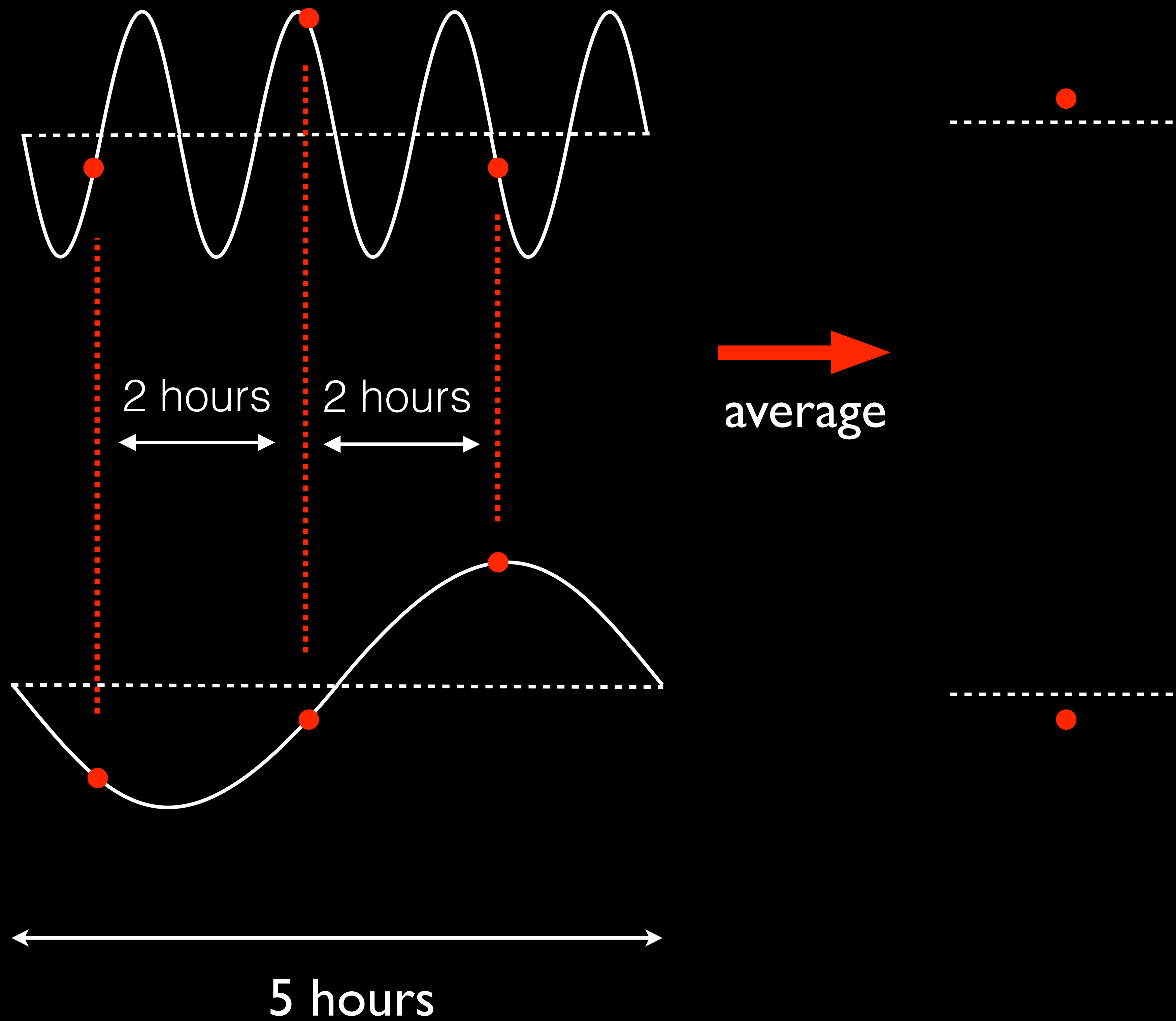
GRANULATION

Granulation



Supergranulation

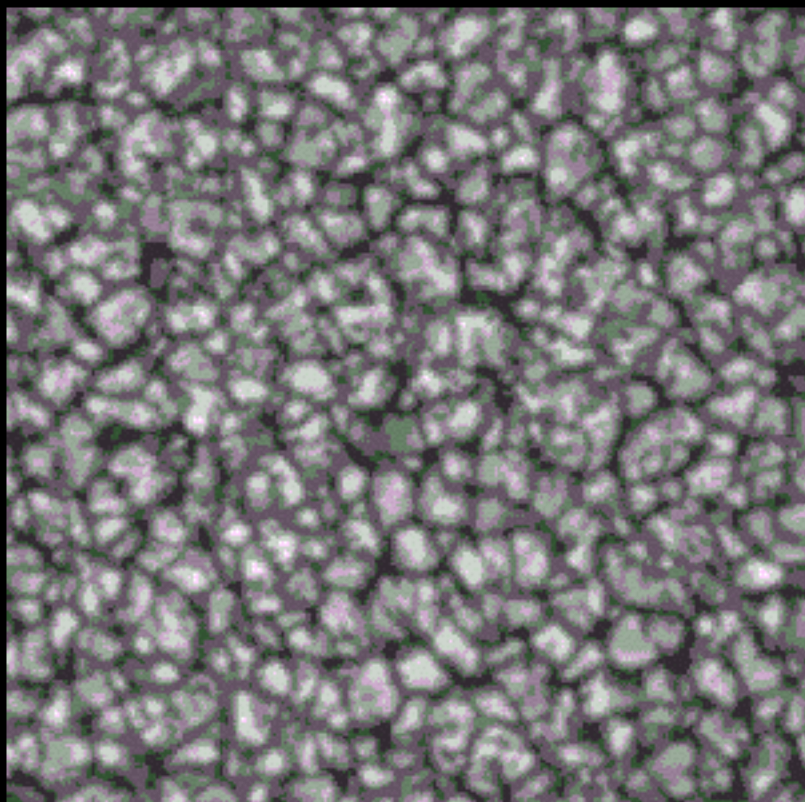




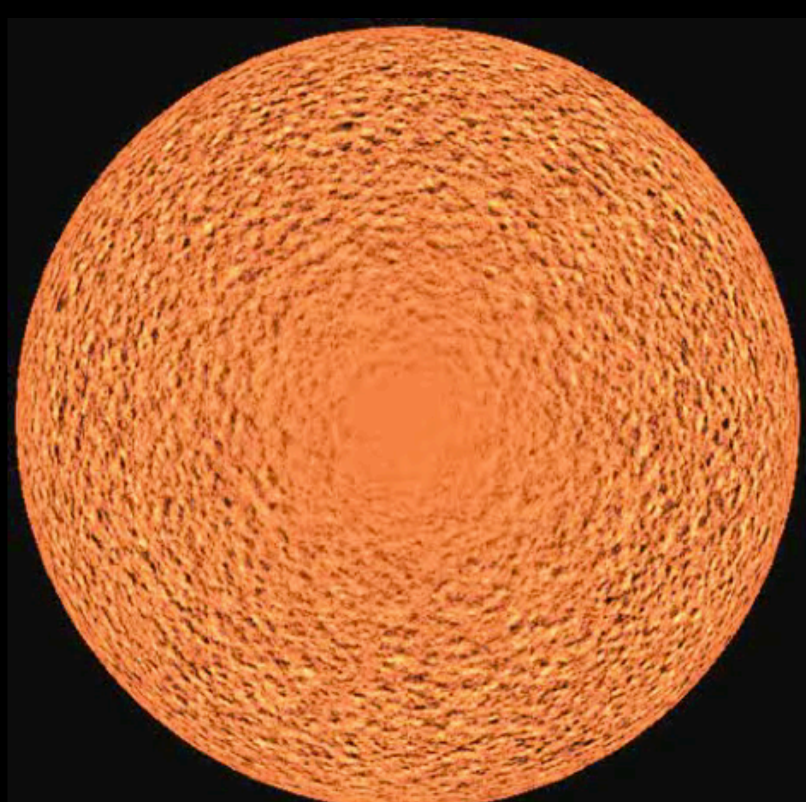
GRANULATION

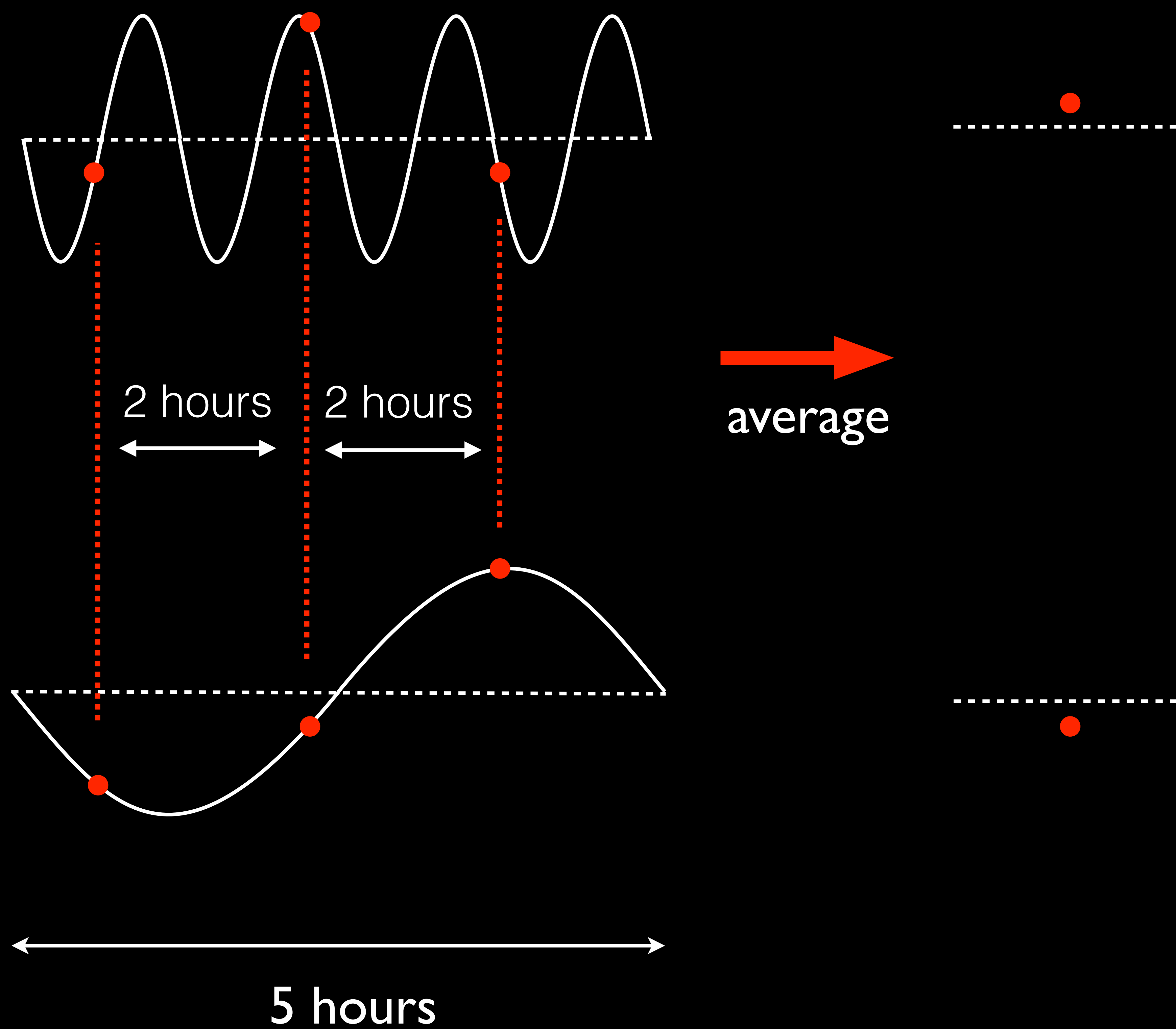
GRANULATION

Granulation



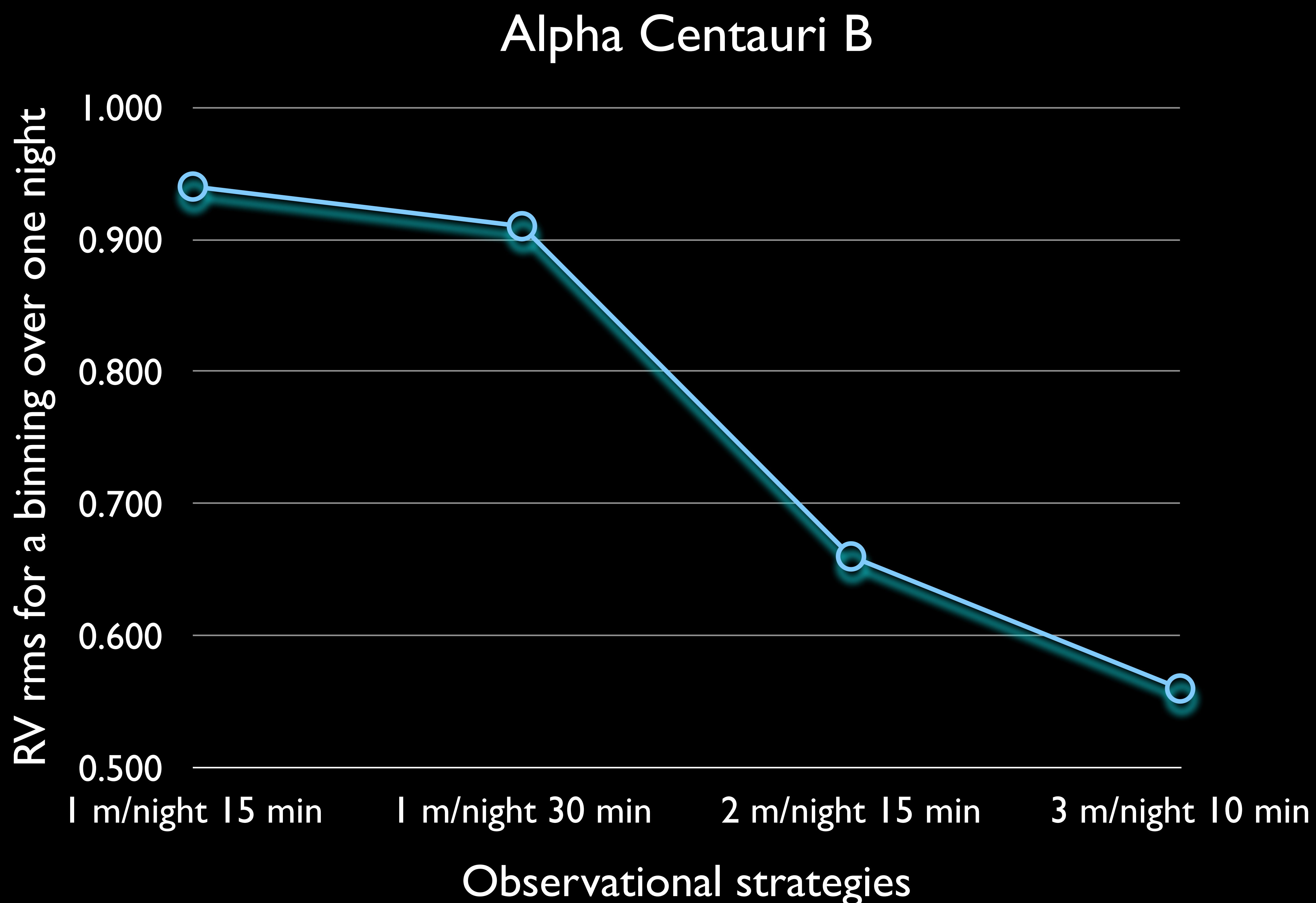
Supergranulation





Granulation

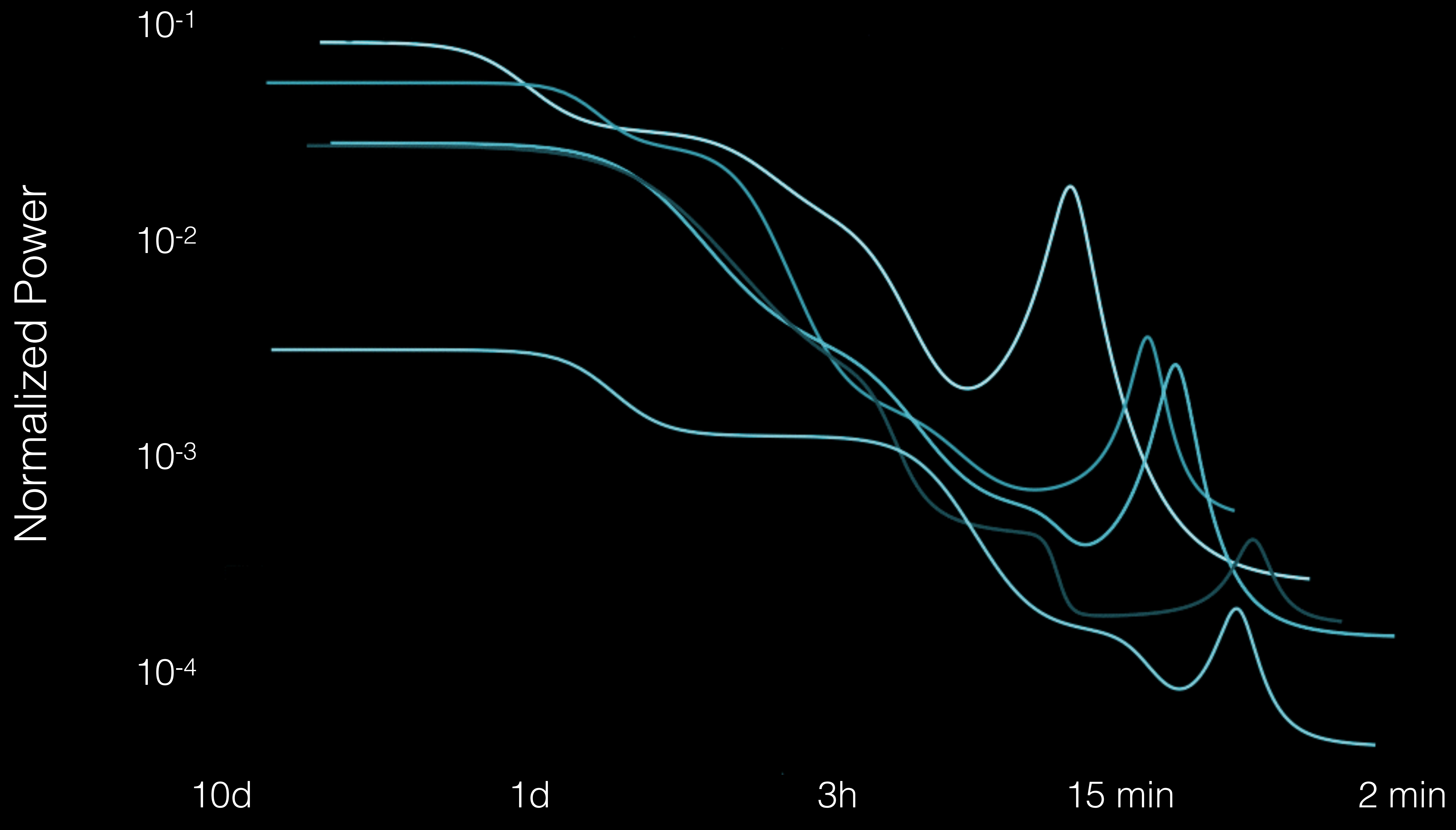
Granulation



Dumusque+ 11

Granulation

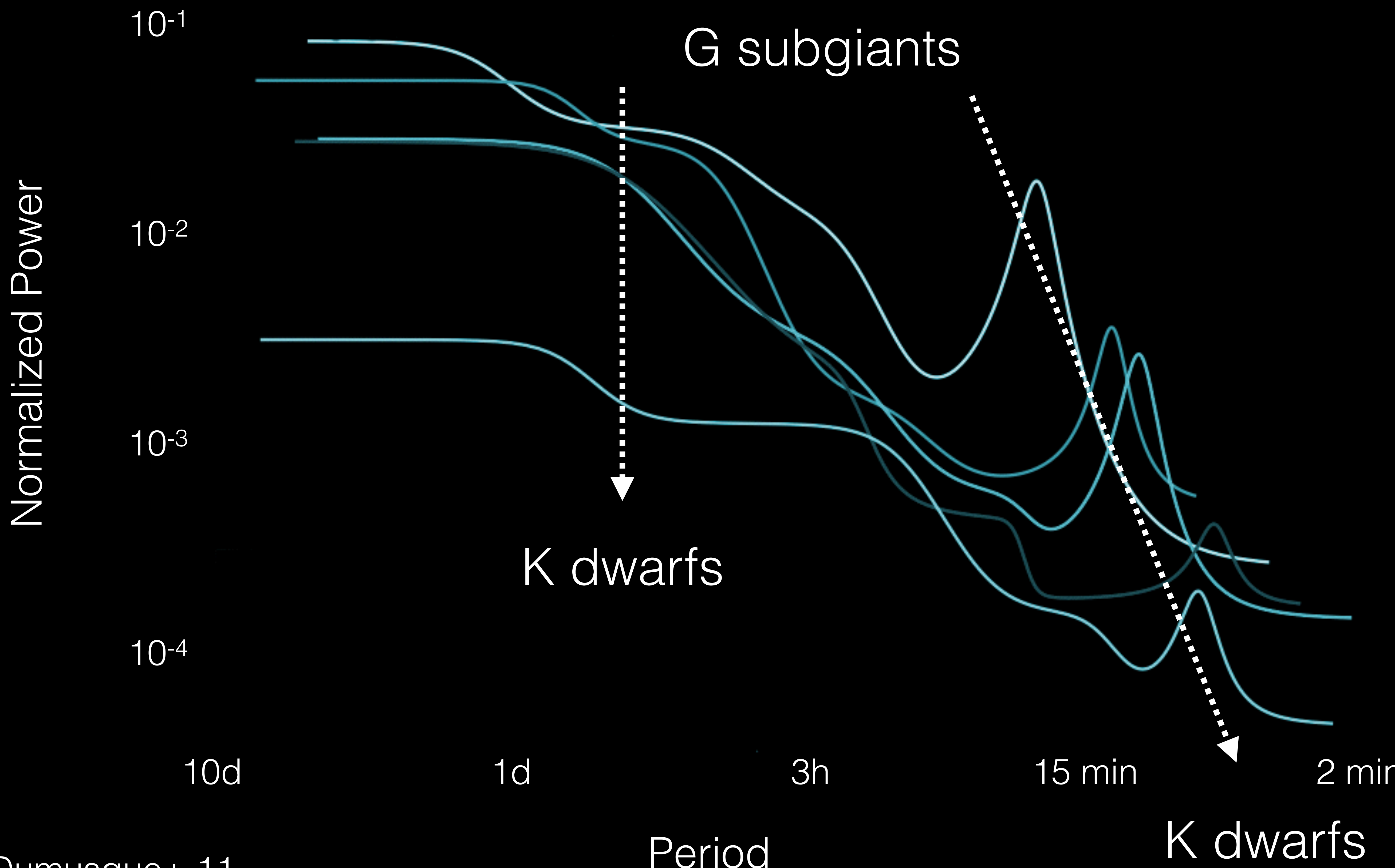
Granulation



Dumusque+ 11

Granulation

Granulation



Dumusque+ 11

Granulation

Granulation

RVs of K dwarfs are less affected by:

-> granulation

-> oscillation

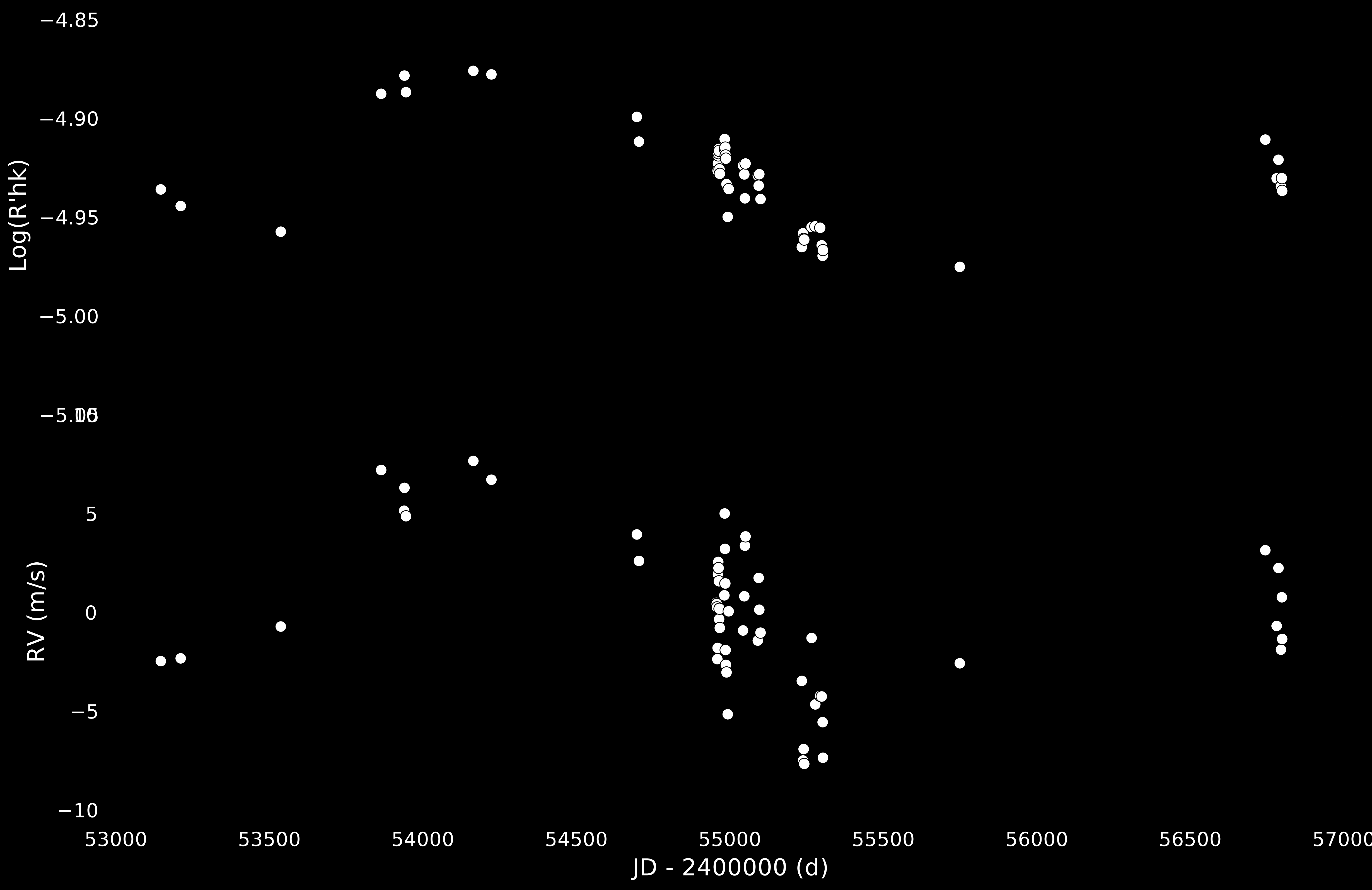
than G dwarfs

Dumusque+ 11

Magnetic Cycles

Magnetic Cycles

Magnetic Cycles



HARPS data

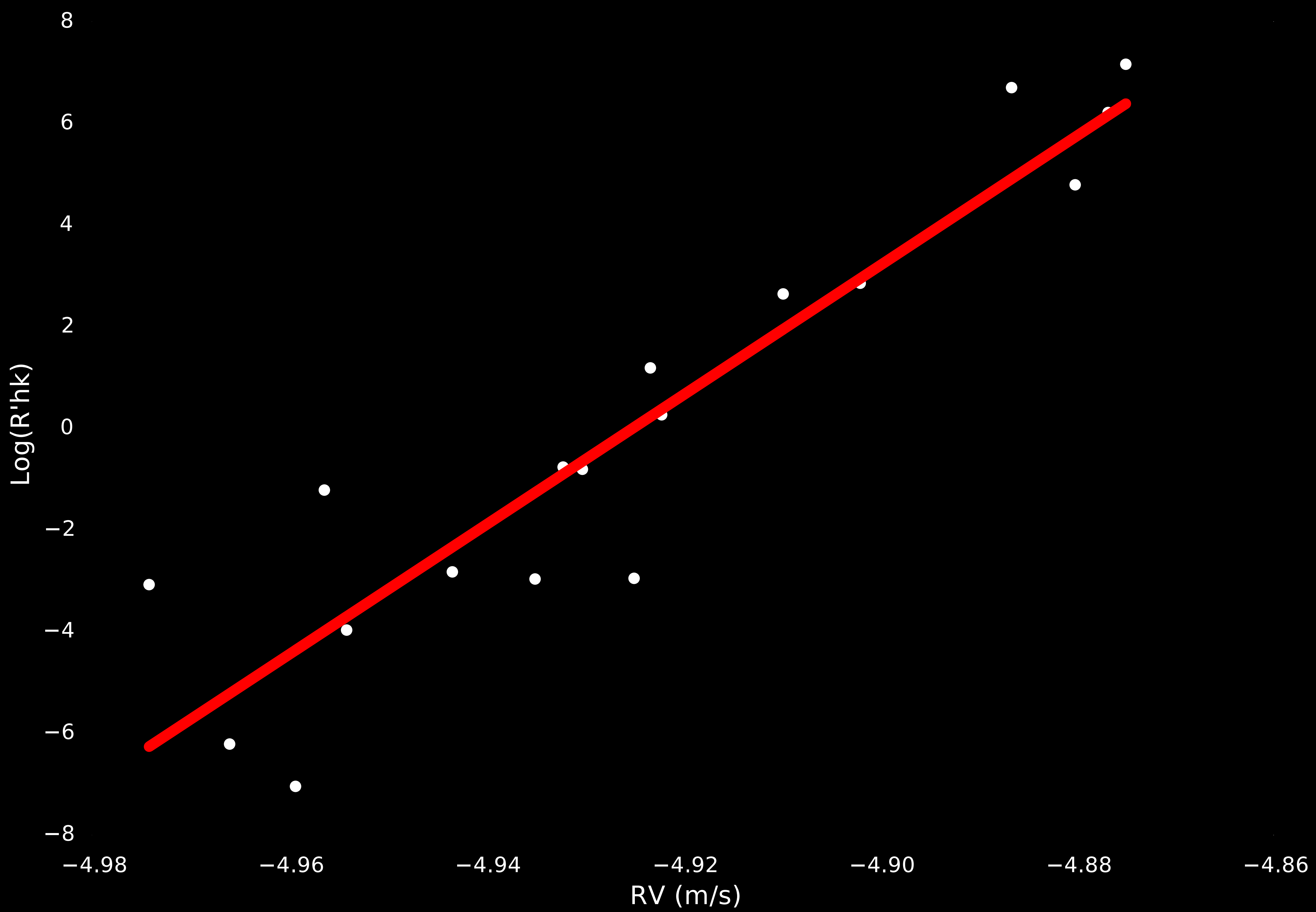
Magnetic Cycles

Magnetic Cycles

1-20 m/s (Lovis+ 11)

- More active regions,
  -> more convective blueshift inhibition
  -> positive RV (Meunier+ 10,Lindegren & Dravins 03)

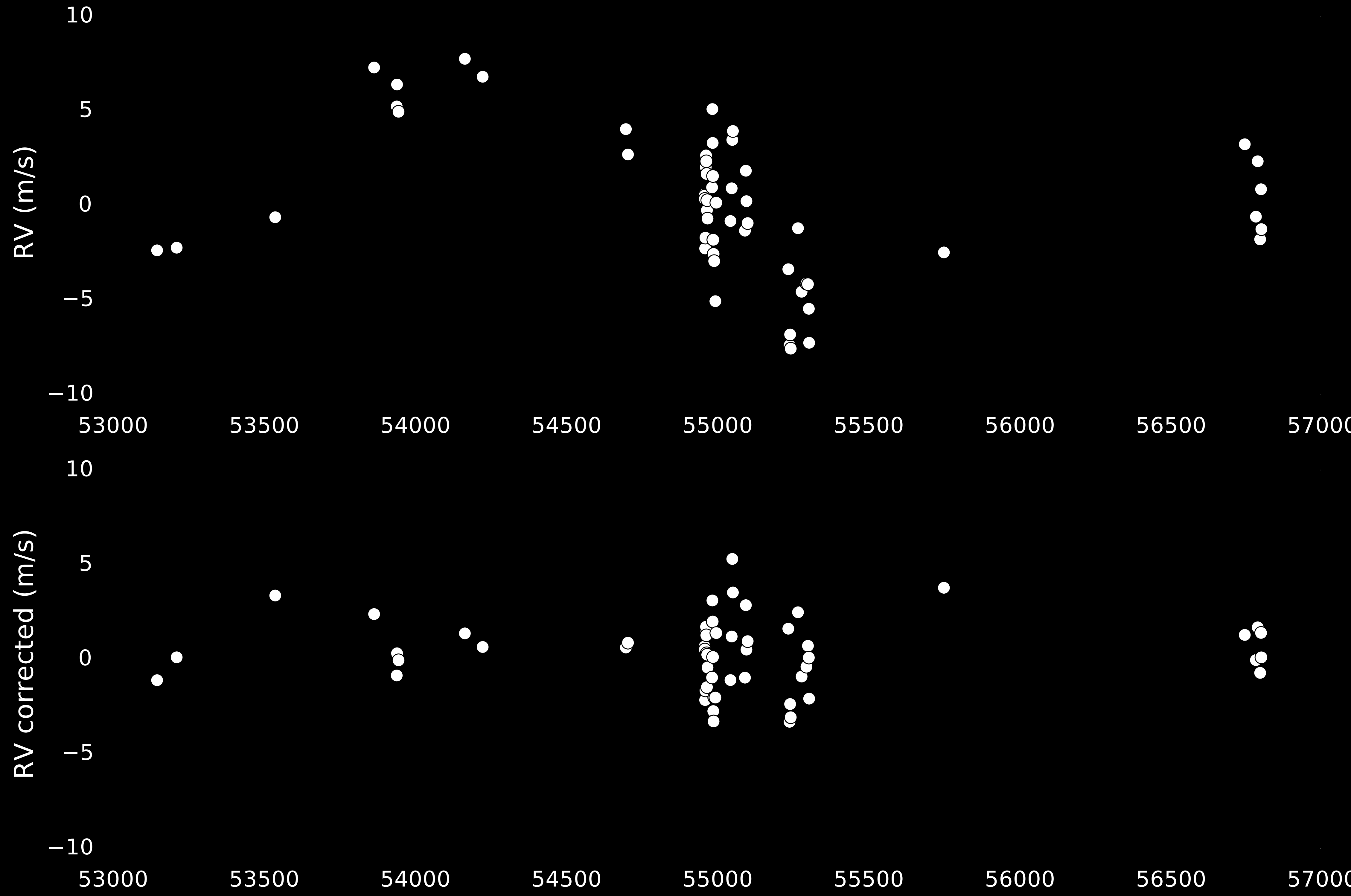
Magnetic Cycles



Meunier+ 13

HARPS data

Magnetic Cycles



Meunier+ 13

HARPS data

Magnetic Cycles

Magnetic Cycles

RVs of K dwarfs are less affected by:

-> MAgnetic cylcles

than G dwarfs

Lovis+ 11

Active regions

Active regions

Active regions

Active regions

a few m/s (Meunier+ 10)

FLUX

Spots are cooler and fainter
Plages are hotter and brighter

Saar & Donahue 97, Queloz+ 01, Hatzes 02, Lagrange+ 10, Boisse+ 11, Dumusque+ 11, Boisse+ 12,

CONVECTION

Convection outside active regions, inhibition of convection inside

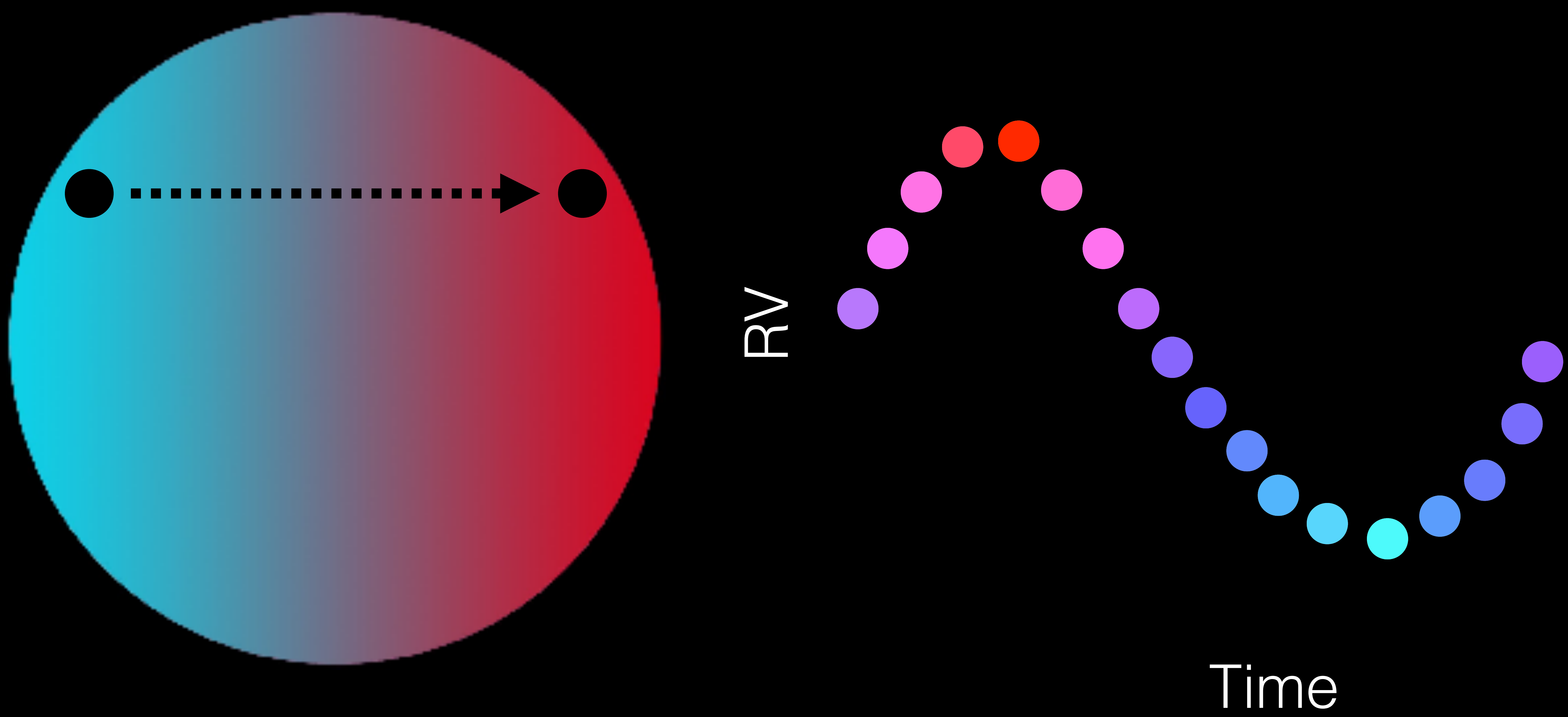
Dravins 81, Lindegren & Dravins 03, Saar 03, Saar 09, Lanza+ 11, Meunier+ 10, Aigrain+12, Dumusque+ 14

Active regions

Active regions

a few m/s (Meunier+ 10)

FLUX

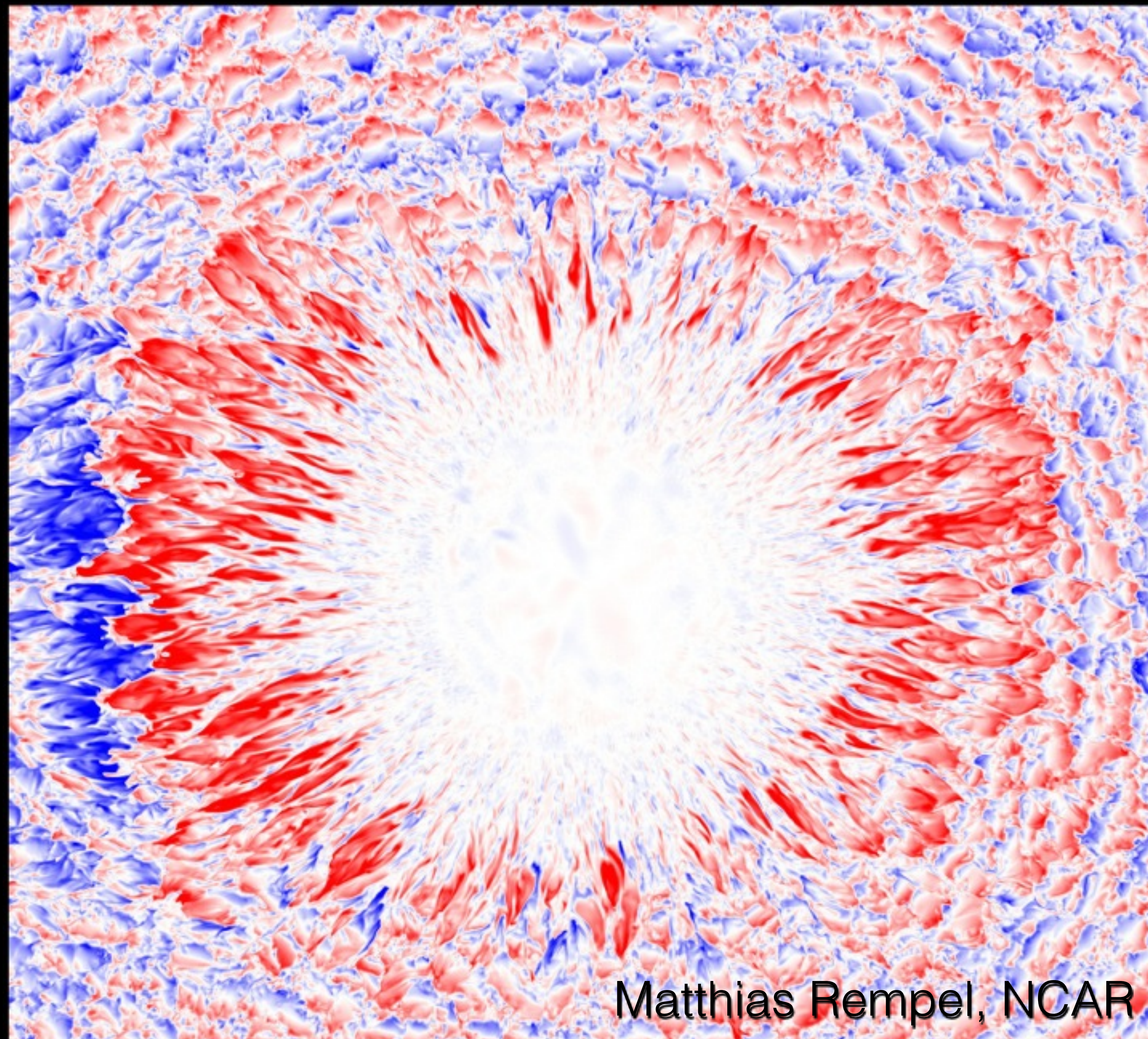


Active regions

Active regions

a few m/s (Meunier+ 10)

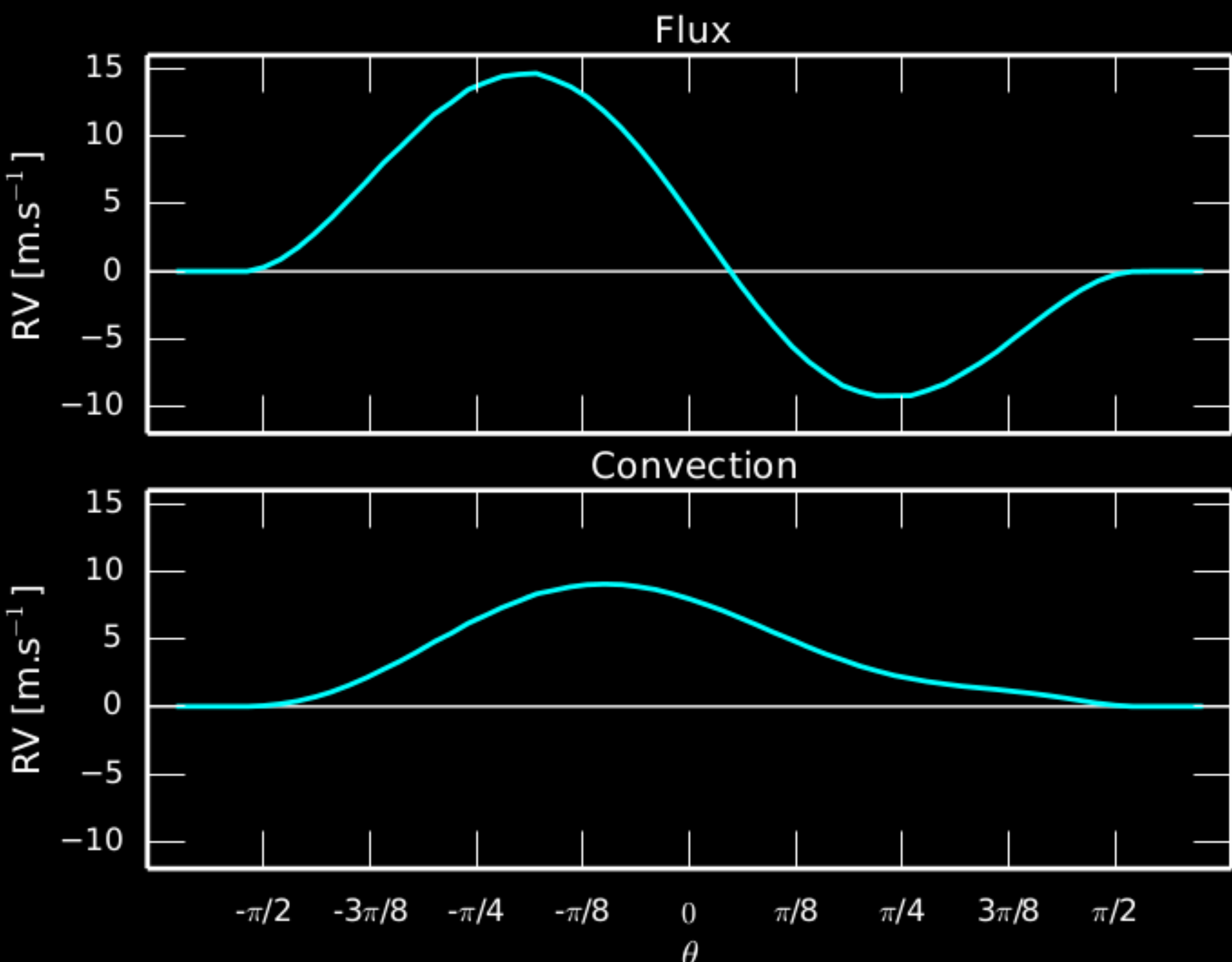
CONVECTION



Active regions

Active regions

a few m/s (Meunier+ 10)



FLUX

CONVE
CTION

SOAP 2.0 Dumusque+ 2014

Active regions
Active regions

Difficulties for Solar type stars:

Long Period Not possible to average out

Not Correlated directly with log(R’hk), BIS SPAN, FWHM

Not Coherent Active regions lives for 1-2 stellar rotations

Active regions

Active regions

False Detections due to activity:

GJ677Cd (Feroz+ 13, Robertson+ 14,
see previous talk by P. Gregory's)

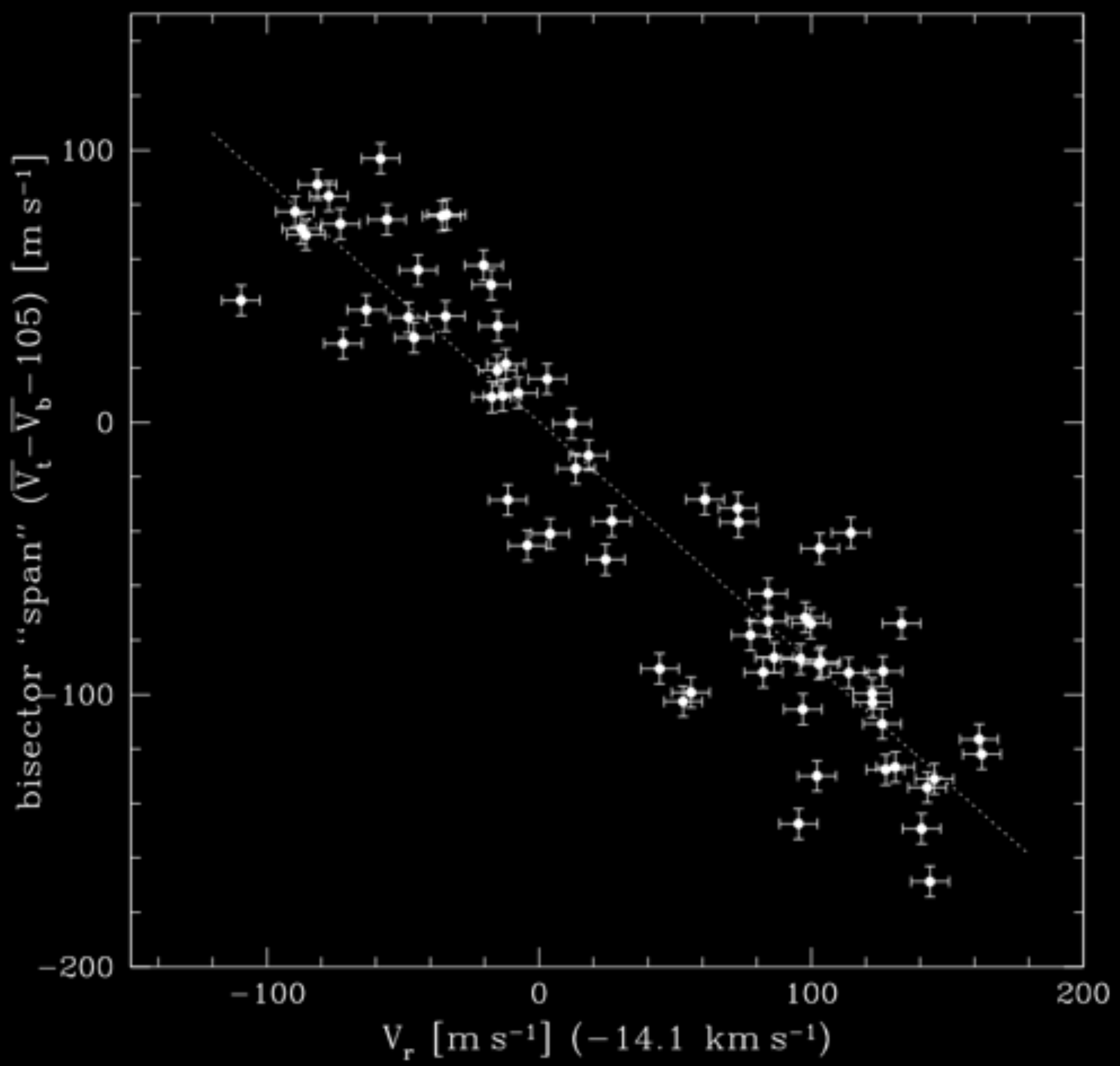
GJ581d (Robertson+ 14, see his previous talk)

HD41248b-c (Santos+ 14, see previous talk by J. Faria)

How to probe Stellar Activity and Correct it?

Active regions
Active regions

Anti-Correlation between RV and BIS SPAN



Problem: Seems to works only for stars more active than the Sun for which the convective effect of spot is negligible

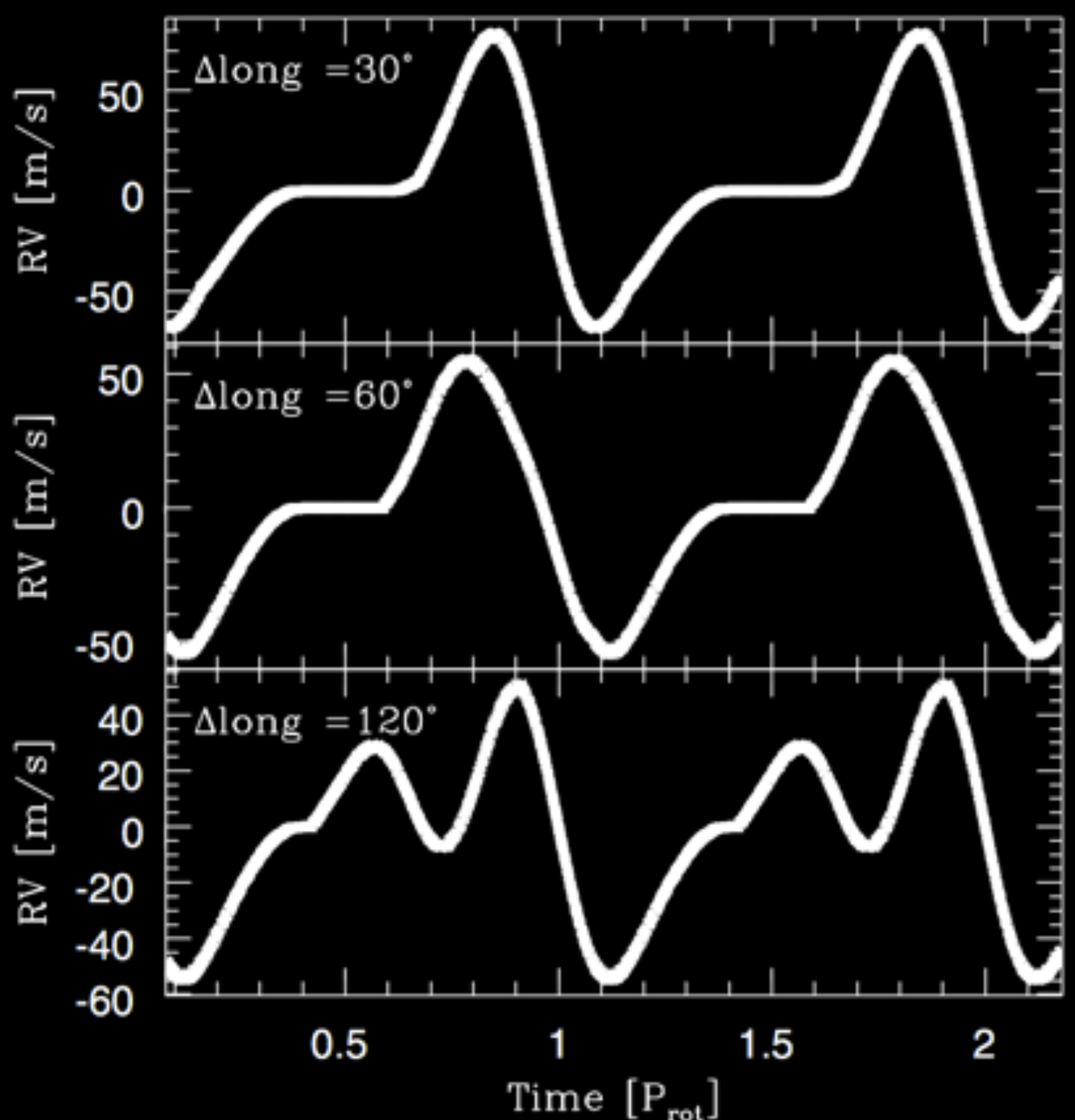
Queloz+ 01

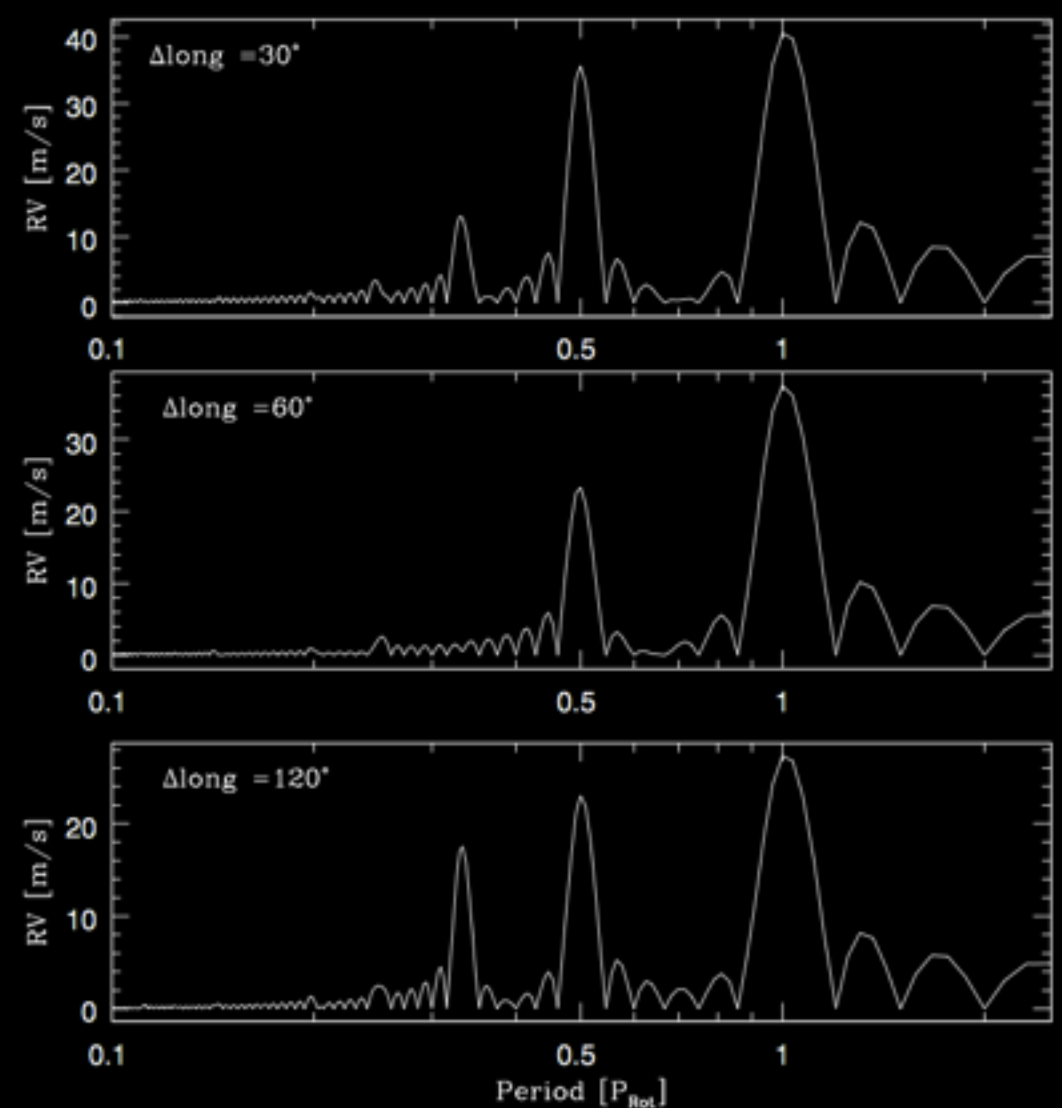
ACTIVE REGIONS

ACTIVE REGIONS

ACTIVE REGIONS ROTATES with the star:

-> Signal at the rotational period and harmonics





Boisse+ 11

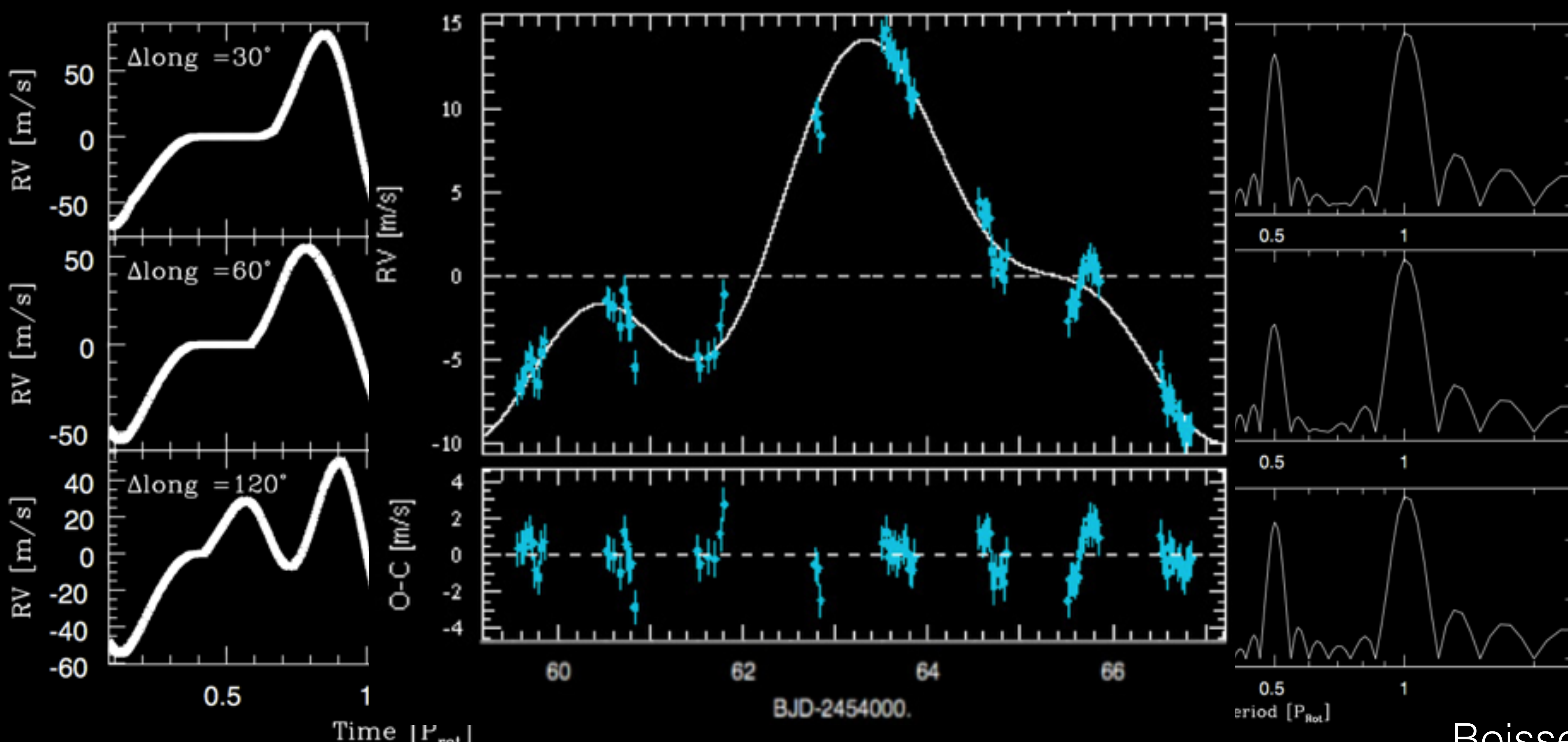
Active regions

Active regions

Active regions rotates with the star:

-> Signal at the rotational period and harmonics

Fit sin waves at the rotational period and harmonics



Boisse+ 11

Active regions

Active regions

This Method has been applied successfully to:

- Alpha Cen Bb (Dumusque+ 12)
- Corot-7b (Queloz+ 09, Boisse+ 11)
- HD189733b (Boisse+ 11)
- GJ674b (Boisse+ 11)
- Iota Horb (Boisse+ 11)

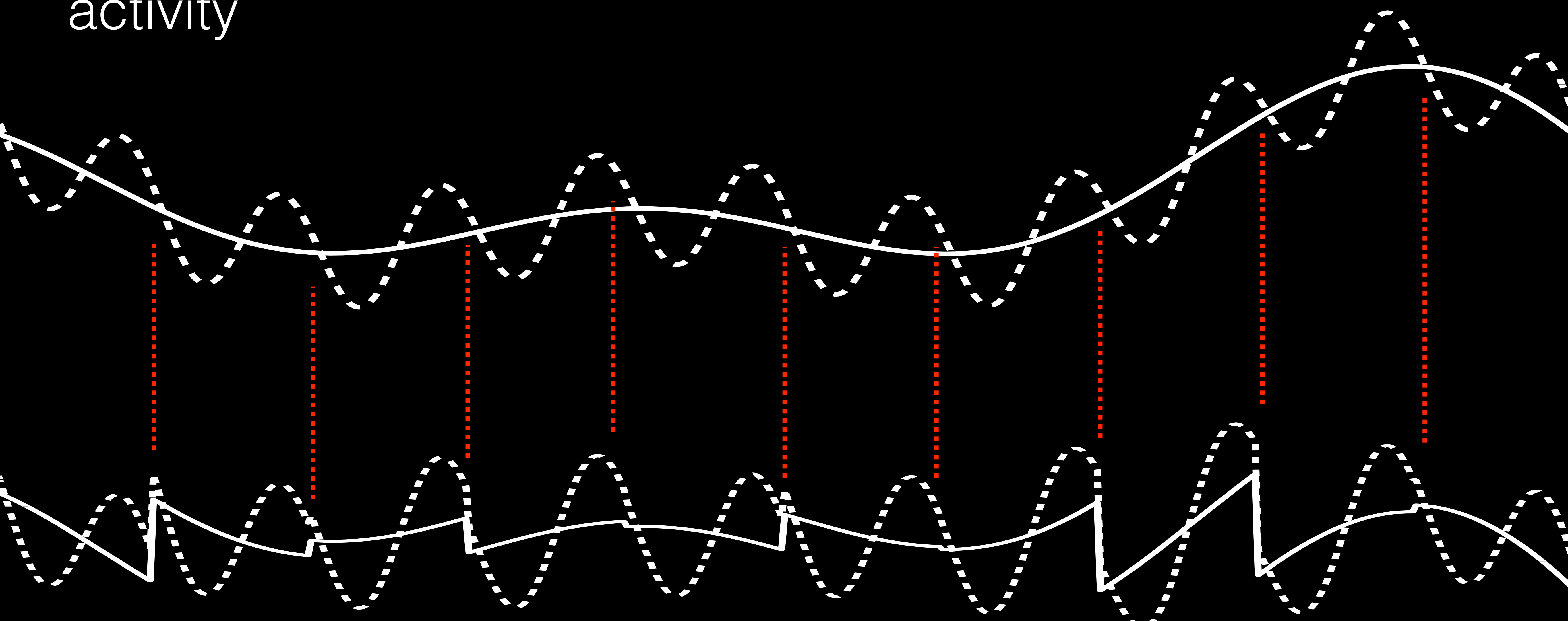
Problem: Active regions evolve as a function of time, so can be applied only on chunks of data, need more tests on quieter stars

Active regions

Active regions

If the Planet have a period much shorter than the stellar rotation

Possible to fit the Rv offset every few days to get rid of activity



Active regions
Active regions

This Method has been applied successfully to:

Corot-7b (Hatzes 11)
Kepler-78b (Pepe+ 13, Howard+ 13)
Kepler-10b (Dumusque+ 14)

Problem: Only for short-period planets compared to stellar rotation

Active regions

Active regions

Using Red Noise models to fit the RV signal

- Feroz & Hobson 13: exponential decorrelation between all points

$$\mathcal{C}[v(t_i, j), v(t_{i'}, j')] = [(\sigma_{i,j}/\alpha_j)^2 \delta_{ii'} + s_j^2 \exp(-|t_i - t_{i'}|/\tau_j)]\delta_{jj'}$$

White noise — Exponential correlation

Problem: Can the red noise model absorb any real signal?

Active regions

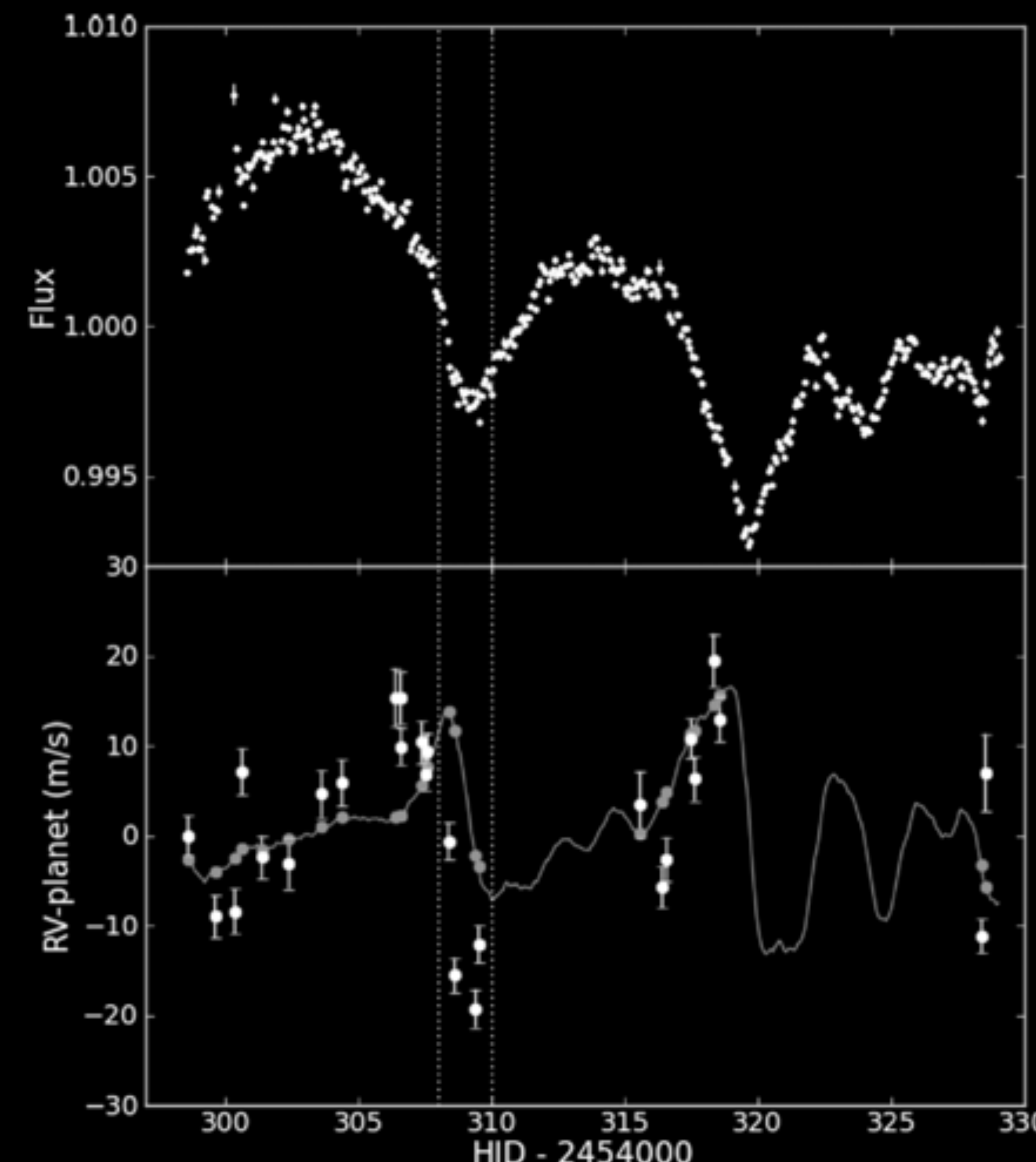
Active regions

Using the photometry to estimate the RV signal:

Aigrain+ 12: The FF' method

$RV_{Flux} \propto F \times F'$

$RV_{Convection} \propto F^2$



Problem: Require space-based photometry. Some spot configuration can give no signal in photometry, but some important signals in RV

Active regions

Active regions

Using the PHOTOMETRY to estimate the RV SIGNAL:

Haywood+ 14: Gaussian Processes

Fitting a Gaussian Process on the photometry

Estimating the RV with the *FF'* method

In addition, fitting a Gaussian process to the RVs with parameters fixed to the result of the photometric fit

Problem: Gaussian processes are very flexible, even with fixed parameters. Requires simultaneous photometry. Does the red noise have the same properties in photometry and in RVs ?

What is the best strategy to deal with stellar signals and mainly Active Regions?

BLIND TEST with fake data

Photometric and RV data including:

- SAMPLING: from real observations
- OSCILLATIONS & GRANULATION: from asteroseismology data (Dumusque+ 11)
- ACTIVITY SIGNAL: from active region simulations including the flux and convective blueshift effect (Dumusque+ 11, Dumusque+ 14)
- PLANETS: at all periods

Blind test

In the very near future, there will be TESS, ESPRESSO, SPIROU, CHEOPS, G-CLEF, PLATO…

It will require a community effort to determine the best strategy to deal with stellar signals

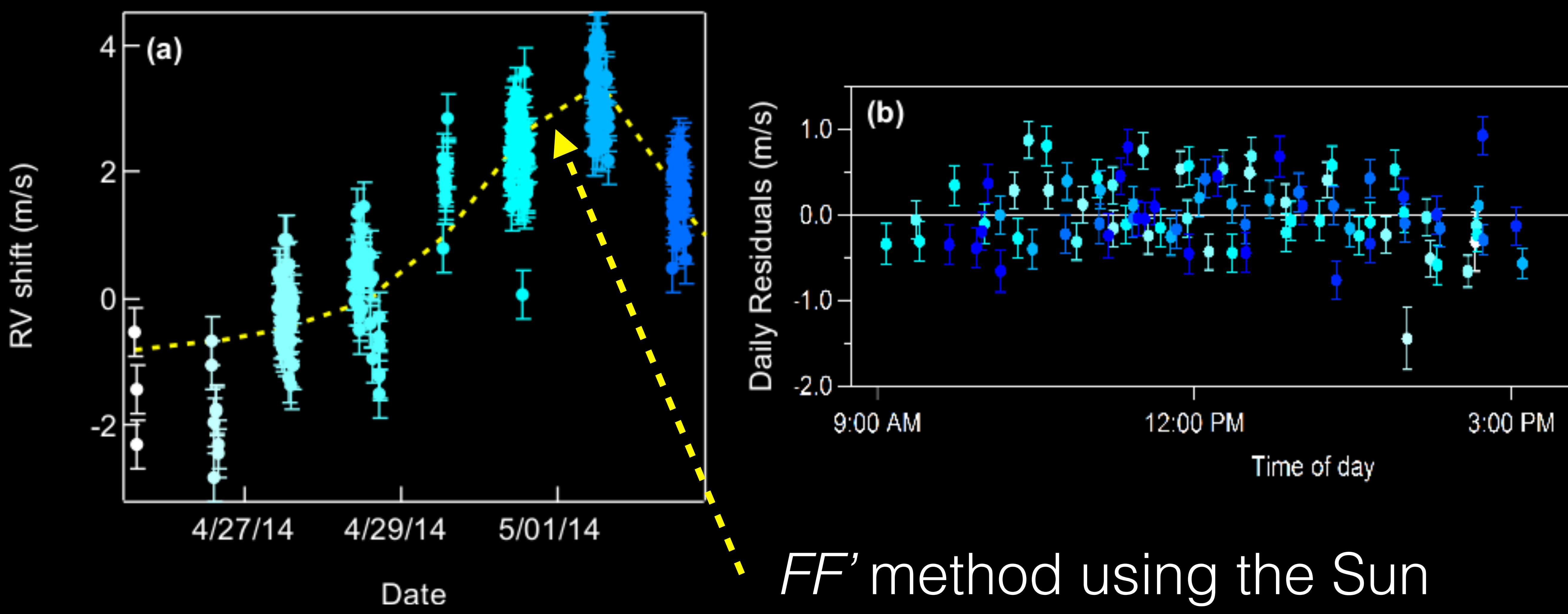
Several group should participate in this bling test

Gregory+	Cameron & Haywood+
Geneva+	Aigrain+
Tuomi+	Hatzes+

FOR THE WINNERS

Solar Telescope

Solar Telescope to feed the sunlight into HARPS-N



FF' method using the Sun flux measured by SOURCE

Goal: Understand stellar signal and detection of Venus

Phillips, CfA

Stellar Signals

Lindegren & Dravins 03

Flares

~ 1 h

<1 m/s (only active M)

Saar 09, Reiners 09

Granulation

15 min - 2 d

a few m/s (Dumusque+ 11)

Del-Moro+ 04, Del-Moro 04
Cegla+ 12, Cegla+ 14

Active regions

a few m/s (Meunier+ 10)

Saar & Donahue 97, Queloz+ 01
Hatzes 02, Meunier+ 10,
Boisse+ 11, Dumusque+ 11,
Lanza+ 11, Aigrain+12,
Boisse+ 12, Dumusque+ 14

10 - 50 d

Gravitational Redshift

< 10 cm/s (Cegla+12)

10 d - 10 yrs

Magnetic Cycles

1-20 m/s (Lovis+ 11)

Makarov 10, Dumusque+ 11
Dumusque+ 12 , Meunier+ 13

~ 10 yrs

Oscillations

< 15 min

a few m/s (Dumusque+ 11)

Kjeldsen+ 95, Bouchy & Carrier 01,
Butler+ 04, Bedding & Kjeldsen 07