Determination of fundamental stellar parameters from the granulation-related background signal – a theoretician's view

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Overview and motivation

- Theoretical investigation, looking at granulation in so-called "local box" model atmospheres

- What do the models say on granulation properties across the HRD?

  - can we reproduce – or even improve – asteroseismic (homology-motivated?) scaling relations of the granulation background?

- Metallicity as third parameter besides T_{eff} and $\log g$

- Useful add-on for determination of stellar parameters? Especially time series of short duration? $\rightarrow$ TESS mission

- Reverse: what can be learned about surface convection as such?

Example spectra: giants, Kepler long cadence
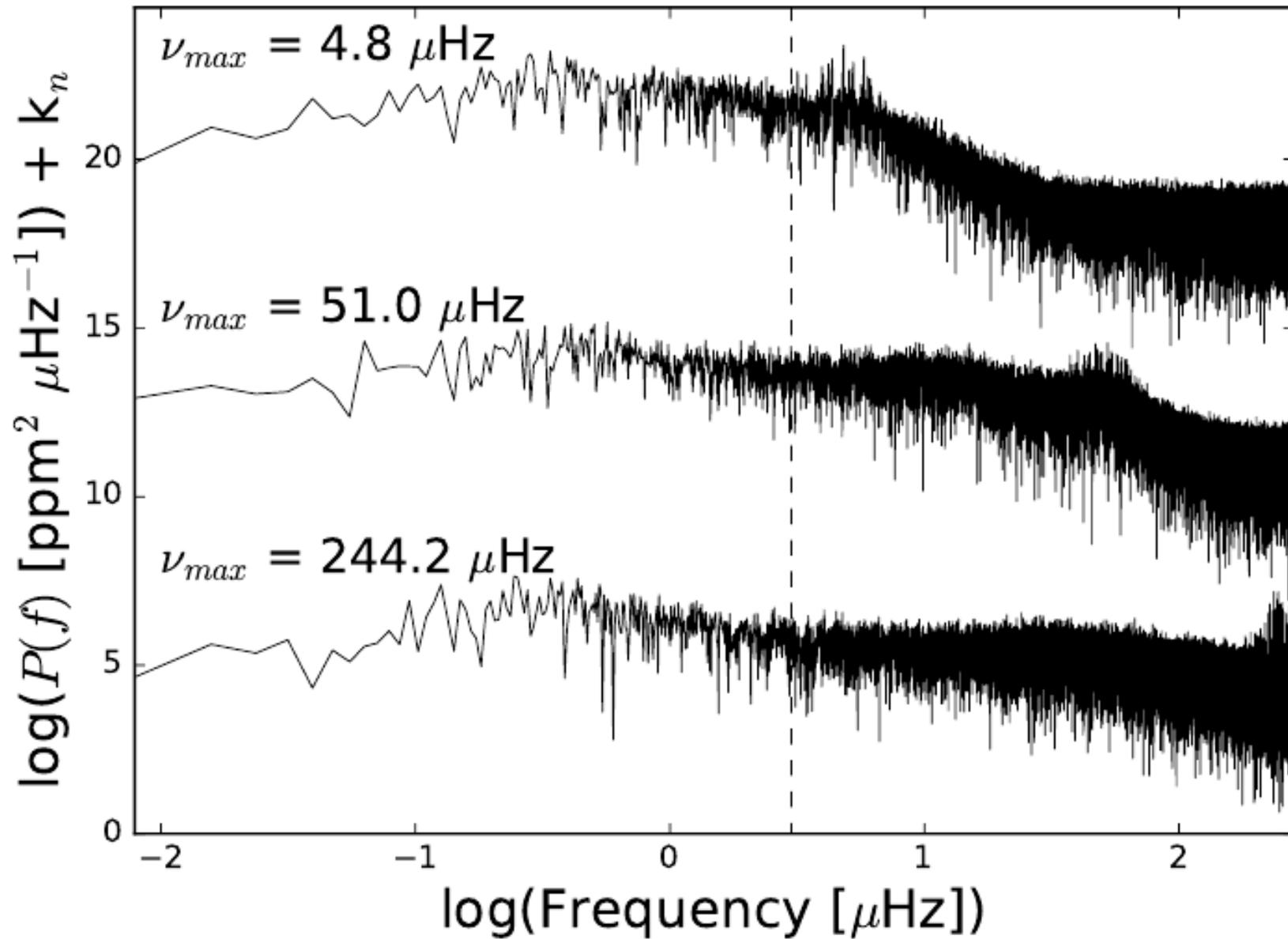
(Figure from Ness et al. 2018)

Looking at the diagnostic potential of the granulation background . . .

- Bastien et al. (2013, 2016): using granulation 8h "flicker" as stellar surface gravimeter, works in the time domain

LETTER

An observational correlation between stellar brightness variations and surface gravity

Fabienne A. Bastien[1], Keivan G. Stassun[1,2], Gibor Basri[3] & Joshua Pepper[1,4]

- Kallinger et al. (2016): adaptive filtering in time domain, ACF

- Bugnet et. al (2018): FliPer, considers power in certain frequency interval of power spectrum

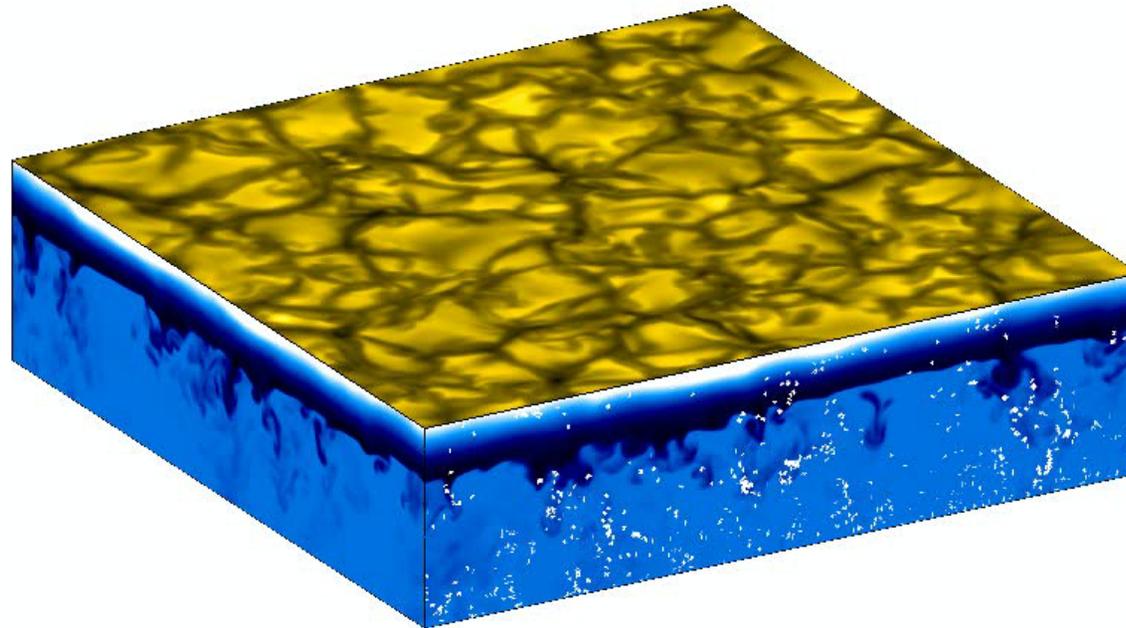- Ness et al. (2018): empirical data, driven approach, ACF, *The Cannon*

"Local box" CO^{5}BOLD 3D model atmospheres of late-type stars

Solar Granulation: d3gt57g44n94
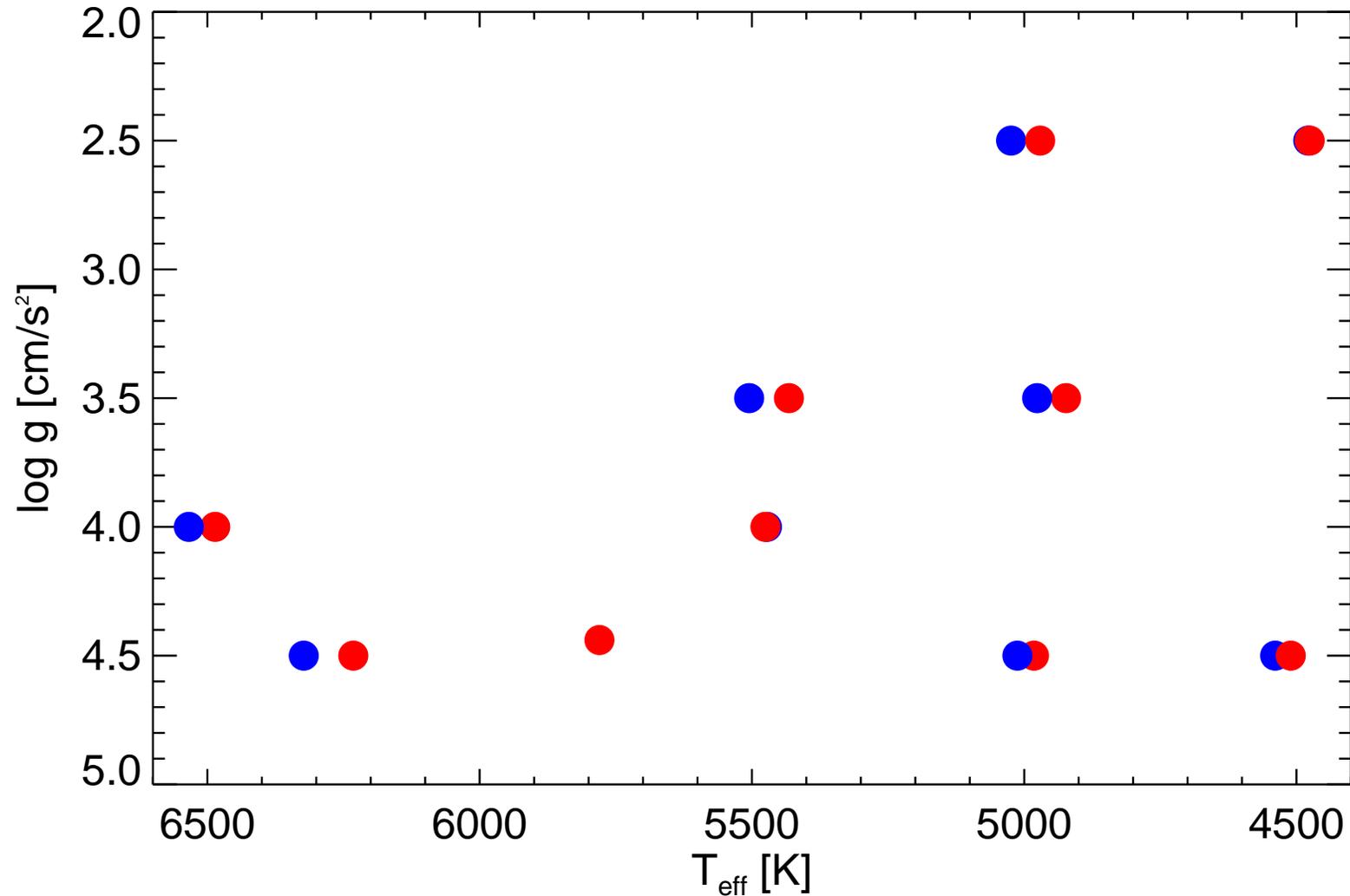Intensity & specific entropy
Time= 331.8 min   dlrms: 15.2 %

- Solution of (M)HD equations coupled to RT in representative small volume

- Spatially inhomogeneous (no assumed symmetry) and time-dependent

- Evolution of stochastic granulation pattern leads to fluctuations in radiative output
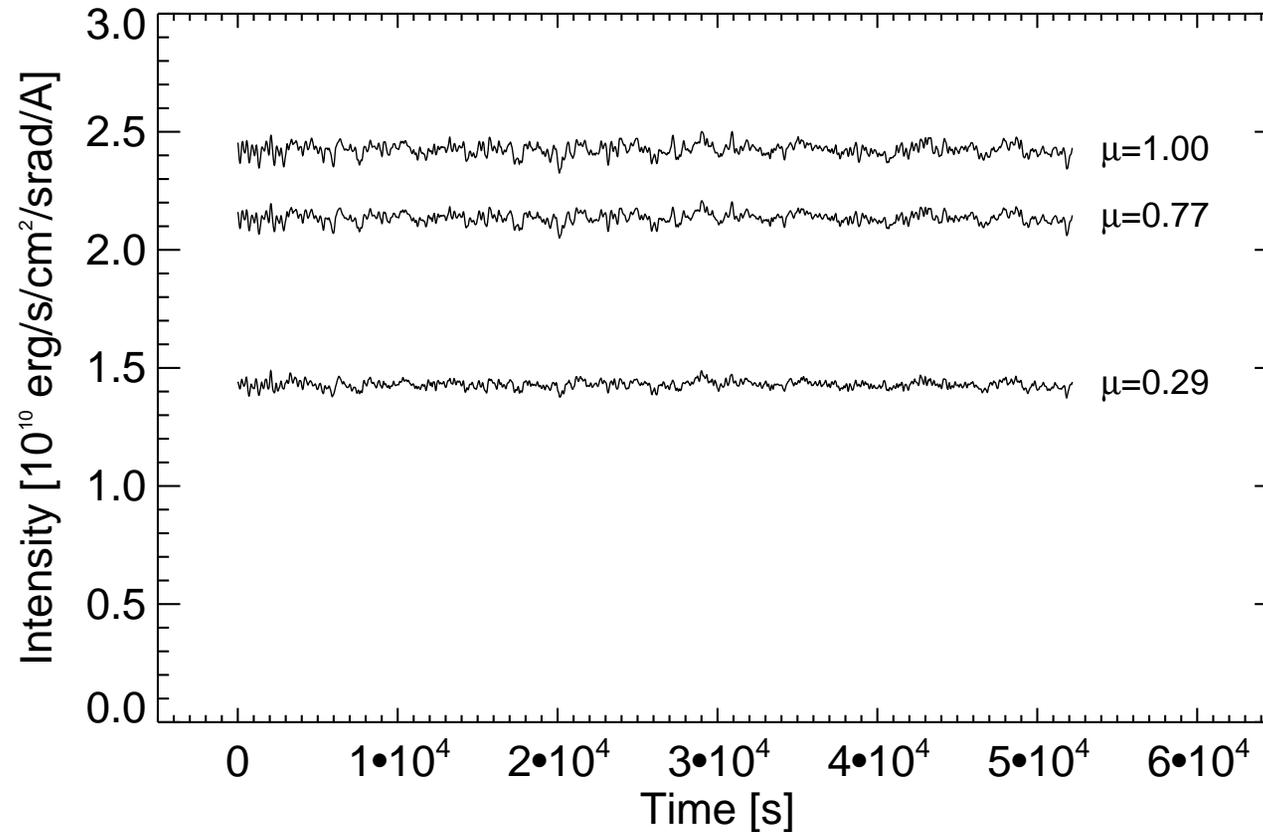
A small set of 3D model atmospheres

- 10 models solar metallicty (red), 9 models $[\mathrm{M/H}] = -2$ (blue)

- Large difference in metallicity $\rightarrow$ detect signal against intrinsic (convective) noise

Fluctuating radiative output of a 3D model as function of time

- Only horizontal average of bolometric emergent intensity considered

- Dependence on limb-angle preserved: $I_{\mathrm{bol}}(t, \mu)$

- With assumption on spatial non-correlation scaling to full disk signal

Fitting simulated power spectrum with analytical model
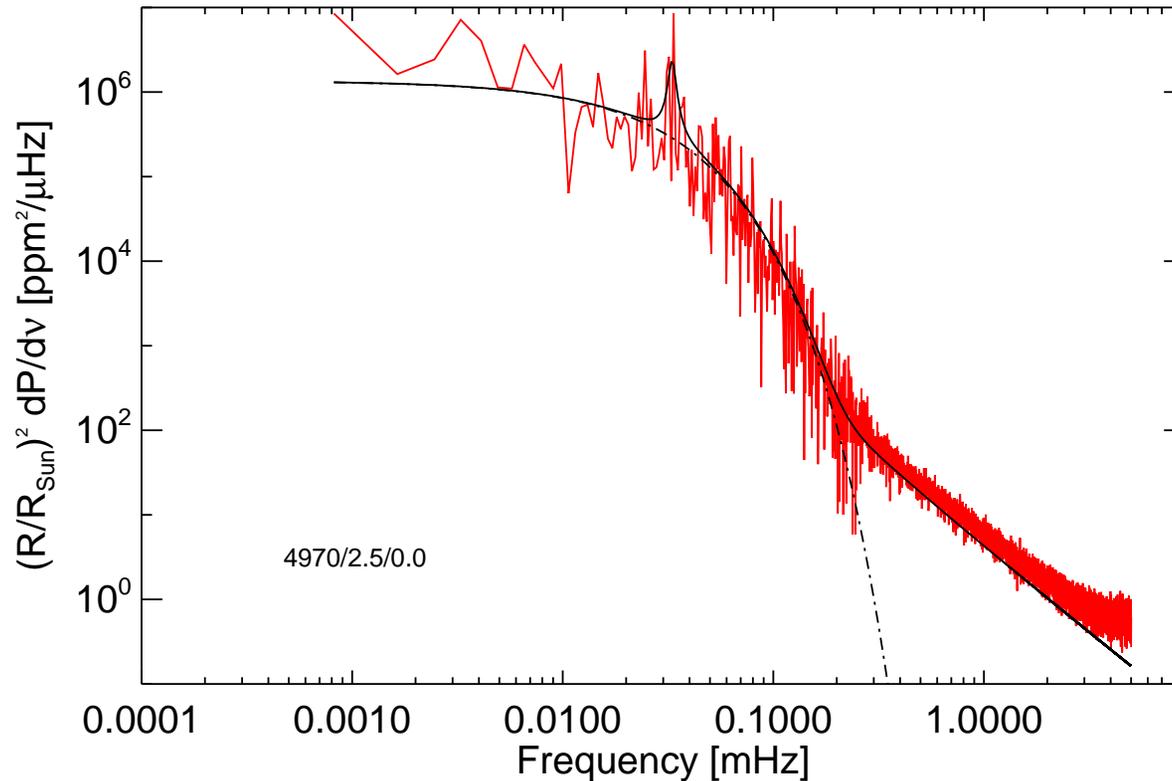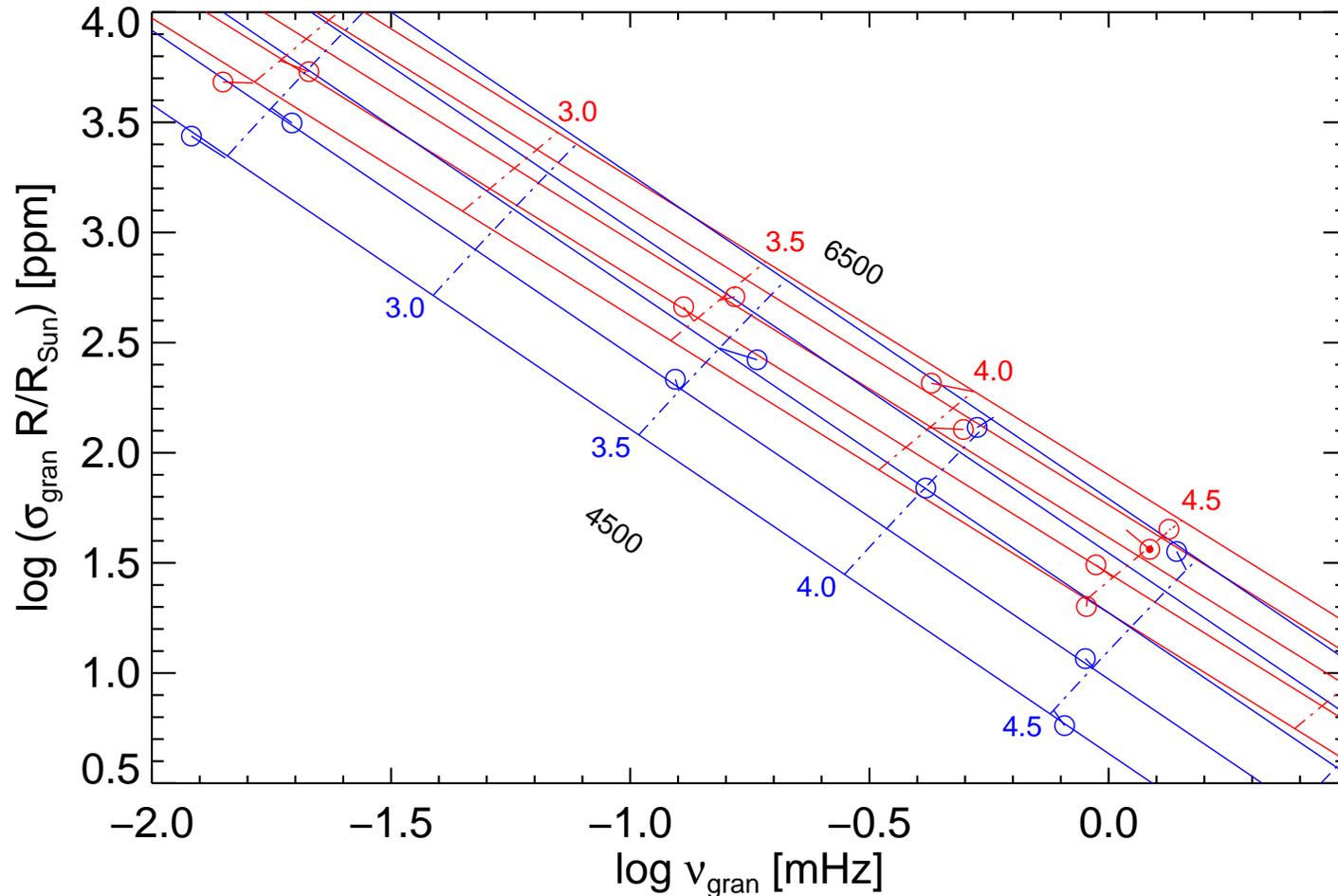

- Exponential backgound model plus box modes

$$\frac{dP}{d\nu}(\nu) = \frac{\sigma_{\mathrm{gran}}^2}{\nu_{\mathrm{gran}}} \exp\left(-\nu/\nu_{\mathrm{gran}}\right) + \text{sum of Lorentzians}$$

characteristic granular frequency ν_{gran}, frequency-integrated fluctuation σ_{gran}

- Rather: scaled frequency-integrated fluctuation $\tilde{\sigma}_{\mathrm{gran}} \equiv \frac{R}{R_\odot}\,\sigma_{\mathrm{gran}}$

  - $\rightarrow$ granular pattern always on star with $1\,R_\odot$ irrespective of $(T_{\mathrm{eff}},\ \log g,\ [\mathrm{M/H}])$

# "Reverse" Hertzsprung-Russell diagram of convective properties

- Circles 3D models: solar metallicity red, sub-solar metallicity blue ($[M/H] = -2$)

- Lines of constant $\log(T_{\text{eff}})$ and $\log g$ from bi-linear fits separately for each $[M/H]$

- Theoretical quantification of T-sensitivity: significant difference with metallicity $\rightarrow \nu_{\text{max}}([M/H])$?, Corsaro et al. 2017 find qualitative correspondence

Comparison to observations at $[\mathrm{M/H}] \approx 0$
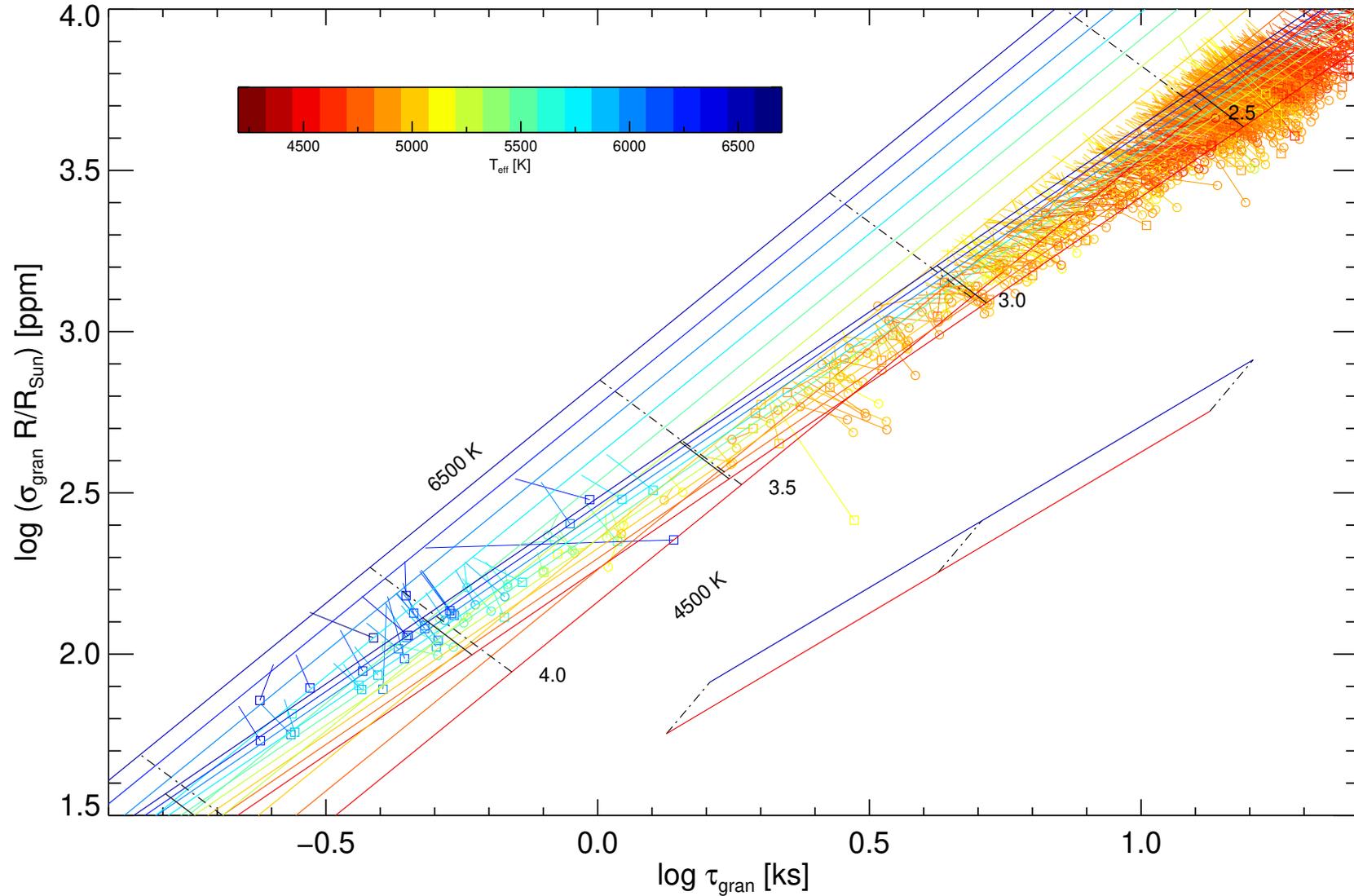
Data courtesy T. Kallinger: Kepler light curves provide granulation background, oscillatory modes provide M and R, T_{eff} mostly from APOGEE (otherwise KIC), no metallicity selection

Bolometric correction for Kepler pass band? $\frac{\delta f_{\mathrm{Kep}}}{f_{\mathrm{Kep}}} = \mathrm{BC}\ \frac{\delta f_{\mathrm{bol}}}{f_{\mathrm{bol}}}$
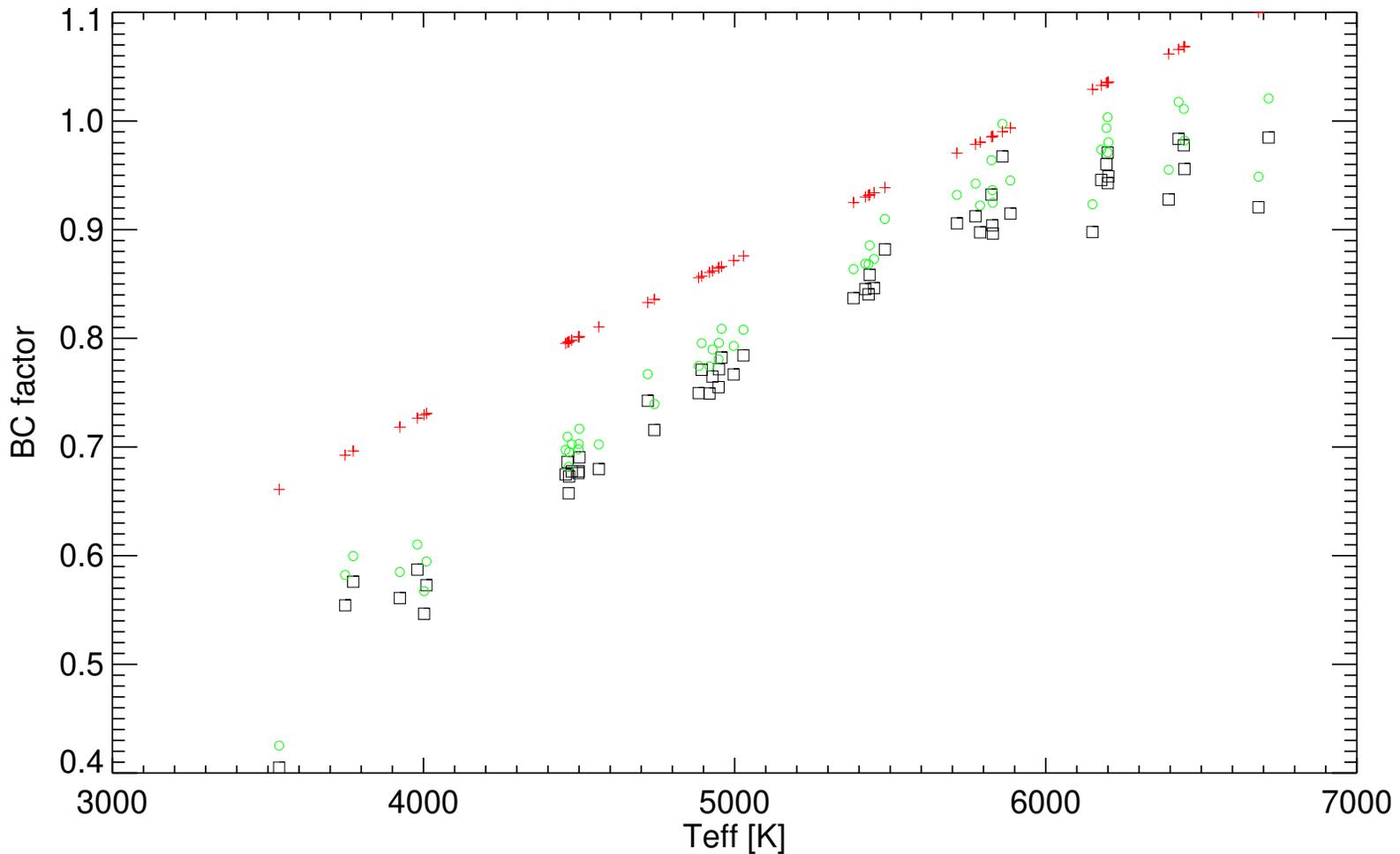
- Red crosses: canonical bolometric correction of Ballot et al. 2011

- Green circles and black squares: 3D models, set of different T_{eff}, $\log g$, [M/H] black squares detailed flux distribution, green circles 3D fluctuations

Points for discussion

- Correspondence between predicted granulation properties and observations is not satisfactory

  - theoretical T-sensitivity of ν_{gran} and $\tilde{\sigma}_{\mathrm{gran}}$ significantly higher than observed
  - scaling with gravity also deviates

- What is/are the reason/s?

  - bolometric correction has an influence but not decisive
  - functional form of background model?
  - "magnetic suppression"? (as seen in F-dwarfs)
  - connection to the deviations seen by Lionel Bigot in interferometric visibilities?

- Robust result: at $[\mathrm{M/H}] = -2$ the granulation-related brightness flicker is about twice as T-sensitive as at $[\mathrm{M/H}] = 0$

- How does the information content of the granulation background compare with the one of the oscillations?