The enigmatic granulation background of HD49933

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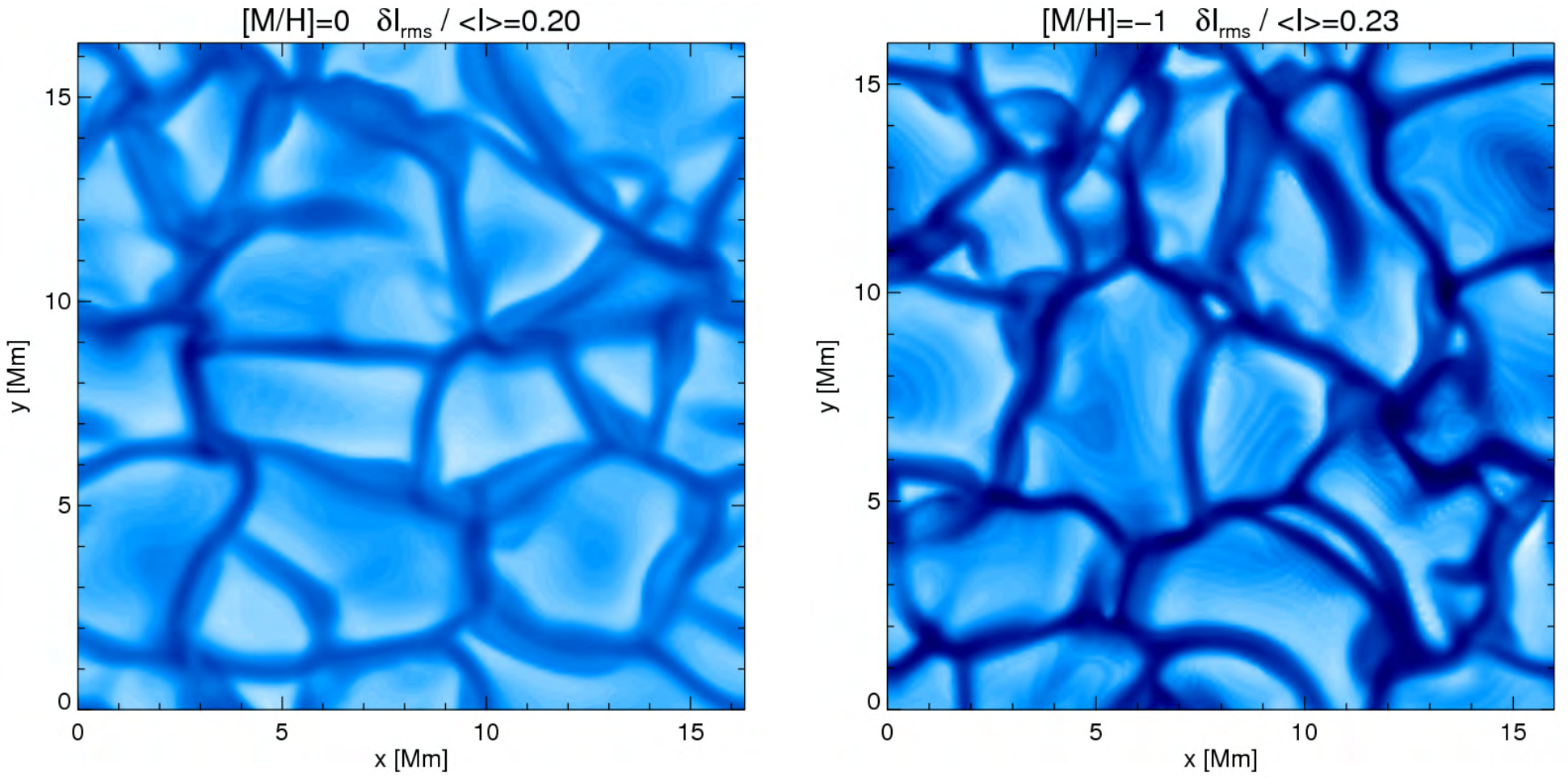
Overview

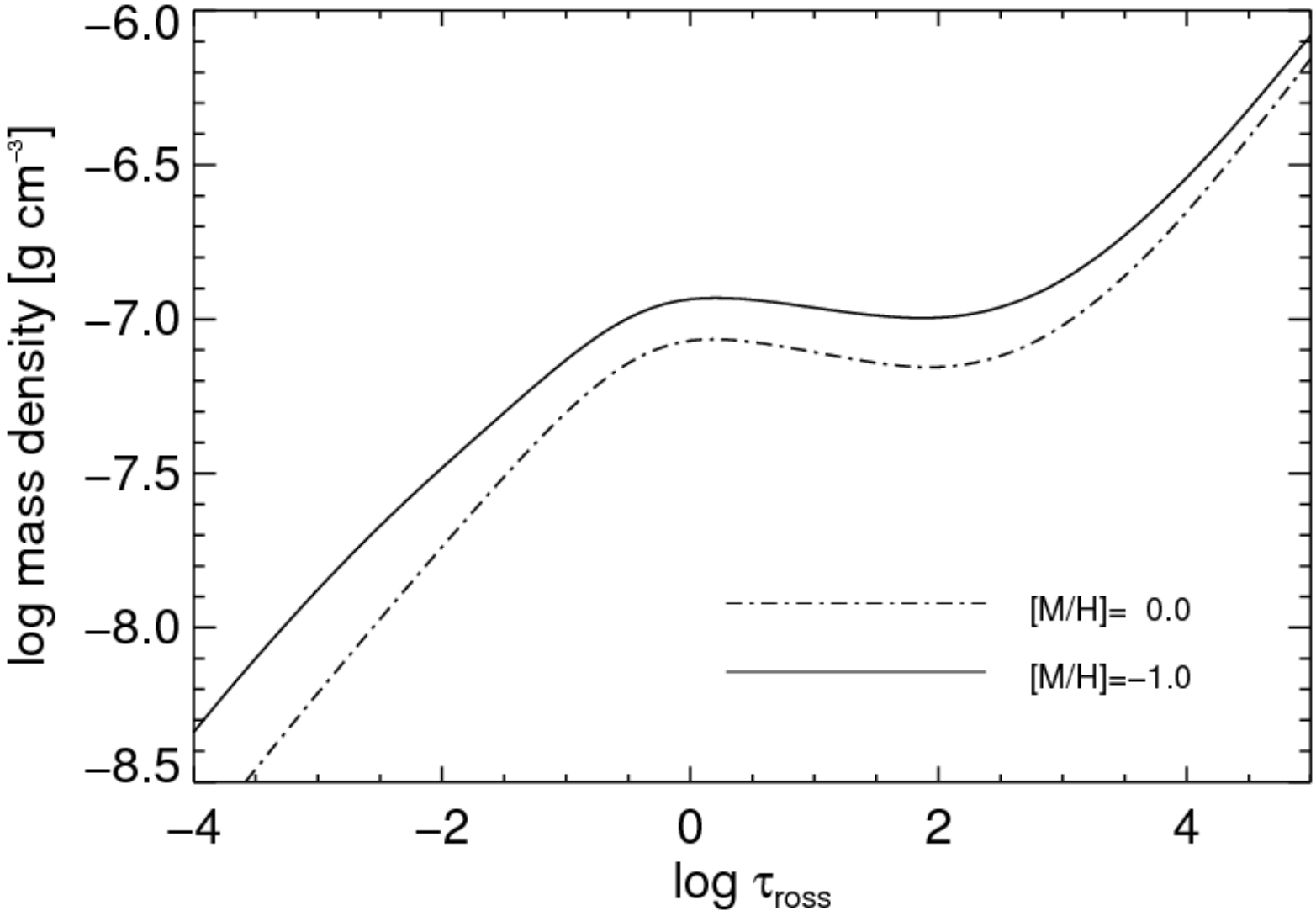
- Predictions of granulation-related photometric fluctuations
  - "background signal" in p-mode region
  - comparison to COROT long-duration observing run: F-dwarf HD49933
- Ab-intio simulations of convective flows including detailed radiative transfer
  - local models, three-dimensional, time-dependent capturing the convective dynamics
  - CO^{5}BOLD radiation-hydrodynamics code
  - "3D stellar atmospheres"
- The match to HD49933 is not satisfactory. Why?
- Observational photometric data courtesy COROT group

Two hydrodynamical model atmospheres for HD49933

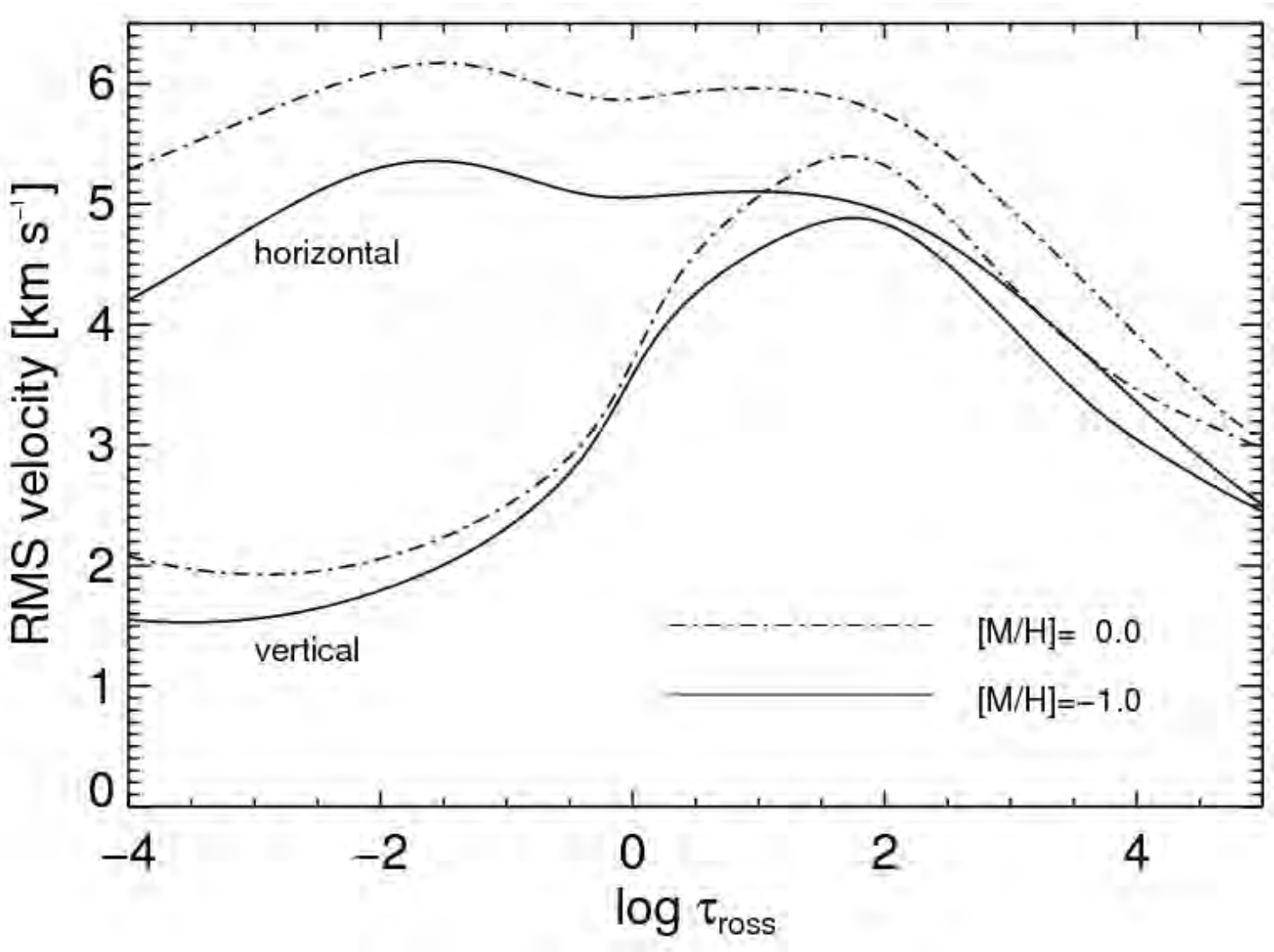


- $T_{\rm eff}$=6740 K, $\log g$=4.25 close to measured parameters
- [Fe/H]=0.0 and -1.0 bracketing the measured value of [Fe/H]≈-0.3. . .-0.4
- Scales of granulation pattern a bit smaller and contrast higher in metal-poor model

Lower metallicity implies higher surface densities



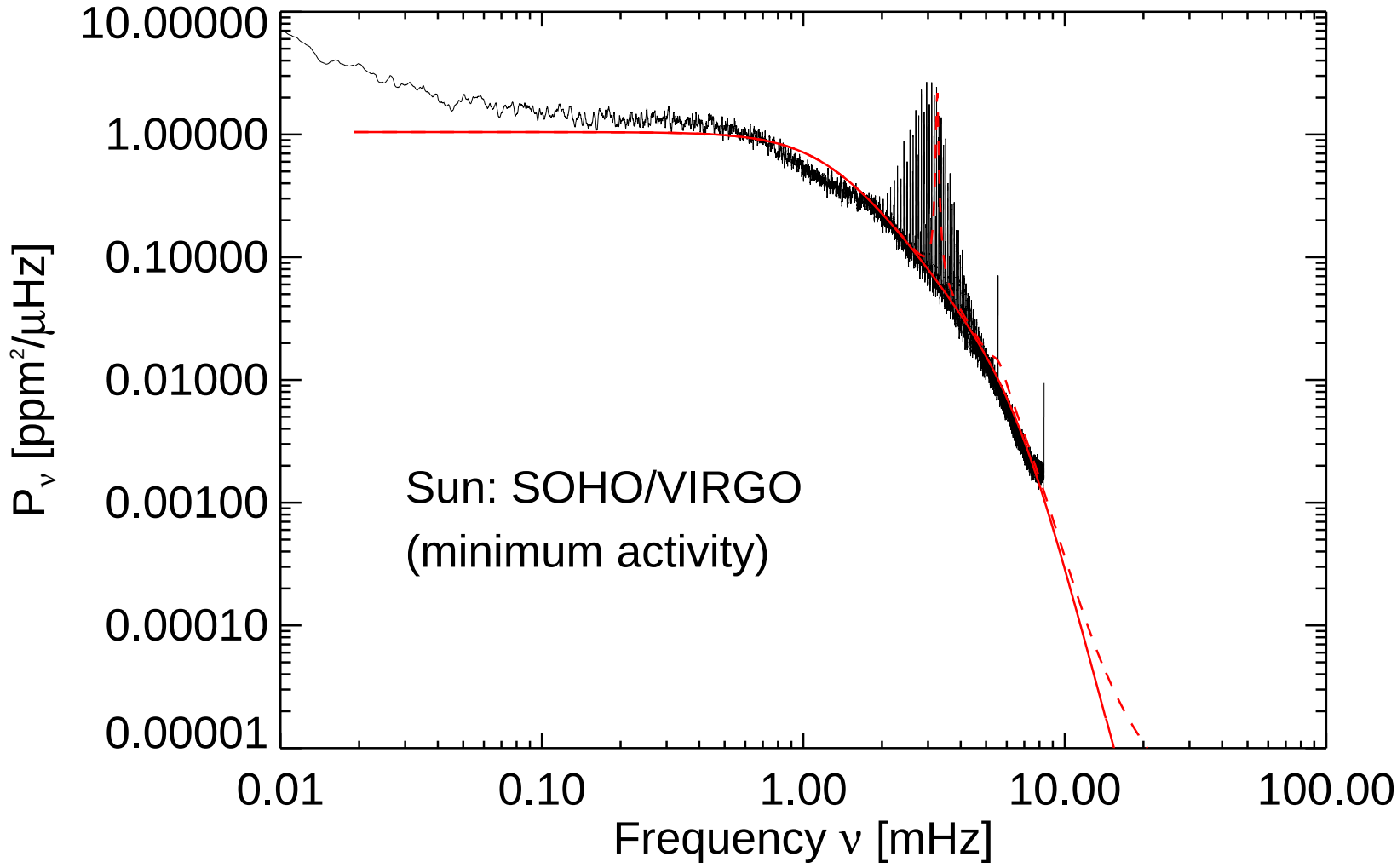
Higher densities and contrasts favor lower velocities



Statistical scaling of local model to full stellar disk

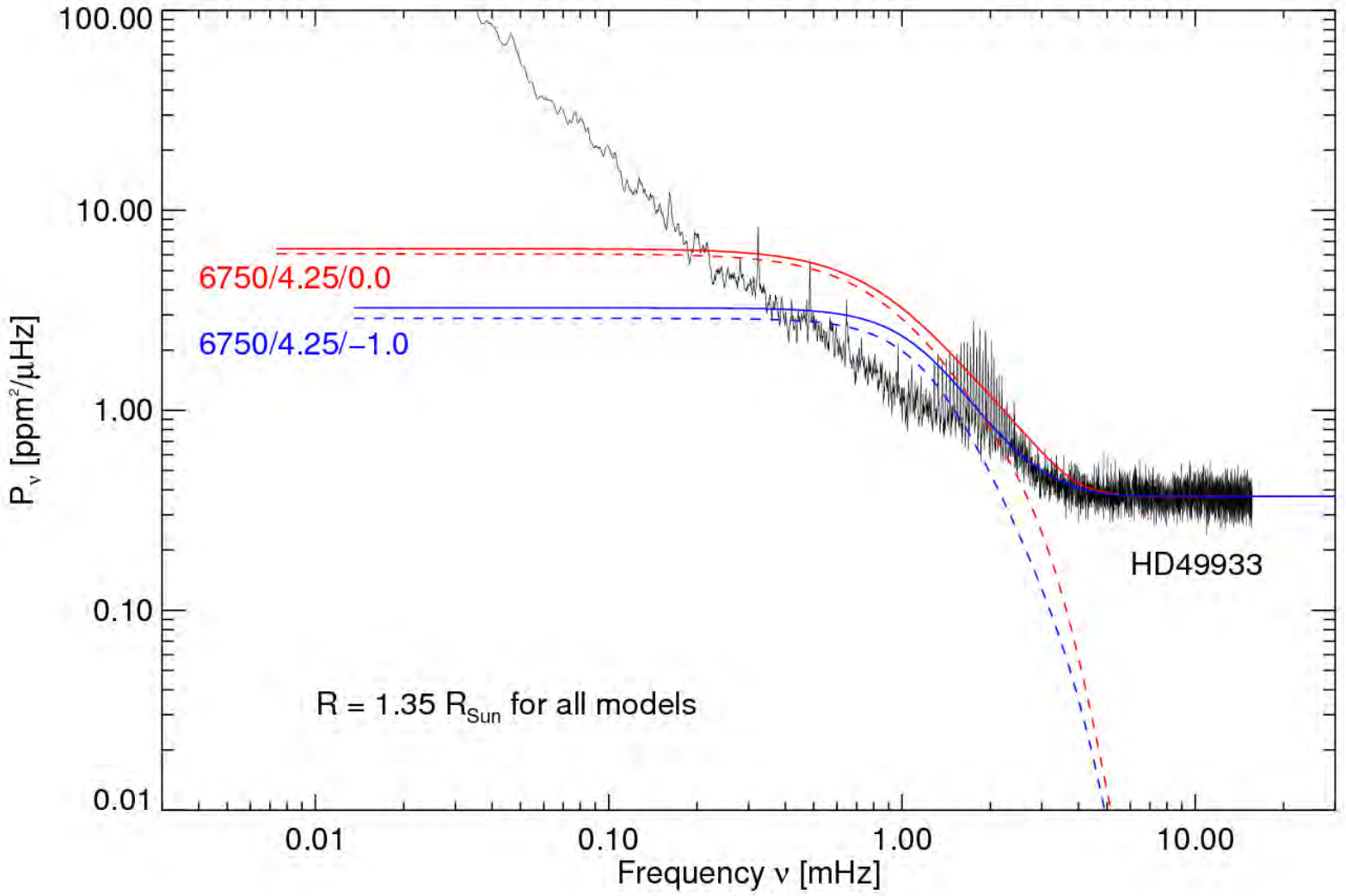
- Hydrodynamical model provides a time series of the radiation intensity at different limb-angles including the temporal convection-related fluctuations
- With an assumption of the stellar radius R this can be scaled to the emission integrated over the stellar disk
  - R^{-2} dependence of temporal spectral power density
  - for details see Ludwig 2006, A&A 445, 661
- Fit of analytical model to synthetic raw power spectrum to reduce noise and eliminate acoustic eigen-modes of computational box

Observational validation: Sun seen by SOHO/VIRGO



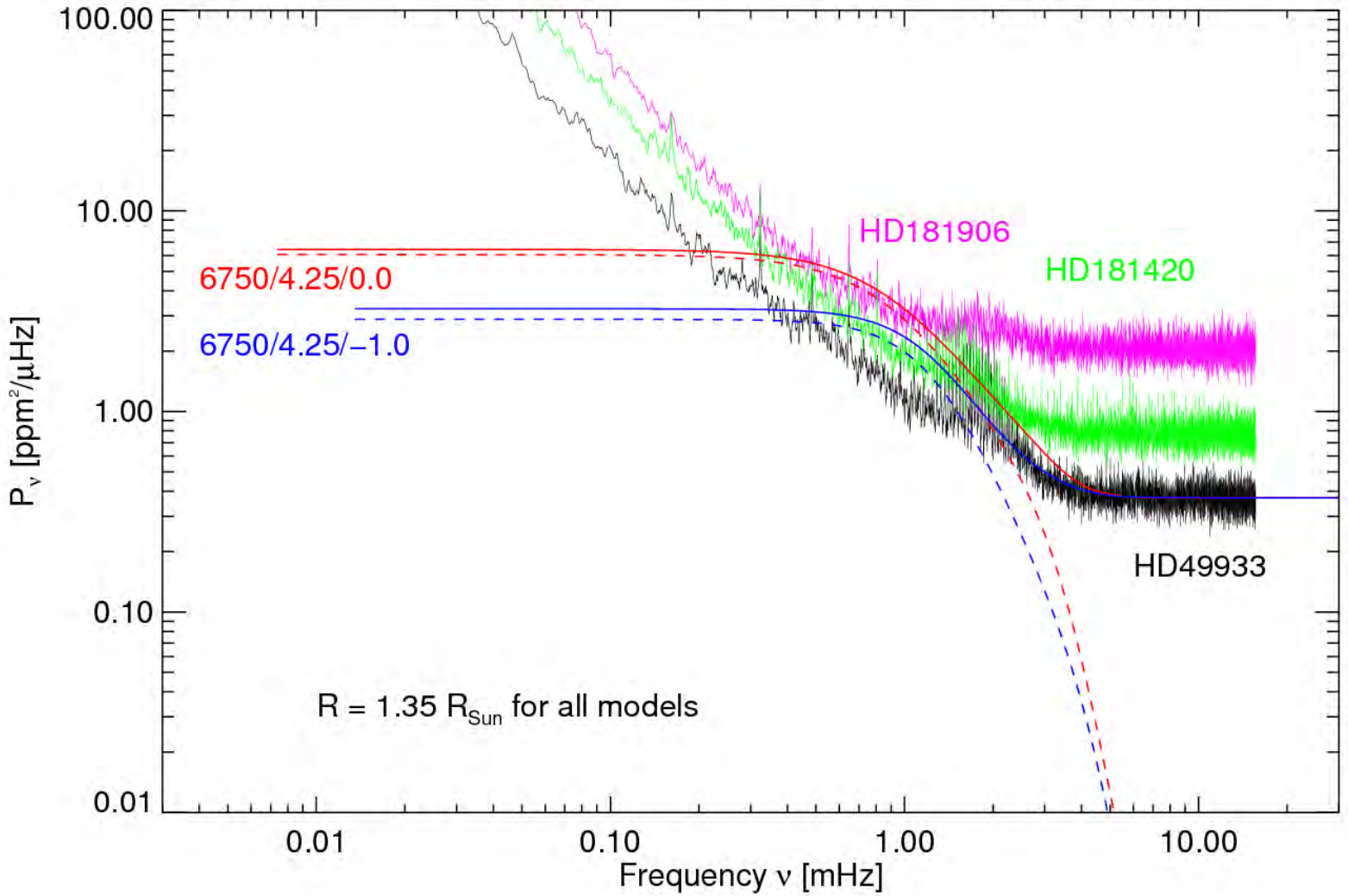
- Satisfactory run of continuum, eigenmodes not directly comparable, absolute scale!
- Magnetic activity dominates signal towards low frequencies

Predictions for COROT's main target HD49933



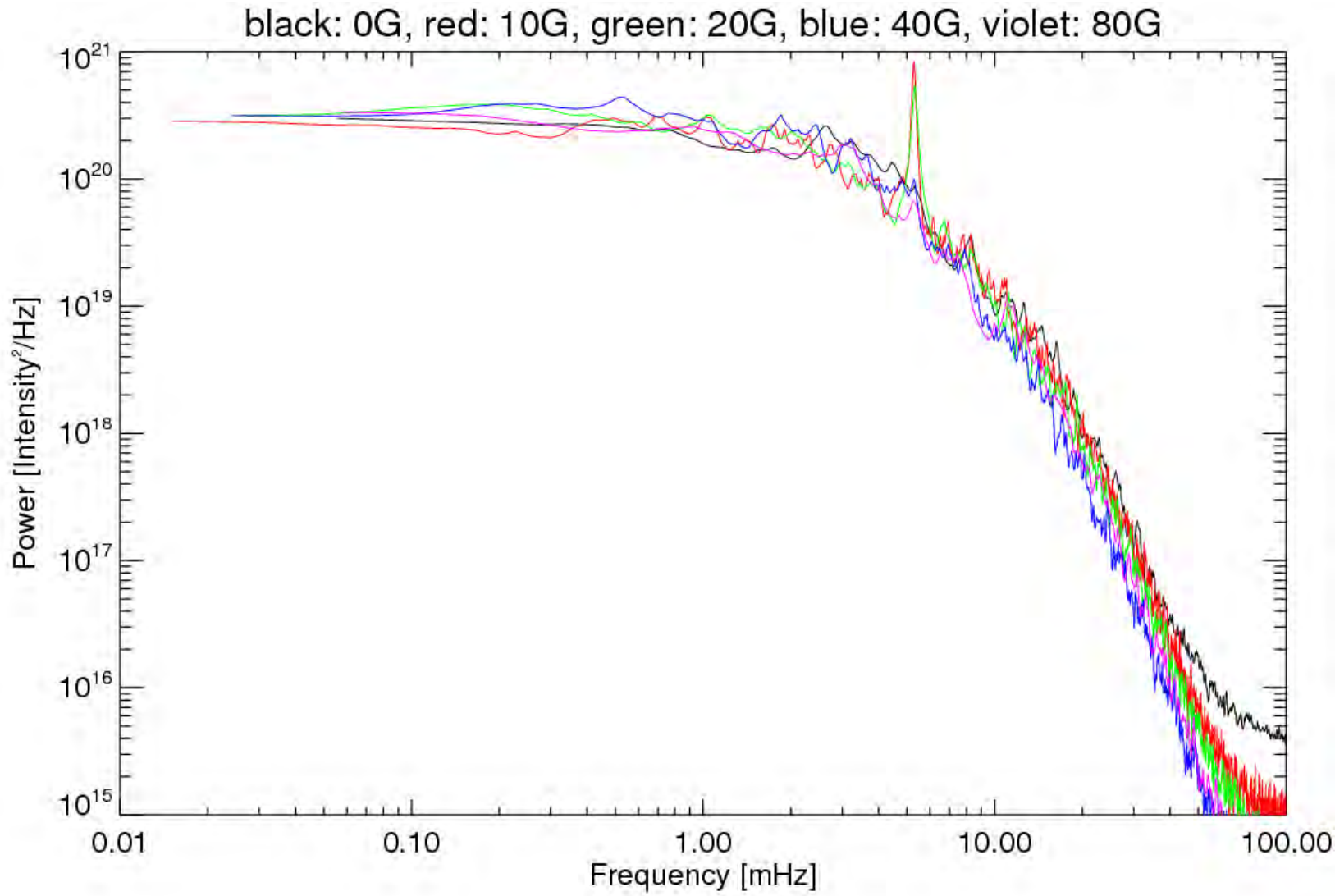
- Bolometric background signal stronger in p-mode region than observed
- Shape of the power spectrum not well matched: activity? local dynamo?

HD49933 does not seem to be an exceptional case



HD49933	$T_{\rm eff}$/K = 6750	$\log g$= 4.24	[Fe/H] = -0.40
HD181420	6650	4.17	-0.04
HD181906	6380	4.15	-0.14

Lightcurves of solar 2D MHD runs of increasing magnetic flux

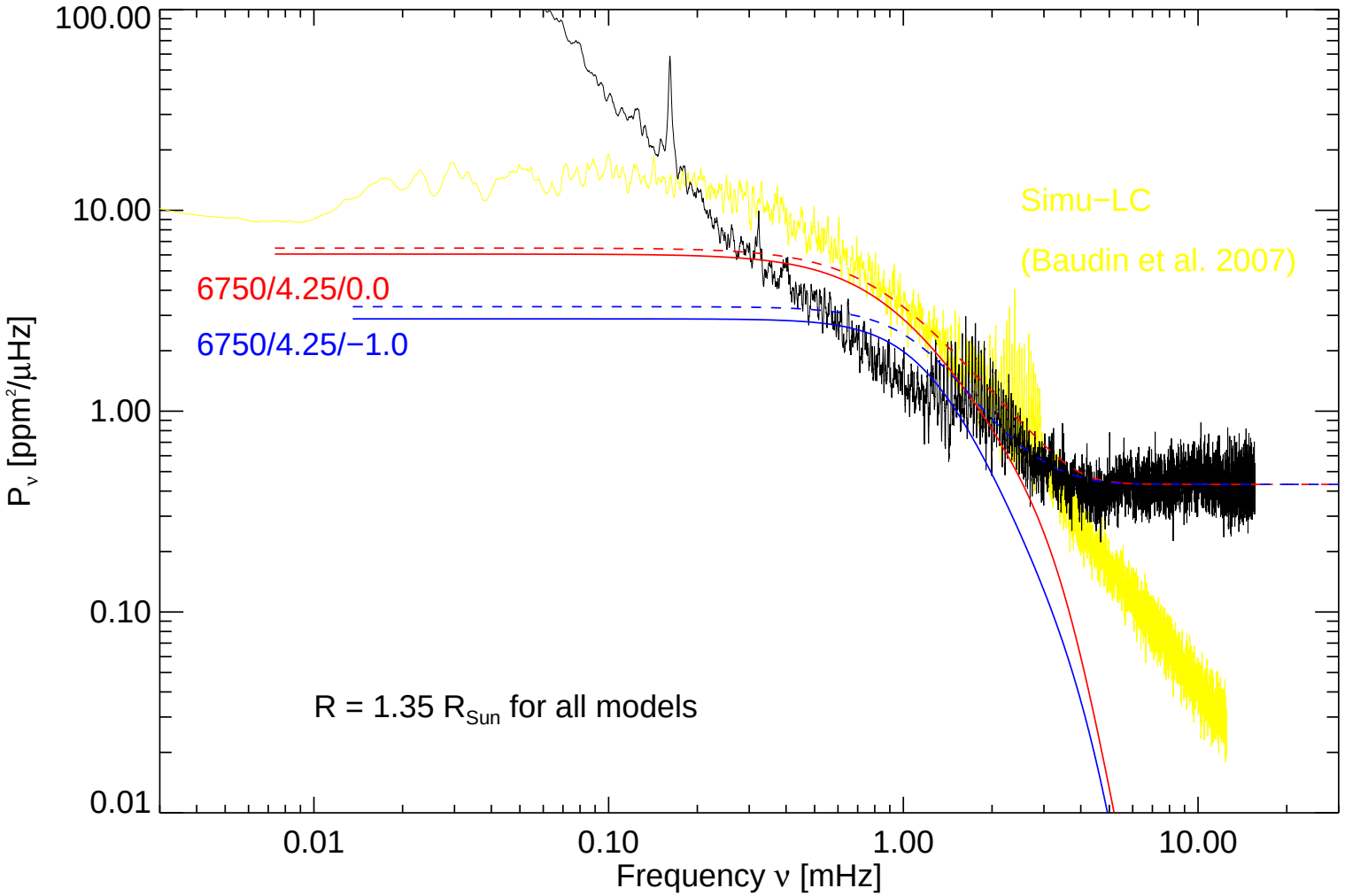


- Change of granular dynamics by magnetic field mainly influences highest frequencies
- Polarization: no globally organized magnetic field on 1 G level (C. Catala, p.comm.)

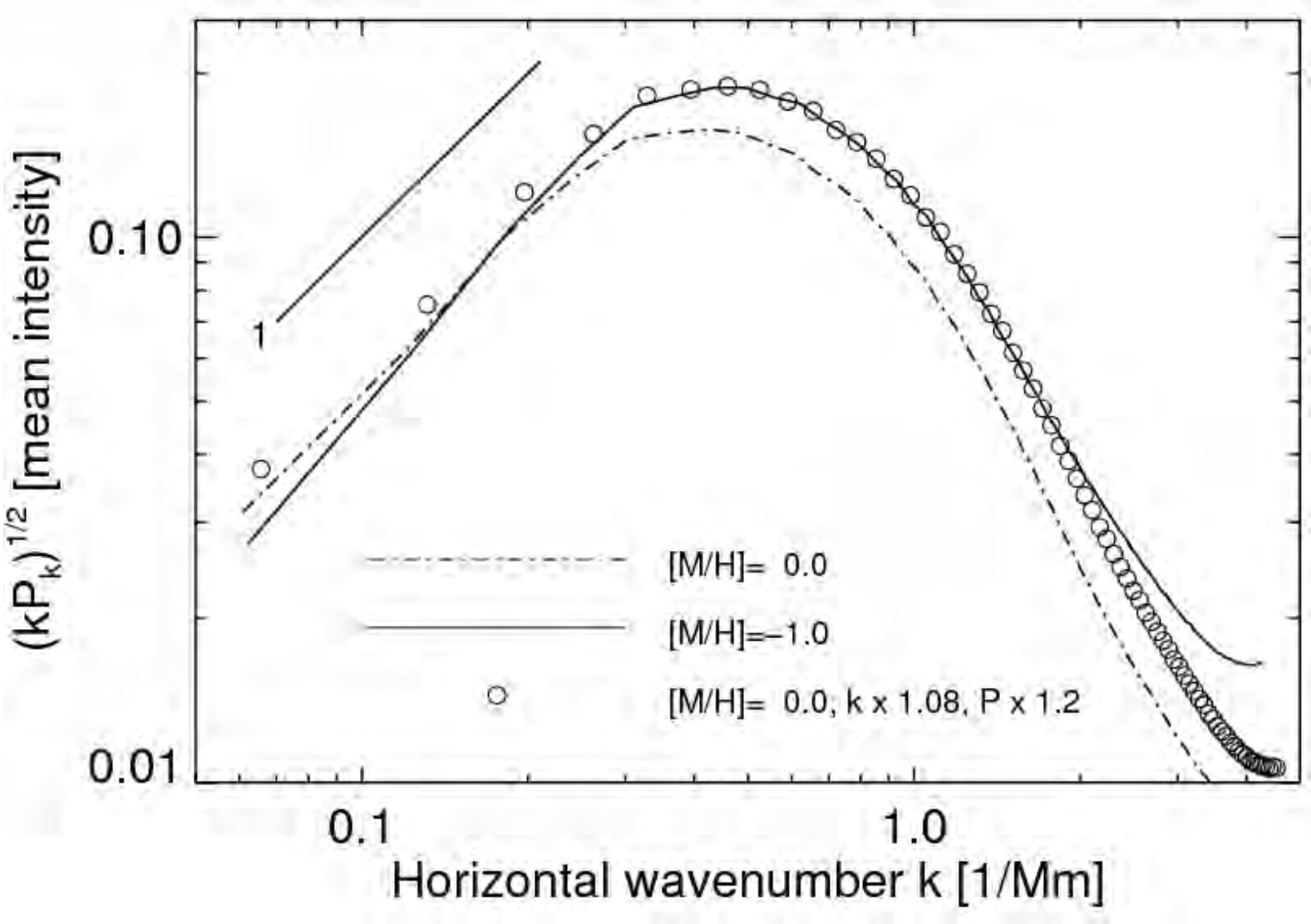
Take away ...

- 3D model atmospheres can be used to predict granulation-related disk-integrated brightness fluctuations
  - reasonably successful for the Sun
- Mismatch between predictions and observed granulation background of HD49933
  - HD49933 typical case among the F-dwarfs observed by COROT
- Are magnetic fields produced by dynamo action the culprit?
  - signature of spots clearly present in light curve
  - no significant magnetic field present which is structured on global scales (polarimetry with NARVAL & ESPADONS)
  - local dynamo action in granulation – if present – unlikely to be responsible for increase of power towards low frequencies

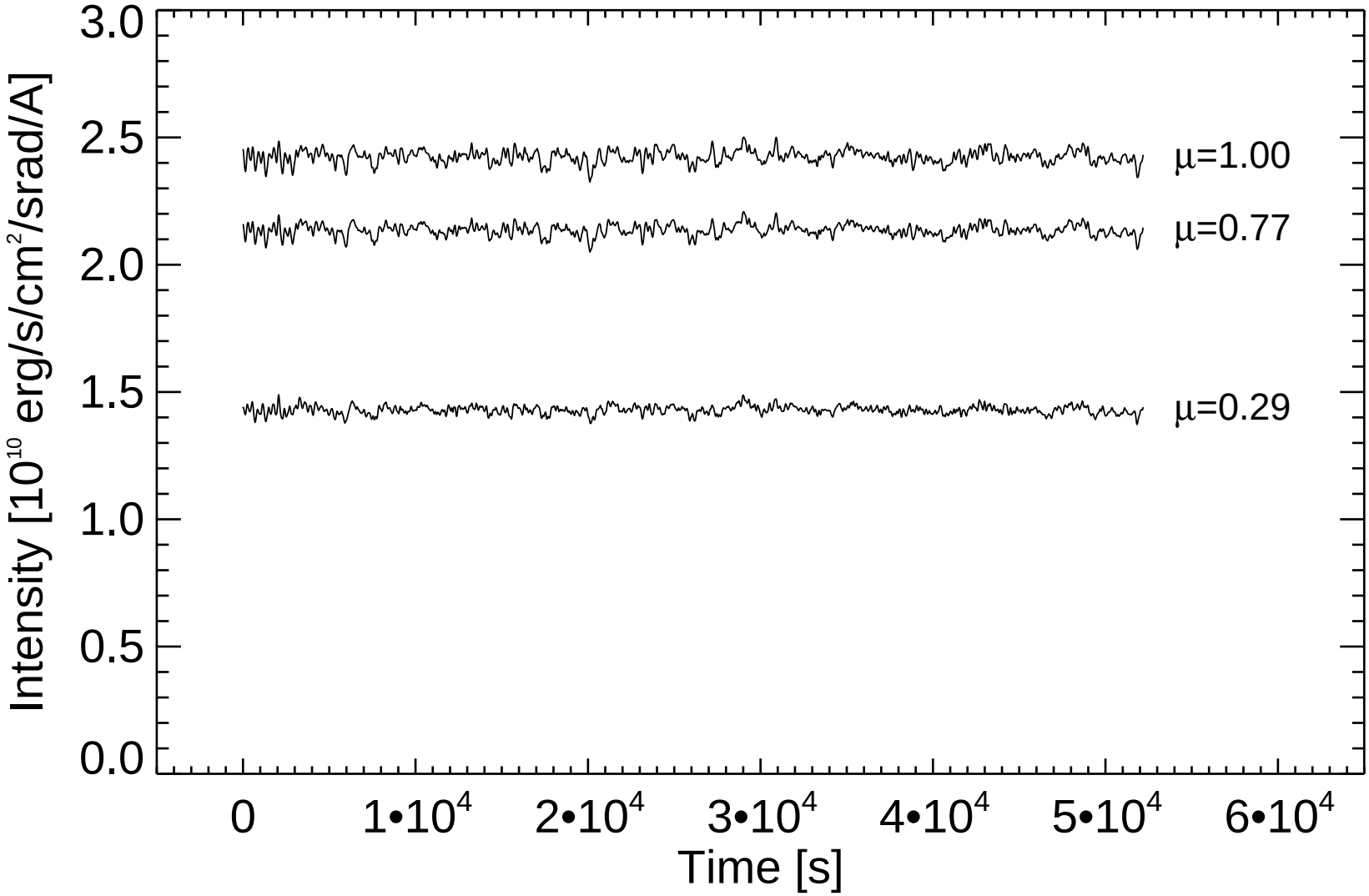
Predictions for COROT's main target HD49933 & Simu-LC



Spatial power spectra of granulation pattern of HD49933 models

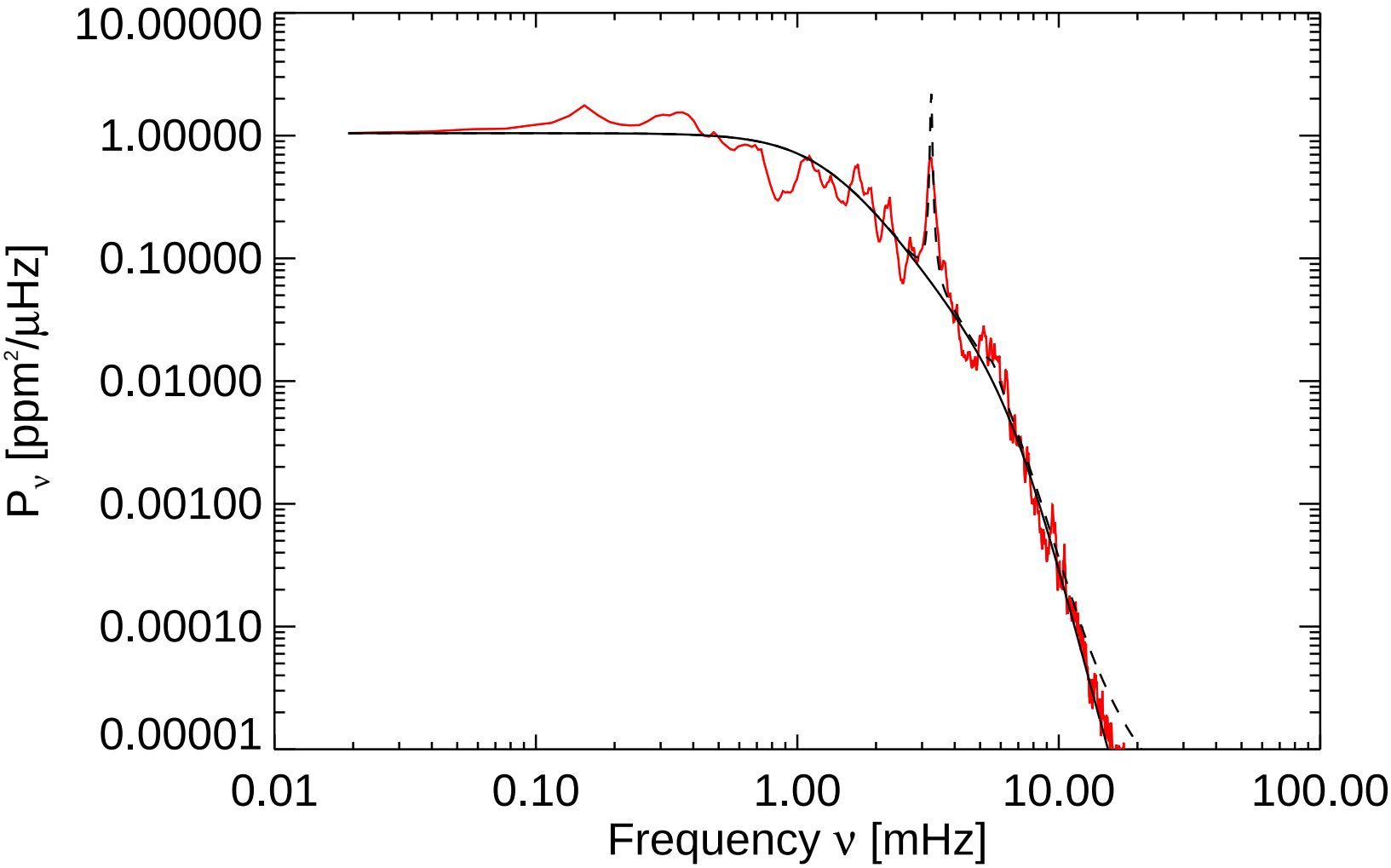


Simulations provide surface averages of emergent intensity



- Statistical scaling of local model to full disk, center-to-limb variation
- Power spectra of photometric time series have R^{-2} dependence

Simulated time series provide only limited statistics



- Power spectrum of simulated time series (red) quite noisy
- Fit of simple analytical model for granulation background + box modes (black)

Extrapolation from local model to disk-integrated properties

- Assumptions entering algebraic considerations:
  - convection pattern statistically homogeneous
  - each simulation patch is statistically independent
  - oscillations different: modes by definiton spatially correlated

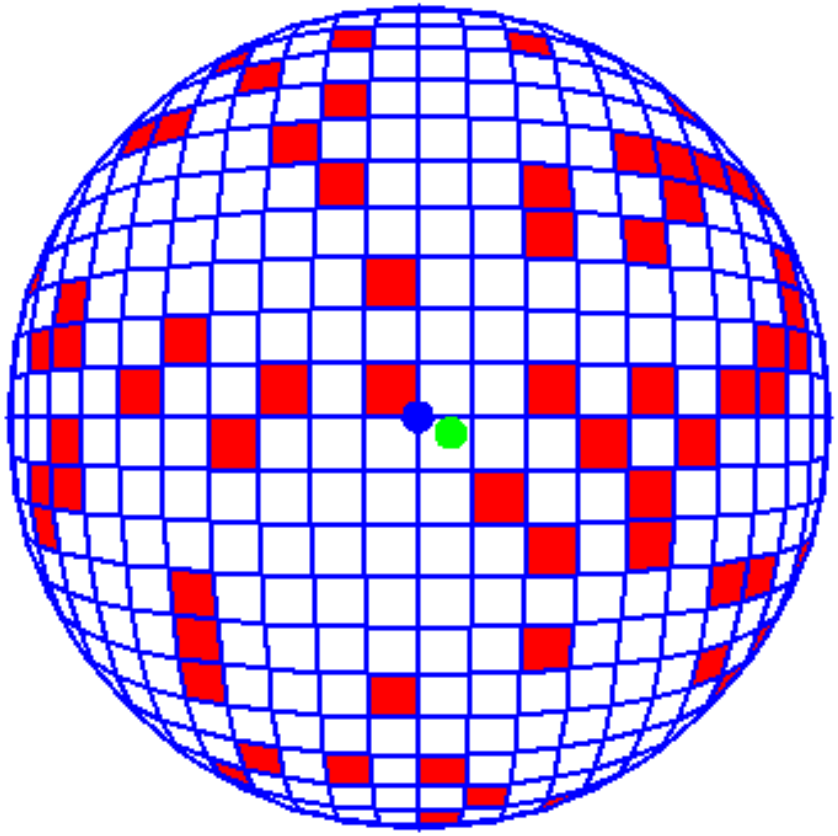
- Expectation of value frequency component of power spectrum

$$\frac{\left\langle \hat{f}\hat{f}^{*}\right\rangle }{\left\langle f\right\rangle ^{2}}=N^{-1}\frac{\sum_{m=1}^{M}w_{m}\mu_{m}^{2}\left\langle \hat{I}_{m}\hat{I}_{m}^{*}\right\rangle }{\left(\sum_{m=1}^{M}w_{m}\mu_{m}\left\langle I_{m}\right\rangle \right)^{2}}$$

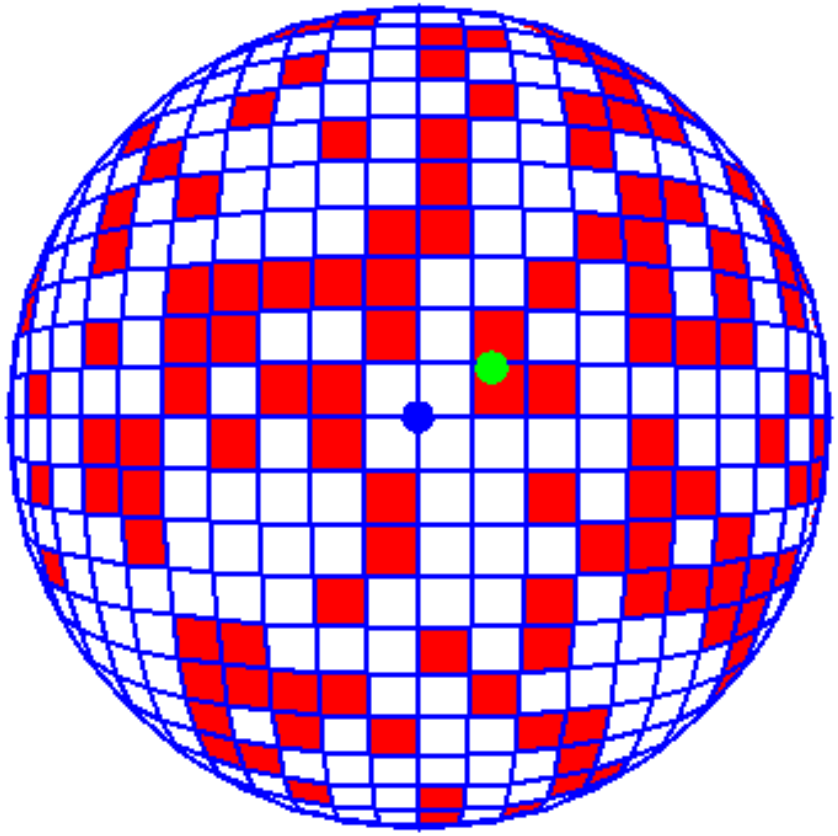
  - superposition of individual power spectra of intensities at different limb-angles
  - N number of radiating patches
  - $NA=2\pi R_{*}^{2}$, A patch area, R_{*} stellar radius

- Power of relative brightness fluctuations scales as R_{*}^{-2}
  - needs to be provided, not intrinsic to the local model

Superposition of "patches" produces disk-integrated fluctuations



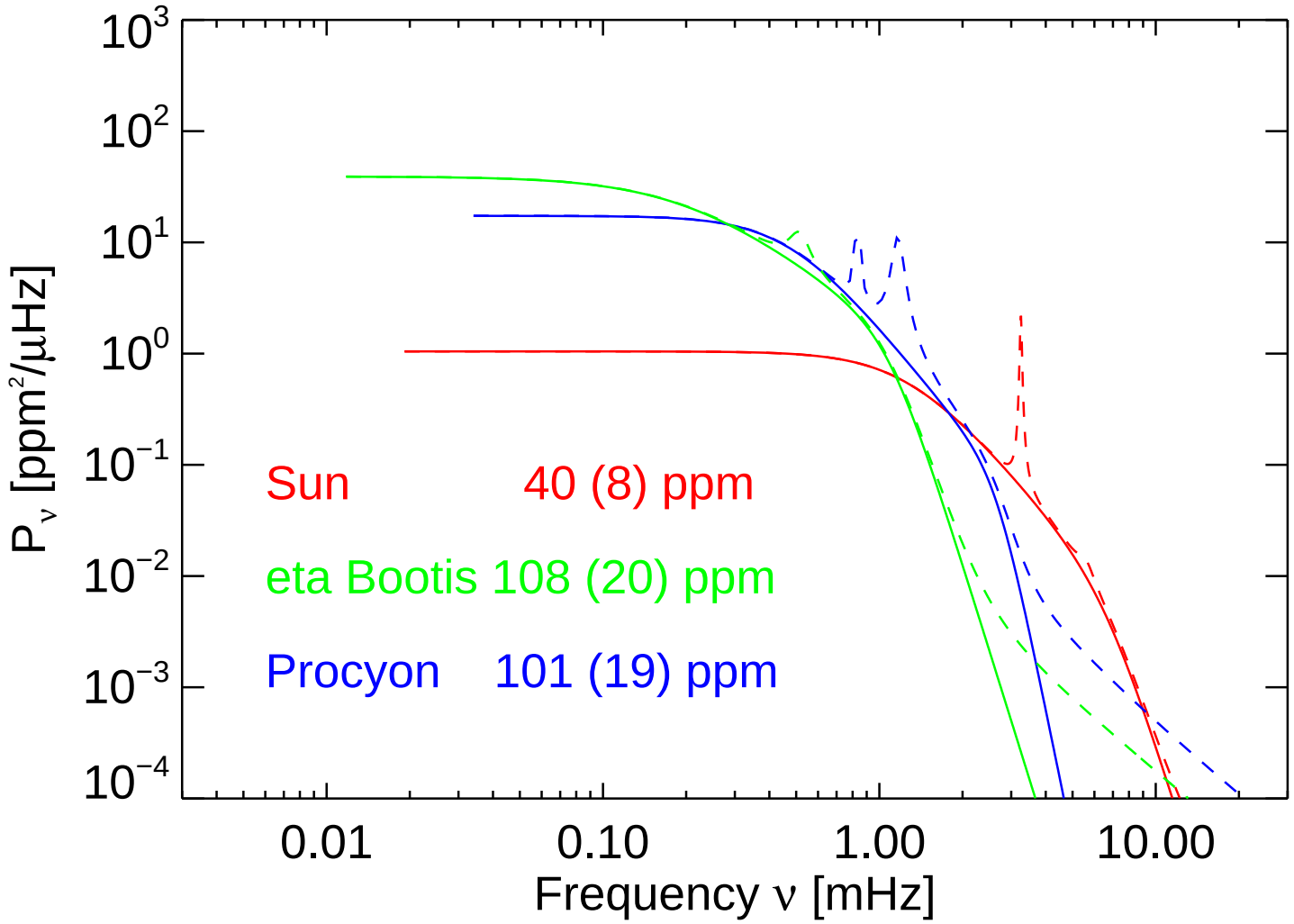
dark



bright

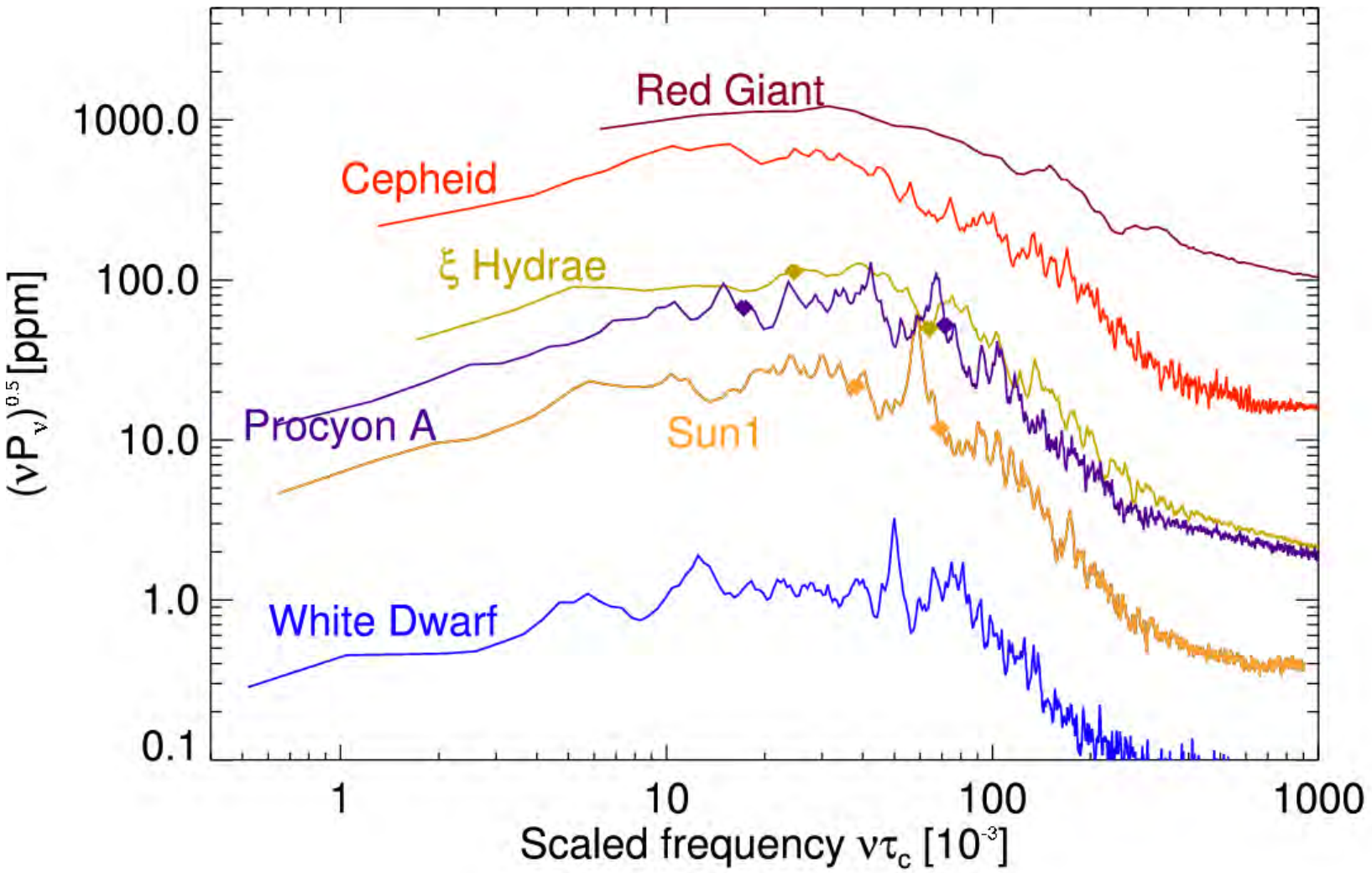
- Temporal fluctuations of disk-integrated flux $f(t) \propto \oint dA\, \mu\, I(x, y, t)$
- Fluctuations in apparent stellar position, photocenter $x_{\rm ph}(t) \propto \oint dA\, \mu\, I(x, y, t)\, x$

Favorite asteroseismological targets: Sun, Procyon, η Bootis



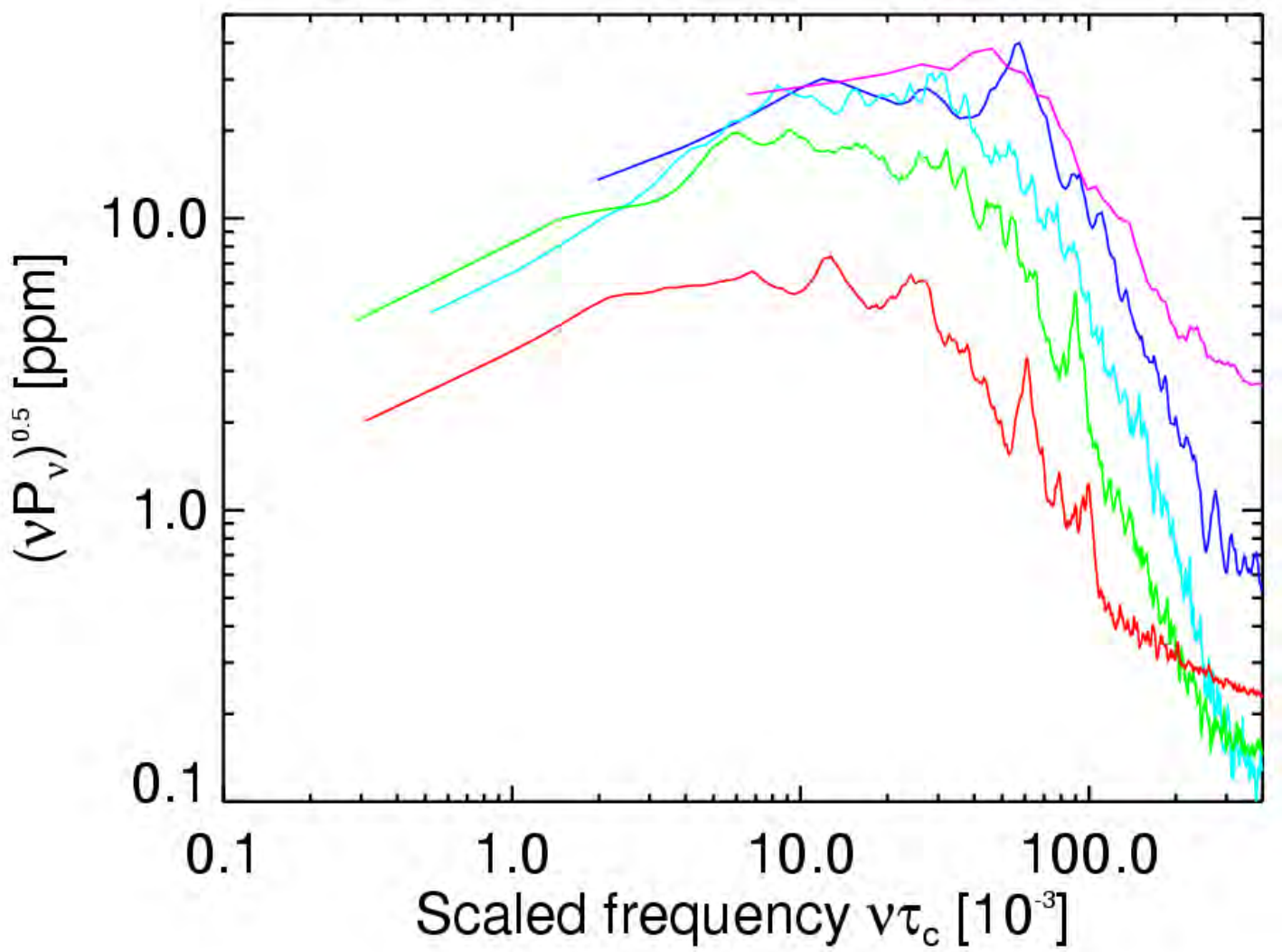
- Statistical uncertainty on total power $\pm 20\%$

Scaling of brightness fluctuations with gravity (and $T_{\rm eff}$)



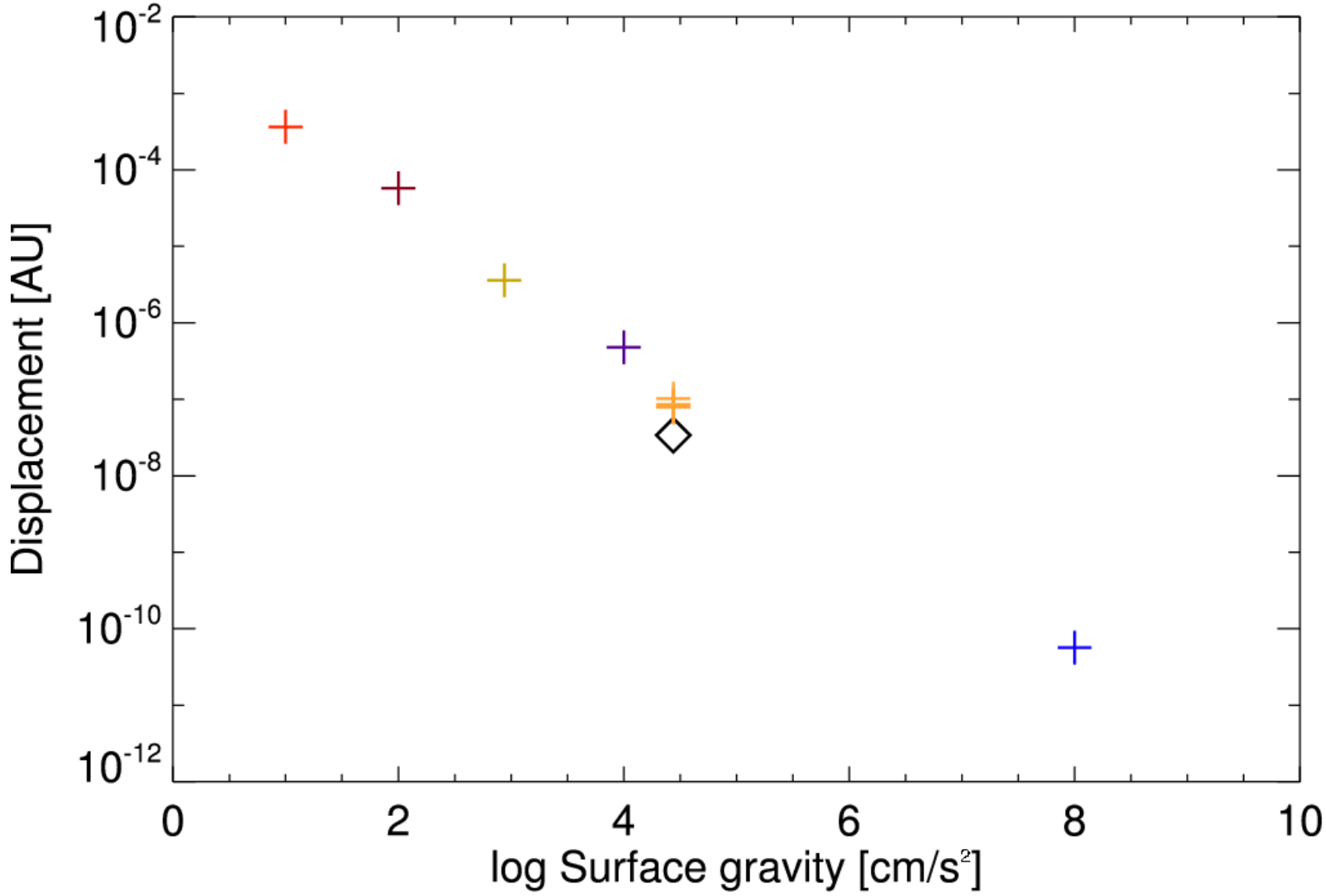
- Time-scales scale approximately with the atmospheric acoustic cut-off time scale $\frac{2H_{\rm p}}{c_{\rm s}}$

Scaling of brightness fluctuations with $T_{\rm eff}$ at solar gravity



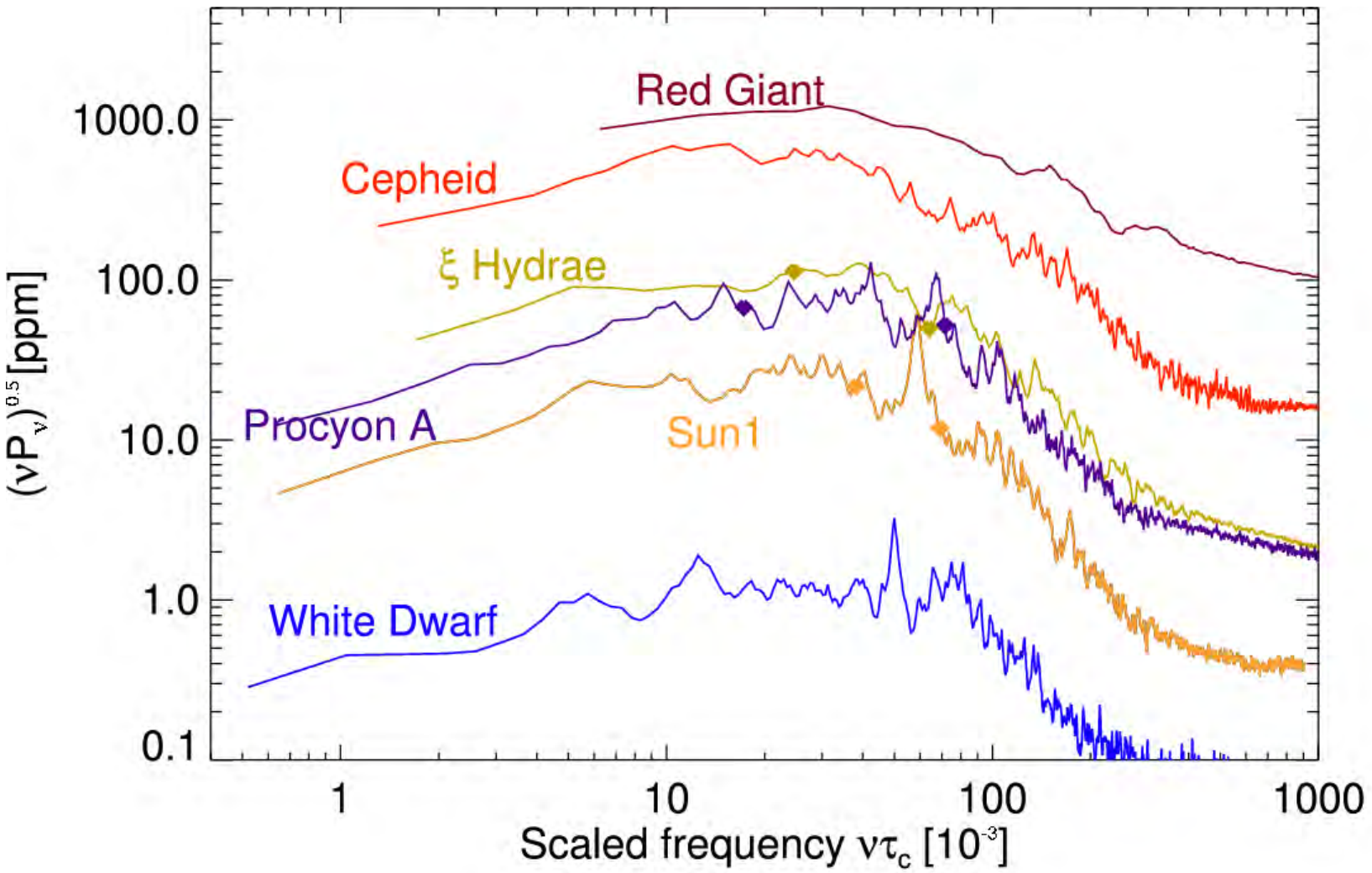
- red 4000 K, green 4600 K, lightblue 5200 K, blue 5800 K, violet 6400 K
- $T_{\rm eff}$>4600 K behavior, $\tau_{\rm c} \approx {\rm const}$, amplitude depends on R-$T_{\rm eff}$ relation

Photocentric fluctuations versus surface gravity



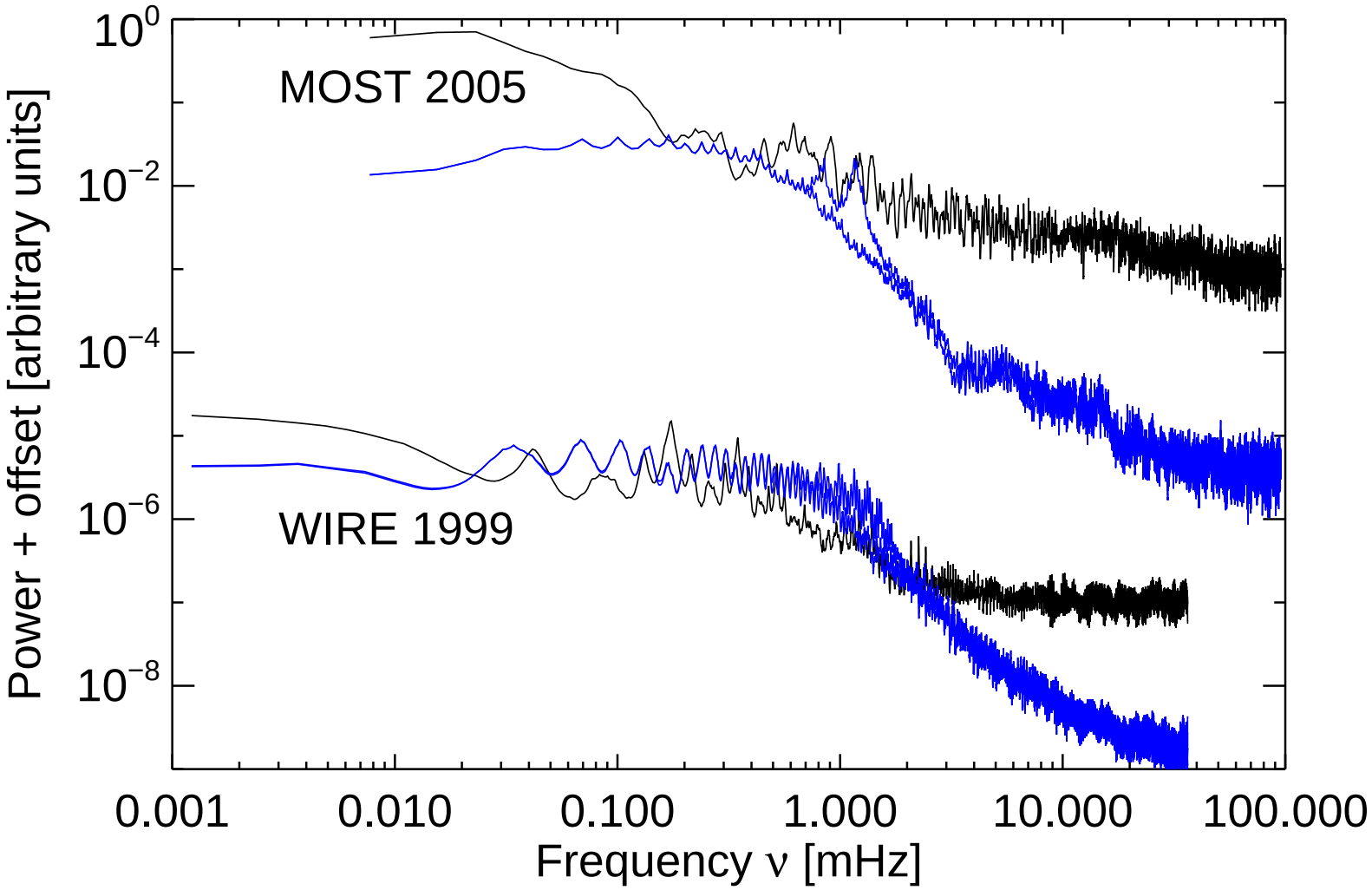
- Metal poor [M/H]=-2 model off the main trend
- Why AU units?

Scaling of brightness fluctuations with gravity (and $T_{\rm eff}$)



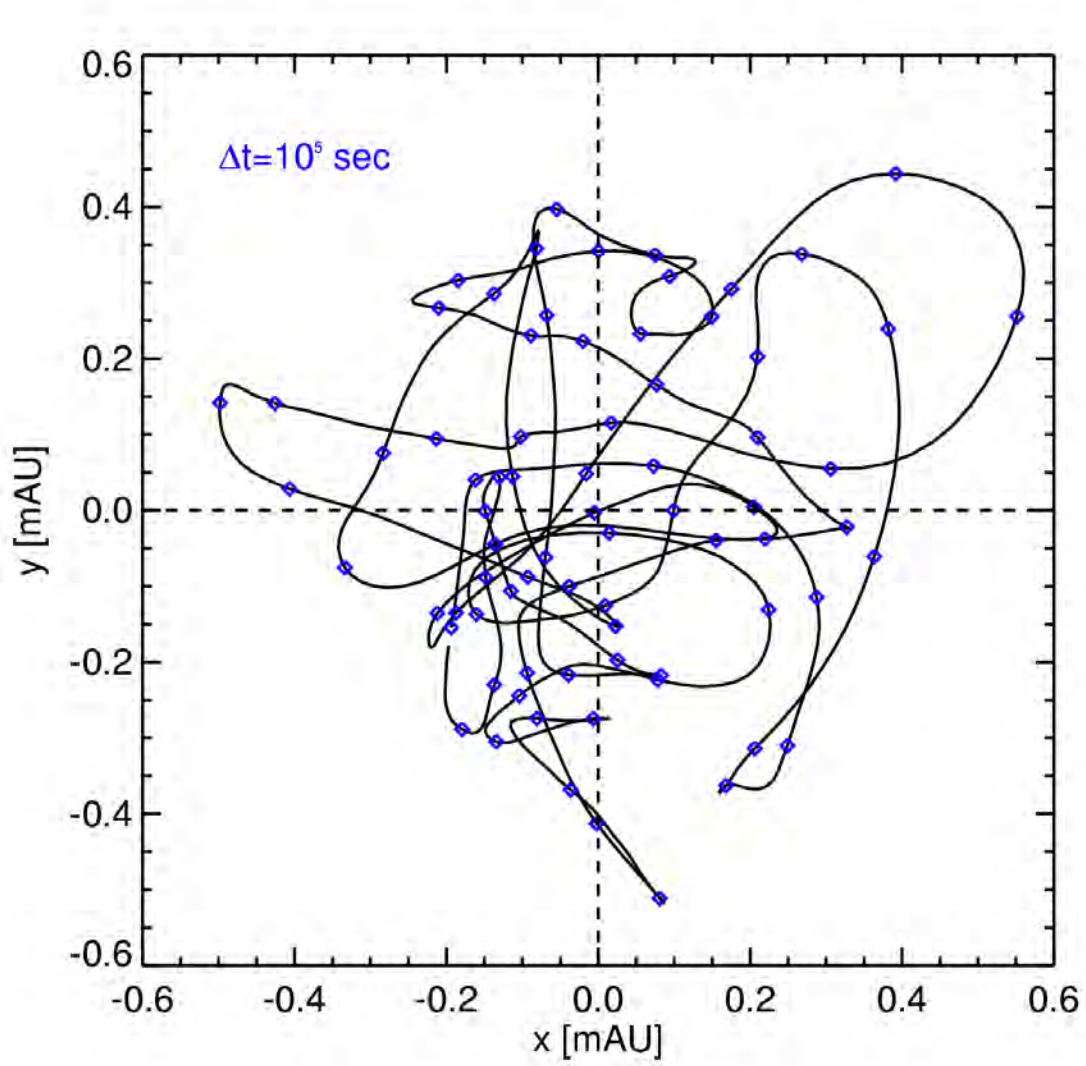
- Time-scales scale approximately with the atmospheric acoustic cut-off time scale $\frac{2H_{\rm p}}{c_{\rm s}}$

Procyon: comparison to MOST & WIRE observations



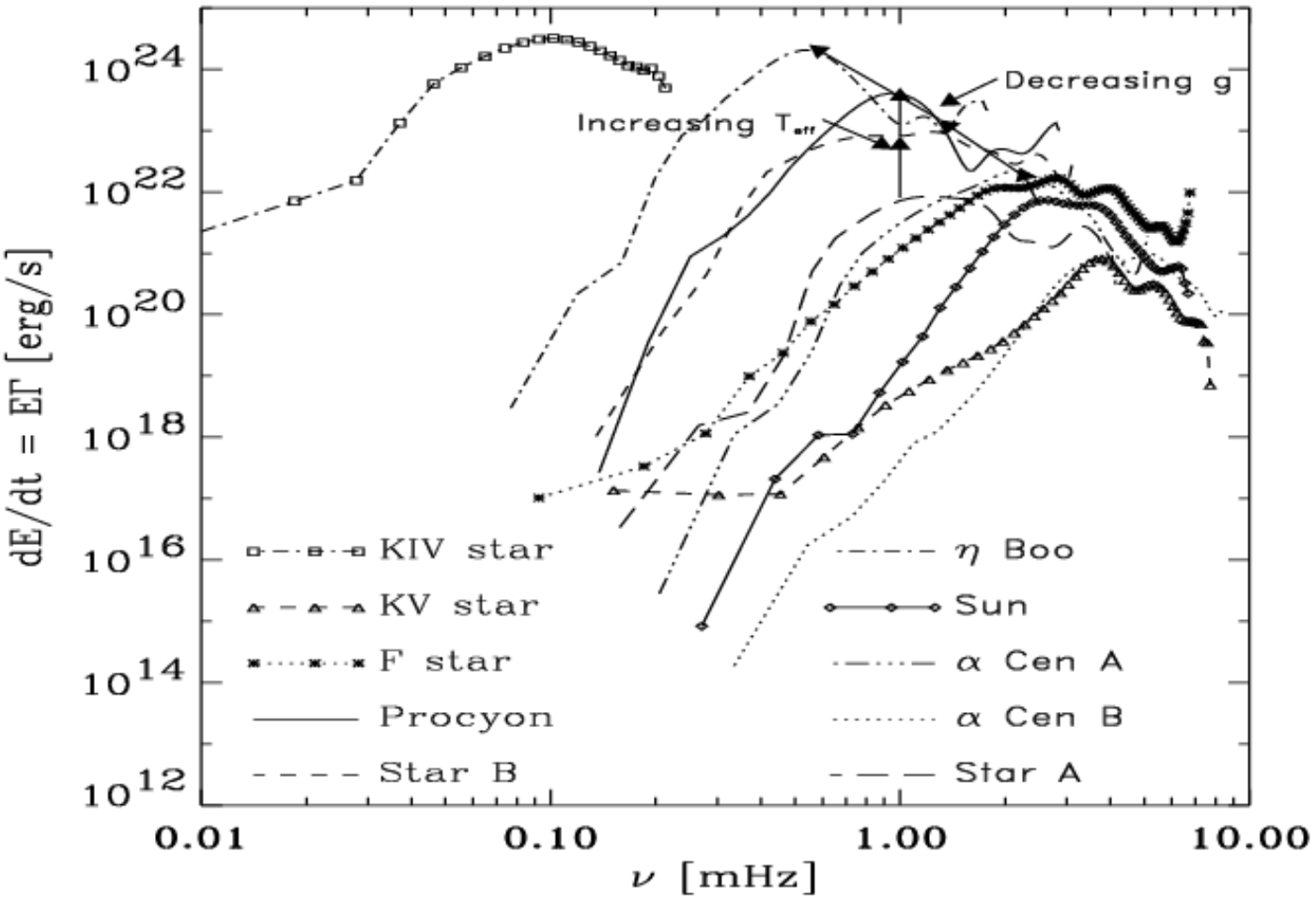
- Theoretical (blue) time series resampled to unevenly sampled observed series (black)
- WIRE: large data gaps, "cross talk" between Fourier modes, spectral power? shape?

CO^{5}BOLD simulated path of the photocenter of a red giant star



- GAIA precision level: only relevant for close-by giants

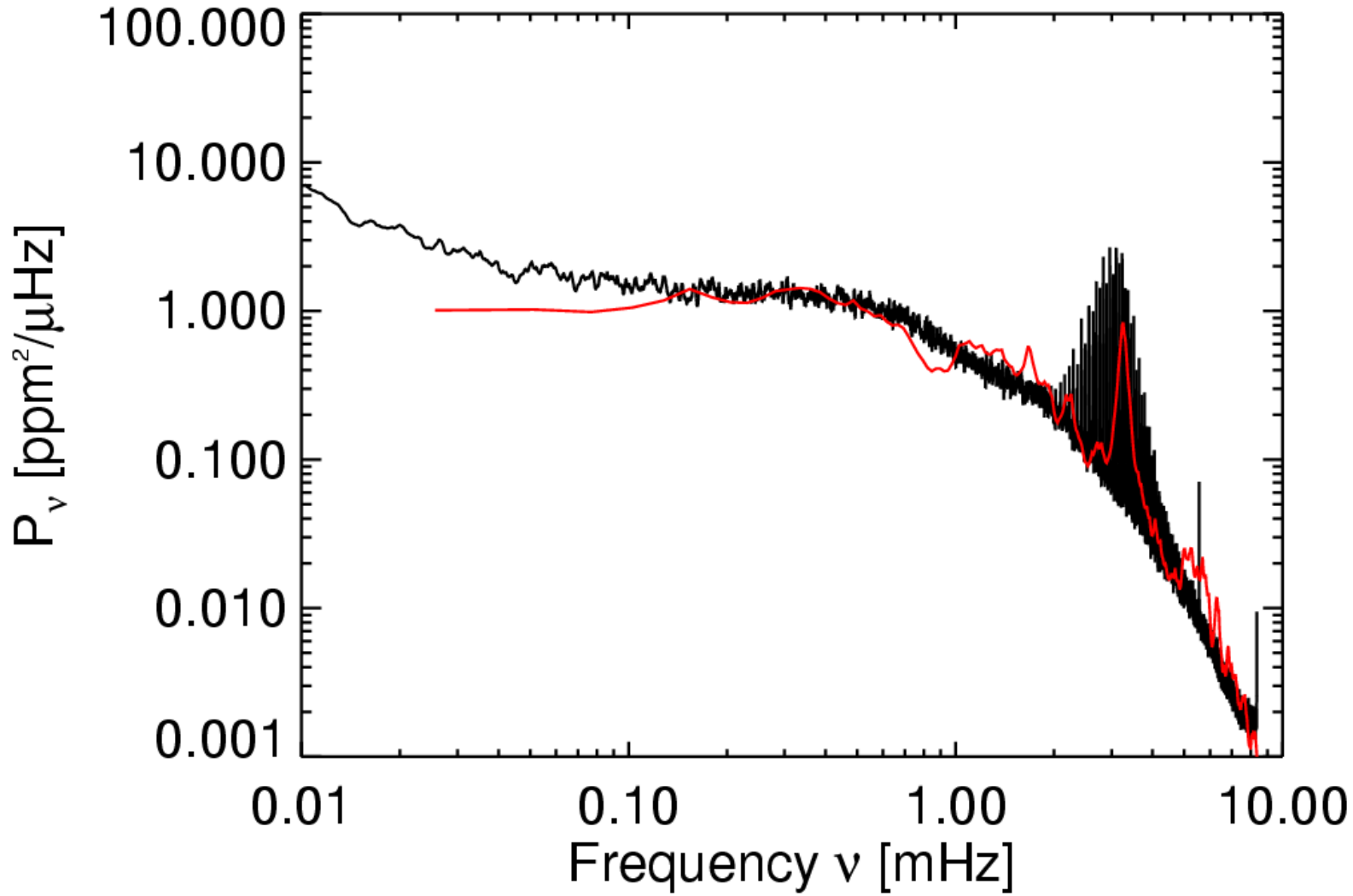
Excitation spectra for 5min-type oscillations in late-type stars



© Stein, Georgobiani, Trampedach, Ludwig, Nordlund, 2004

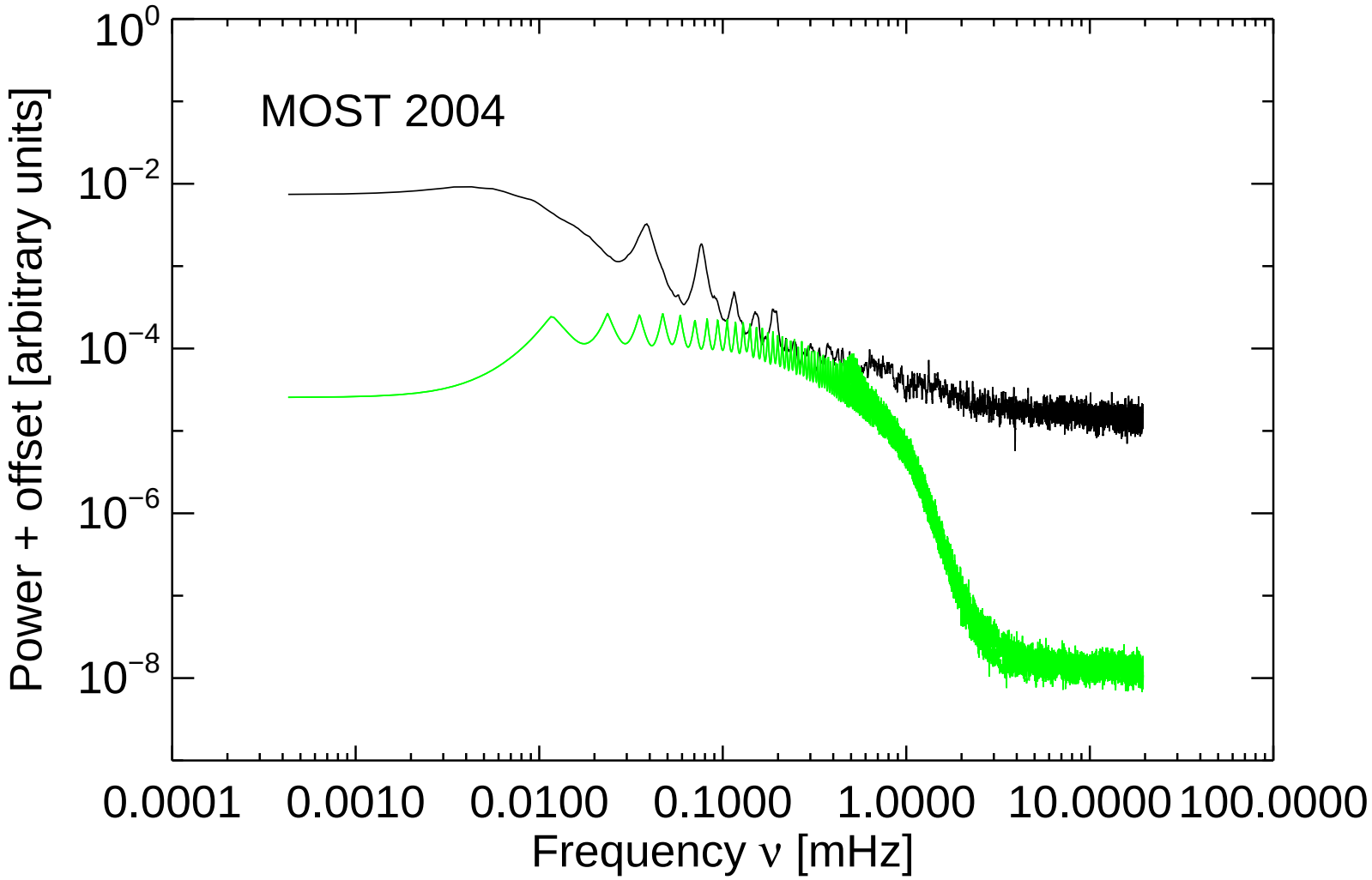
- Some simulated time sequences long enough to resolve box modes
- Model for studying mode *damping*?

Solar photometry: SOHO/VIRGO & non-grey CO^{5}BOLD model



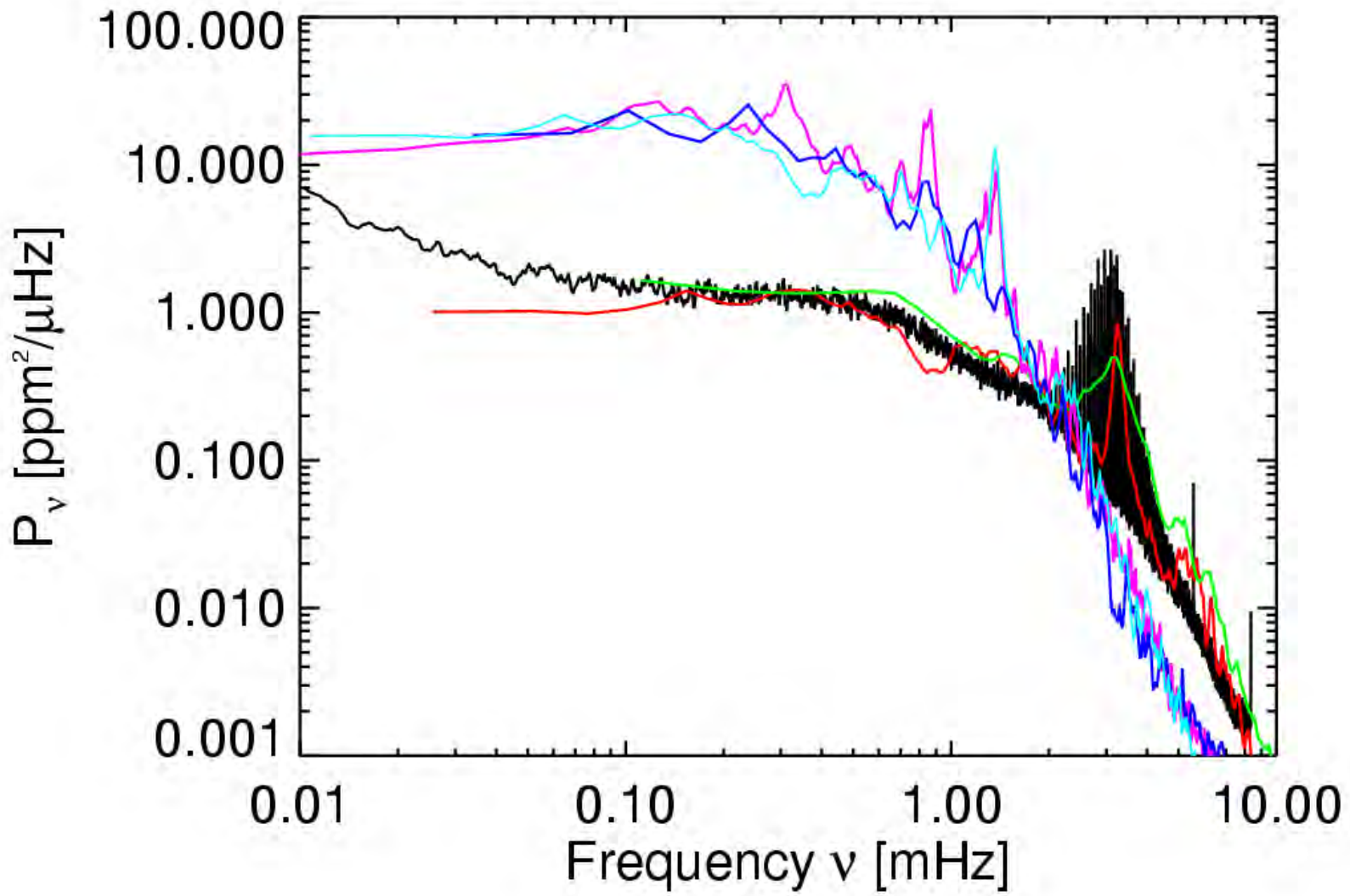
- VIRGO: solar minimum, SPM & PMO6 data, steep decline $\approx \nu^{-4}$ towards high ν
- CO^{5}BOLD: validates approach, limited statistics, p-modes?

η Bootis: comparison to MOST observations



- Power compatible at intermediate frequencies, S/N level not quite sufficient
- Waiting for COROT ... (inspired by Samuel Backett)

Stellar connection: Sun & Procyon (& beyond)



- red & green Sun, blue Procyon non-grey, violet Procyon grey
- light blue scaled Sun: $P_\nu \times 15.5$, $\nu \times 0.42 \rightarrow \frac{\sigma_f}{\langle f \rangle} \times 2.6$, MOST $\approx \times 5$