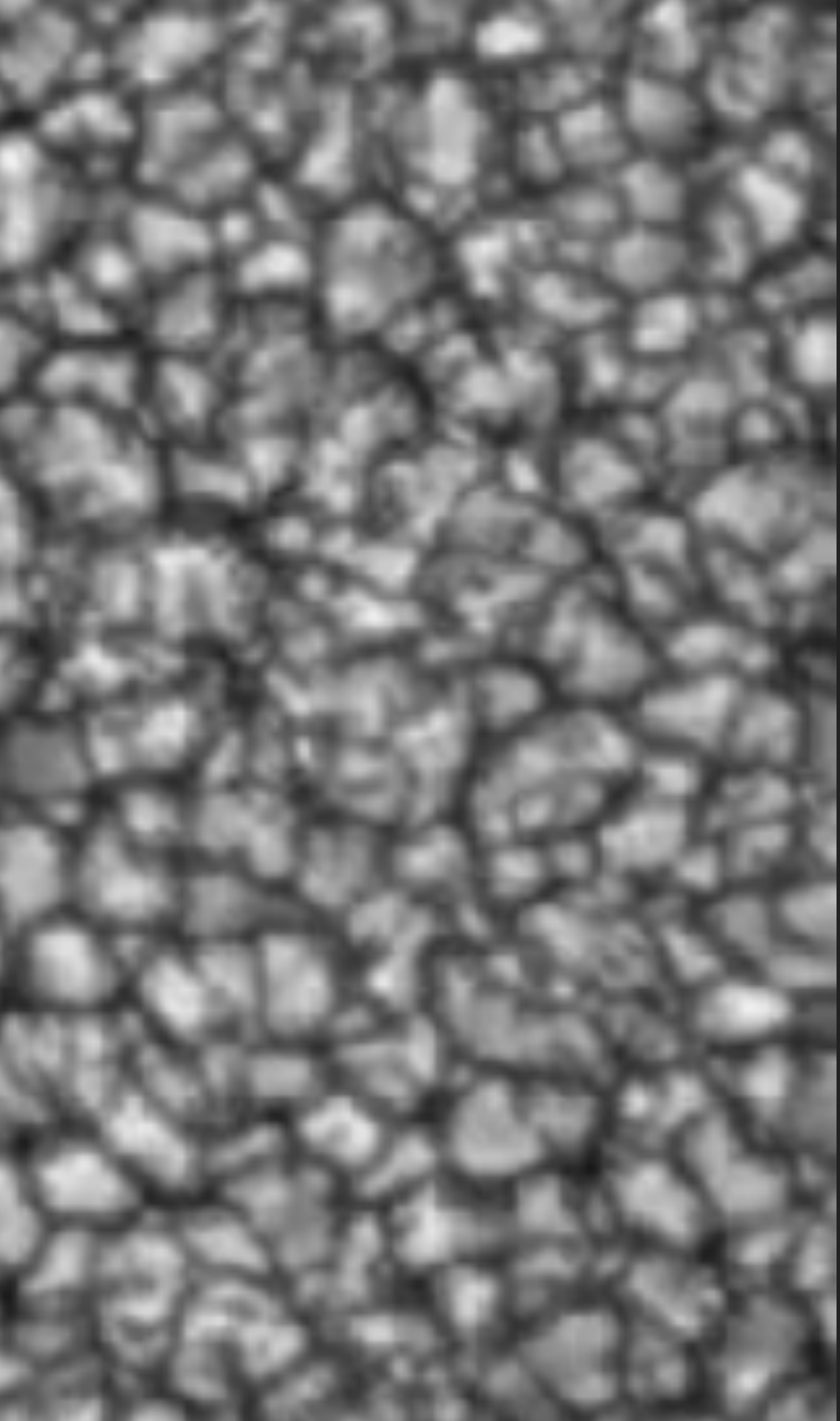
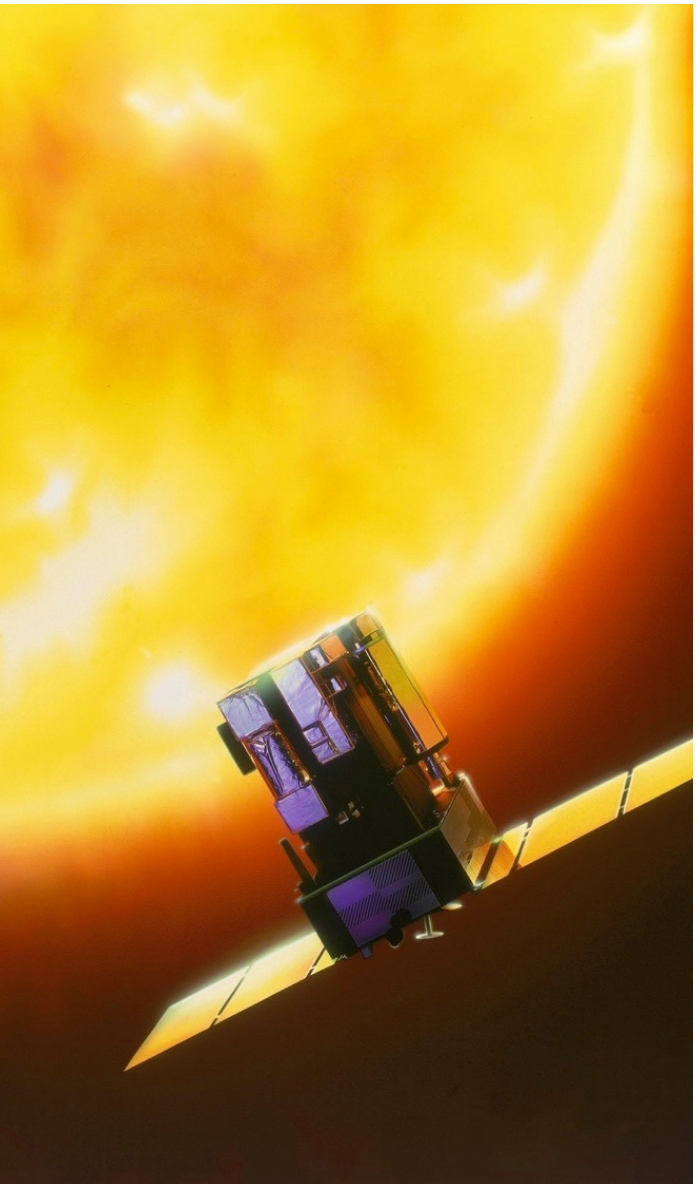
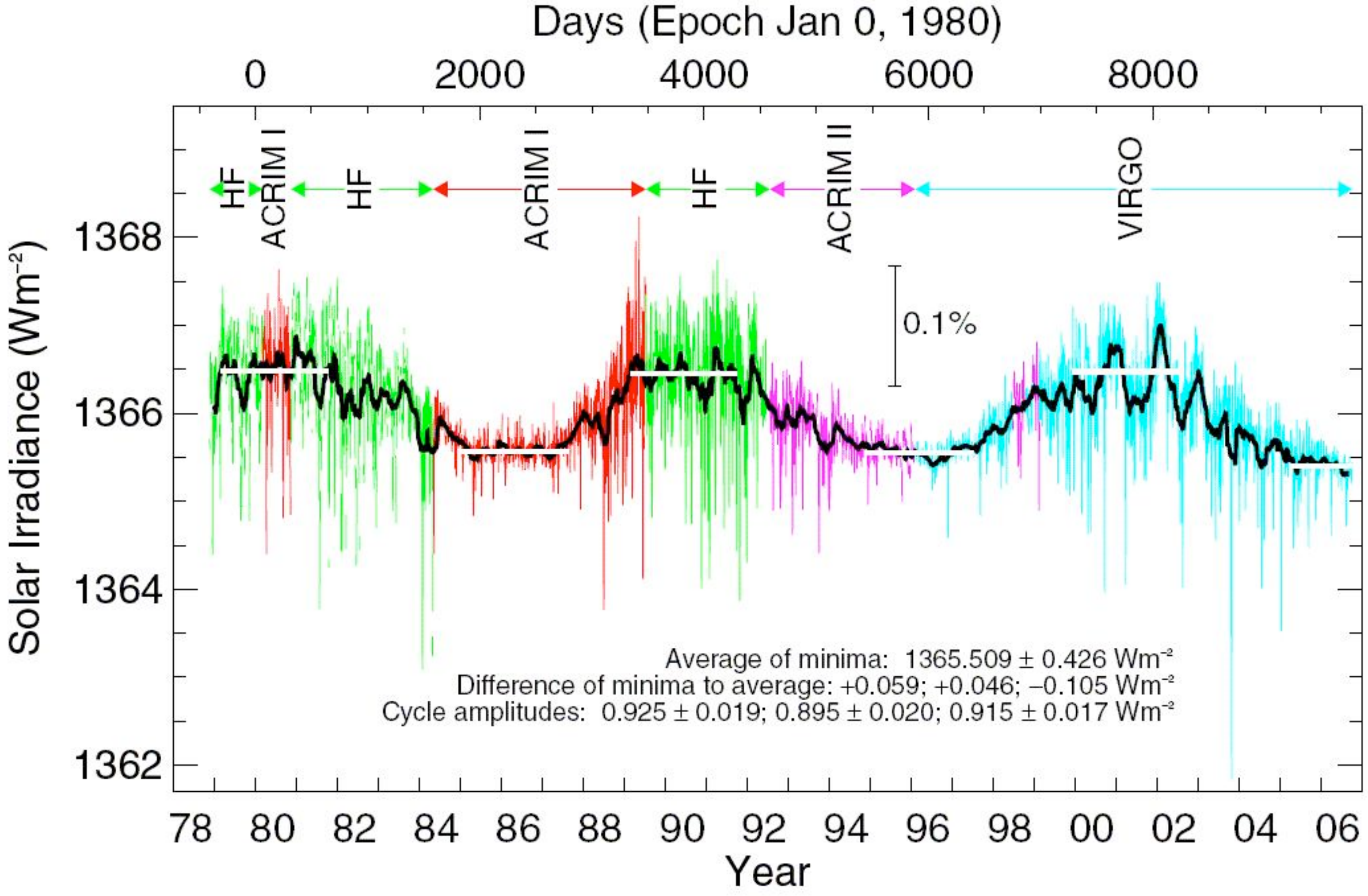


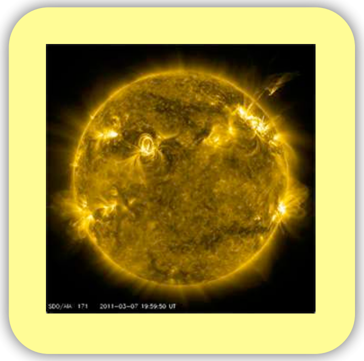
THOMAS KALLINGER

ANOTHER OBSERVERS POINT OF VIEW ON STELLAR GRANULATION

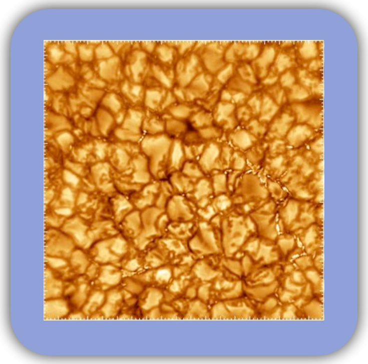


SOHO/VIRGO

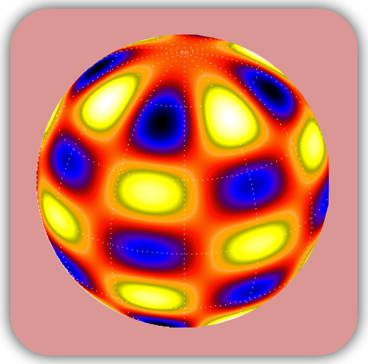




activity

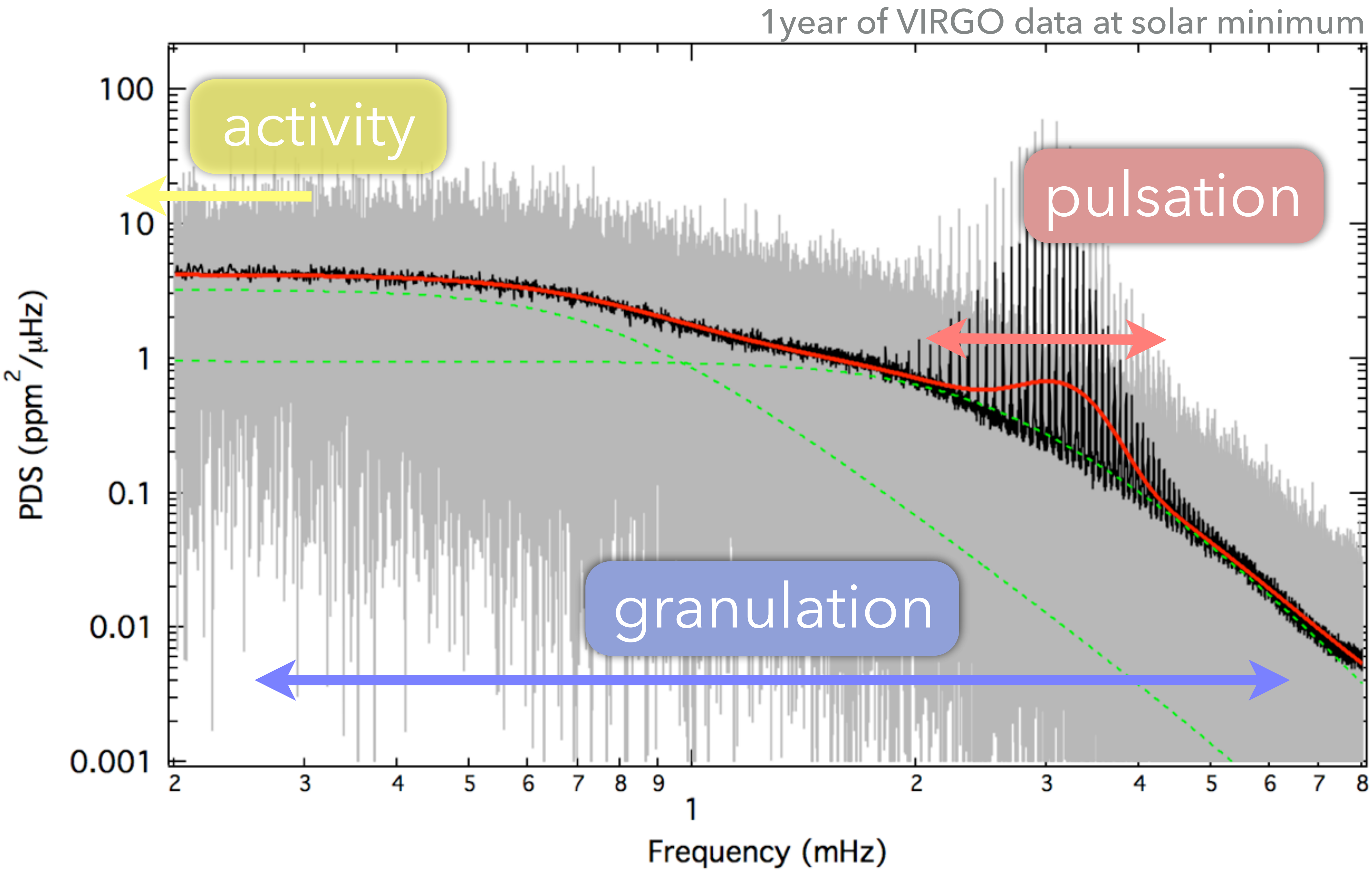


granulation



pulsation

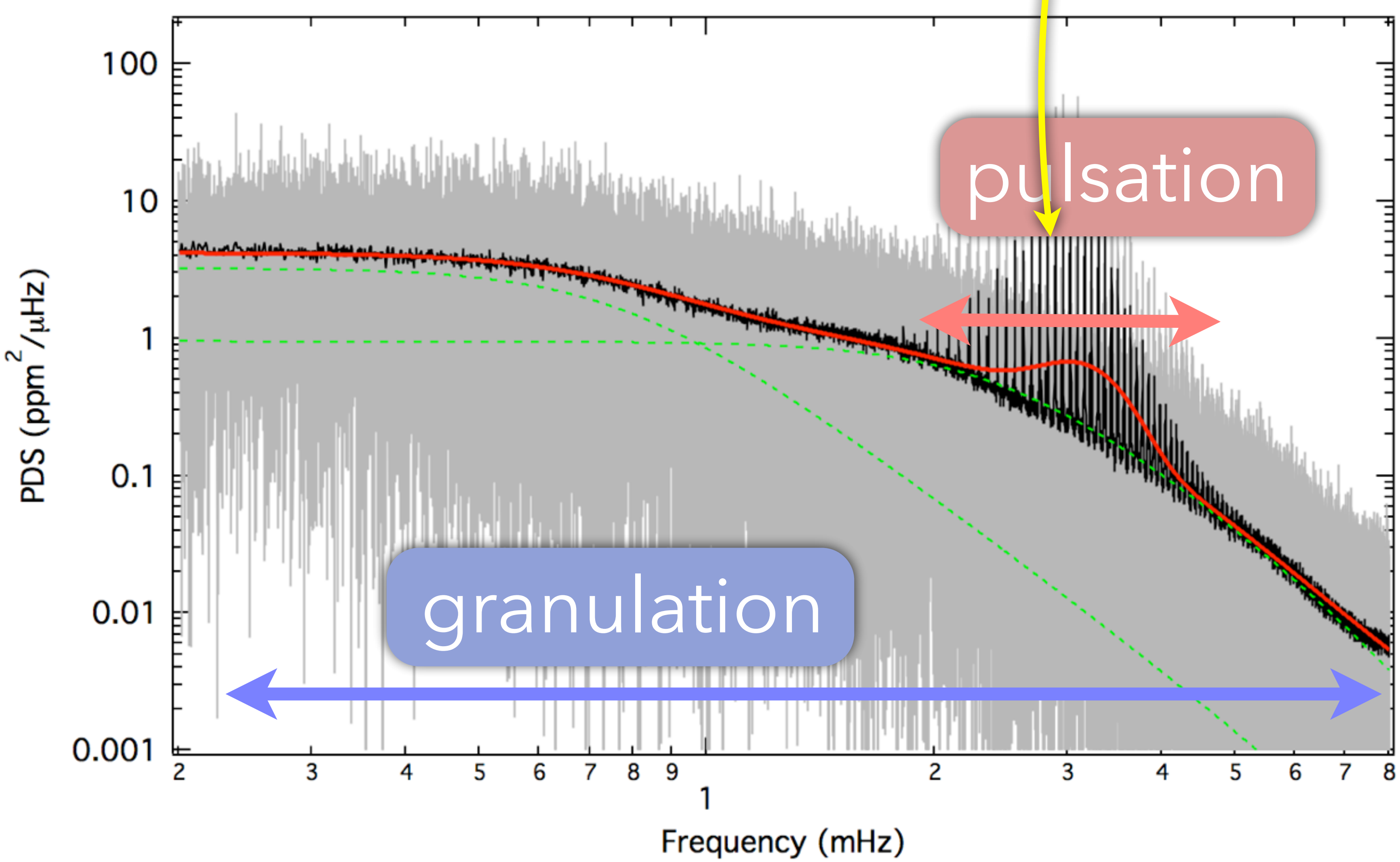
THE SOLAR SIGNAL



GLOBAL MODEL

noise granulation pulsation

$$P(\nu) = P_n + \sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^4} + P_g \exp \frac{-(\nu_{max} - \nu)^2}{2\sigma_g^2}$$



"granulation" parameters

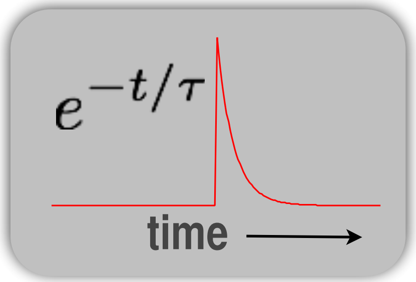
τ ... time scale

σ ... amplitude

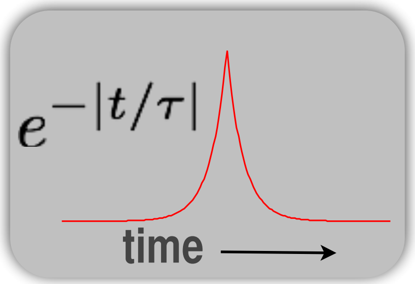
ς ... normalisation constant

HARVEY'S MODEL ZOO

e.g.



$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^2}$$

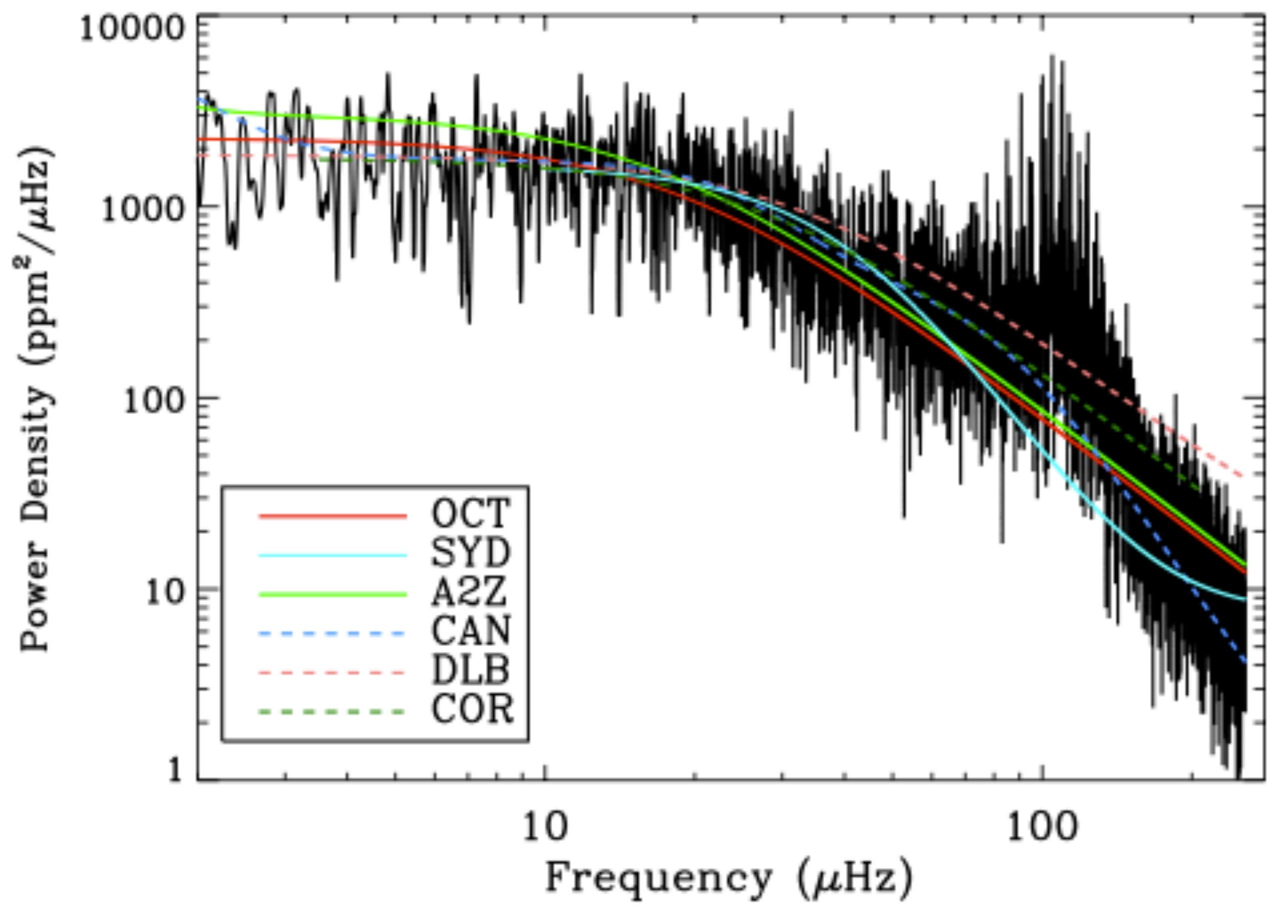


$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{[1 + (2\pi\nu\tau_i)^2]^2}$$

$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^4}$$

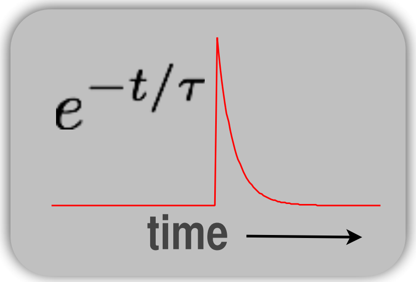
$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^{\alpha_i}}$$

Mathur et al. 2011



HARVEY'S MODEL ZOO

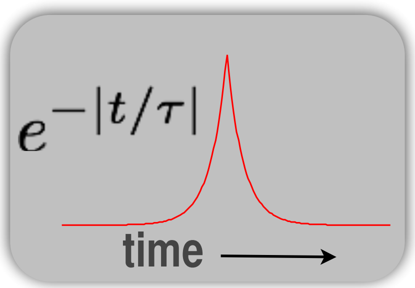
e.g.



$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^2}$$

?

$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^4}$$

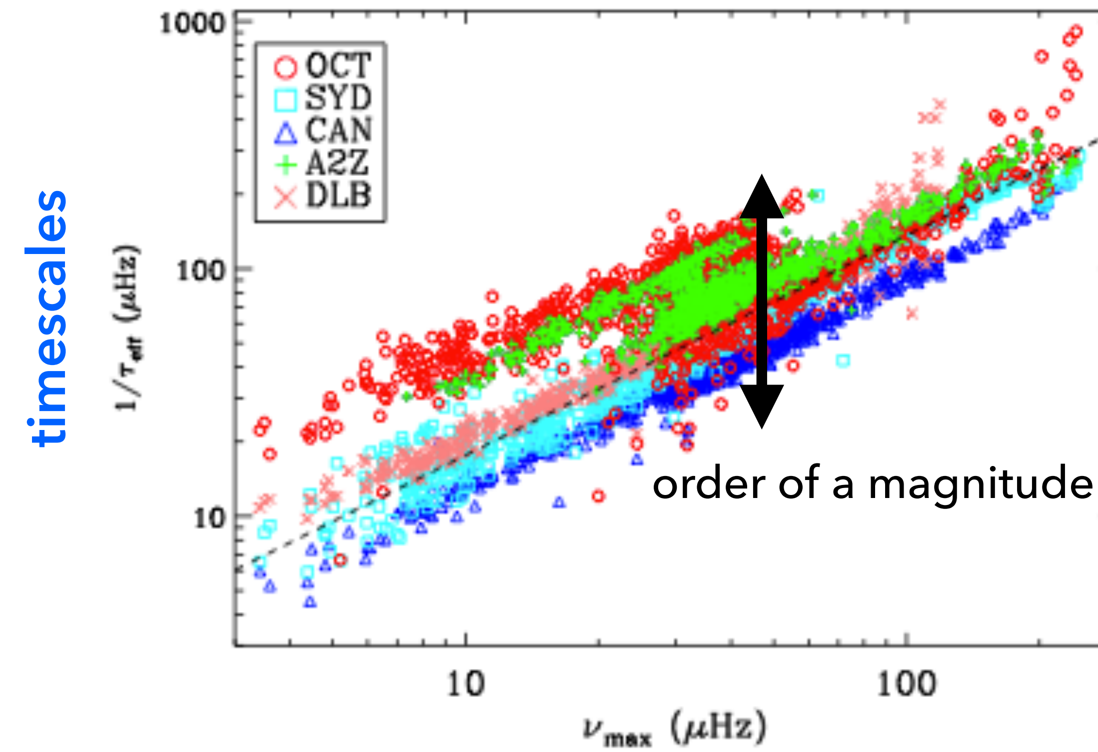


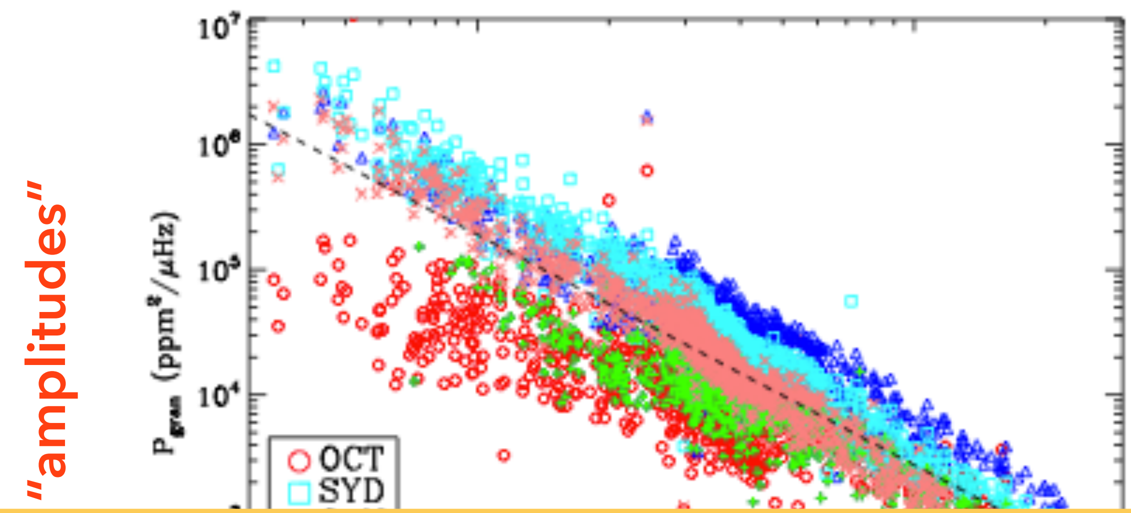
$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{[1 + (2\pi\nu\tau_i)^2]^2}$$

?

$$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1 + (2\pi\nu\tau_i)^{\alpha_i}}$$

Mathur et al. 2009





➠ Bayesian model comparison

ν_{max} (μHz)

the tool ...

MultiNest

Feroz et al. 2009

... Bayesian Nested Sampling Algorithm

- probability distributions for the parameters
- global evidence for the fit

A/E $$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1+(2\pi\nu\tau_i)^2}$$

B/F $$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1+(2\pi\nu\tau_i)^4}$$

C/G $$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{[1+(2\pi\nu\tau_i)^2]^2}$$

D/H $$\sum_i \frac{\zeta \sigma_i^2 \tau_i}{1+(2\pi\nu\tau_i)^{\alpha_i}}$$

i=1,2 ... 1 or 2 components

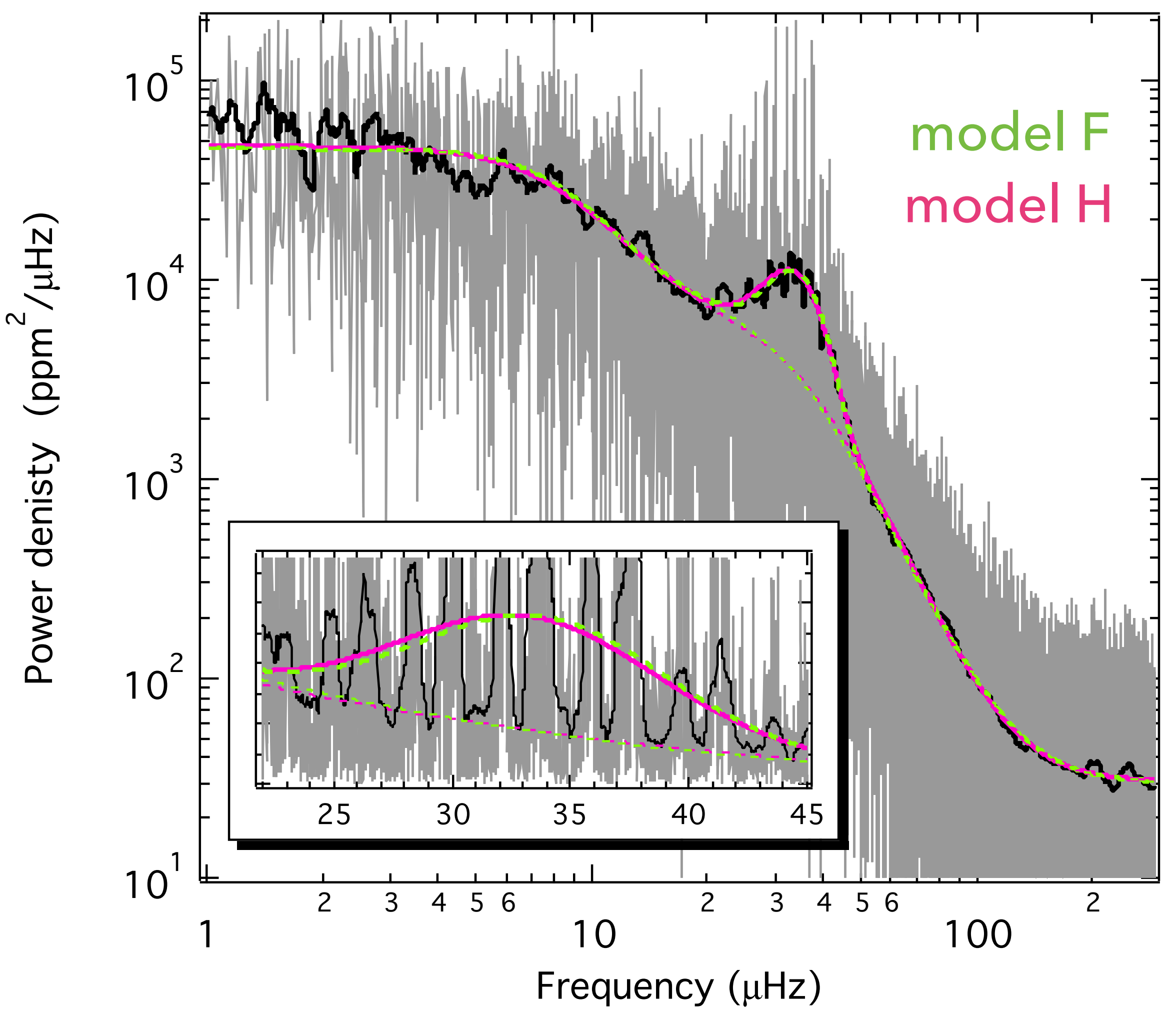
	$\ln(z/z_0)$	p	Gaussian P_g	ν_{max}	σ	1st component a_1	b_1	c_1	2nd component a_2	b_2	c_2
A	-1587.7	$< 10^{-200}$	5.4(2)	30.38(02)	13.1(2)	560(12)	2.3(1)	2*			
B	-255.7	$\sim 10^{-111}$	4.8(3)	35.7(3)	5.1(2)	624(6)	23.7(2)	4*			
C	-75.8	$\sim 10^{-33}$	5.5(3)	34.5(2)	6.0(1)	606(6)	22.5(2)	2/4*			
D	-243.4	$\sim 10^{-102}$	5.1(3)	35.2(2)	5.7(2)	601(28)	20.8(4)	3.7(1)			
E	-1592.4	$< 10^{-200}$	5.4(2)	30.42(02)	13.2(2)	571(15)	2.3(2)	2*	31(4)	34.1(6)	2*
F	**-1.7**	**0.166**	**5.5(2)**	**33.8(4)**	**6.1(2)**	**466(14)**	**9.4(5)**	**4***	**399(19)**	**31.9(1)**	**4***
G	-36.6	$\sim 10^{-16}$	5.7(2)	33.9(2)	6.4(2)	352(26)	8.5(9)	2/4*	502(18)	25.7(6)	2/4*
H	**-0.1**	**0.833**	**5.6(3)**	**33.5(5)**	**6.1(3)**	**470(35)**	**9.7(6)**	**3.6(3)**	**365(59)**	**35.8(3)**	**4.2(2)**

Kallinger et al. (2014)

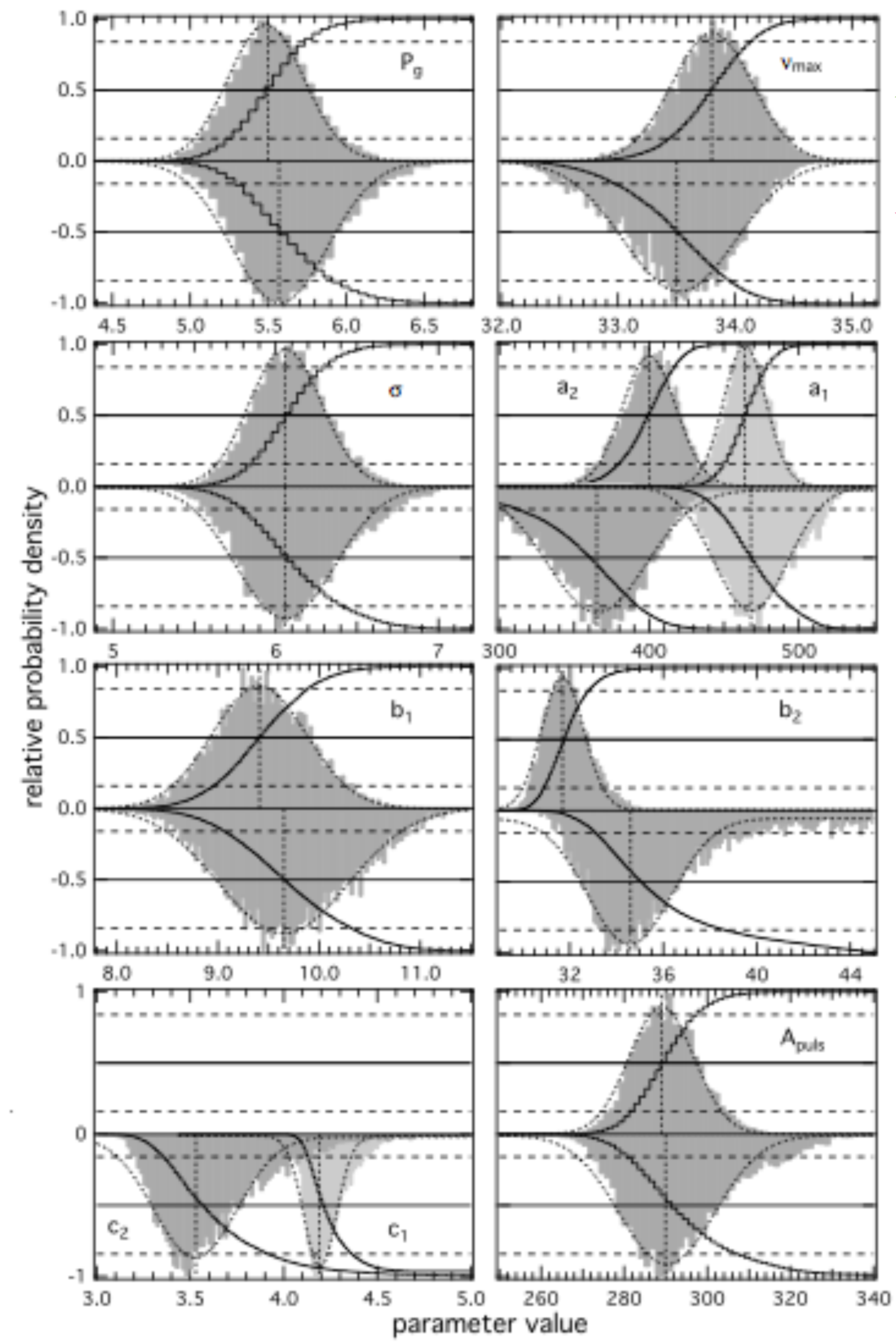
the winner is...

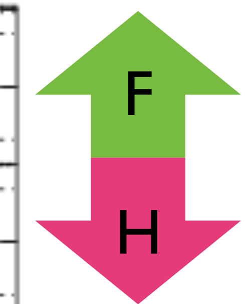
2 component model F and H

THE WINNING MODEL(S)



posterior distributions



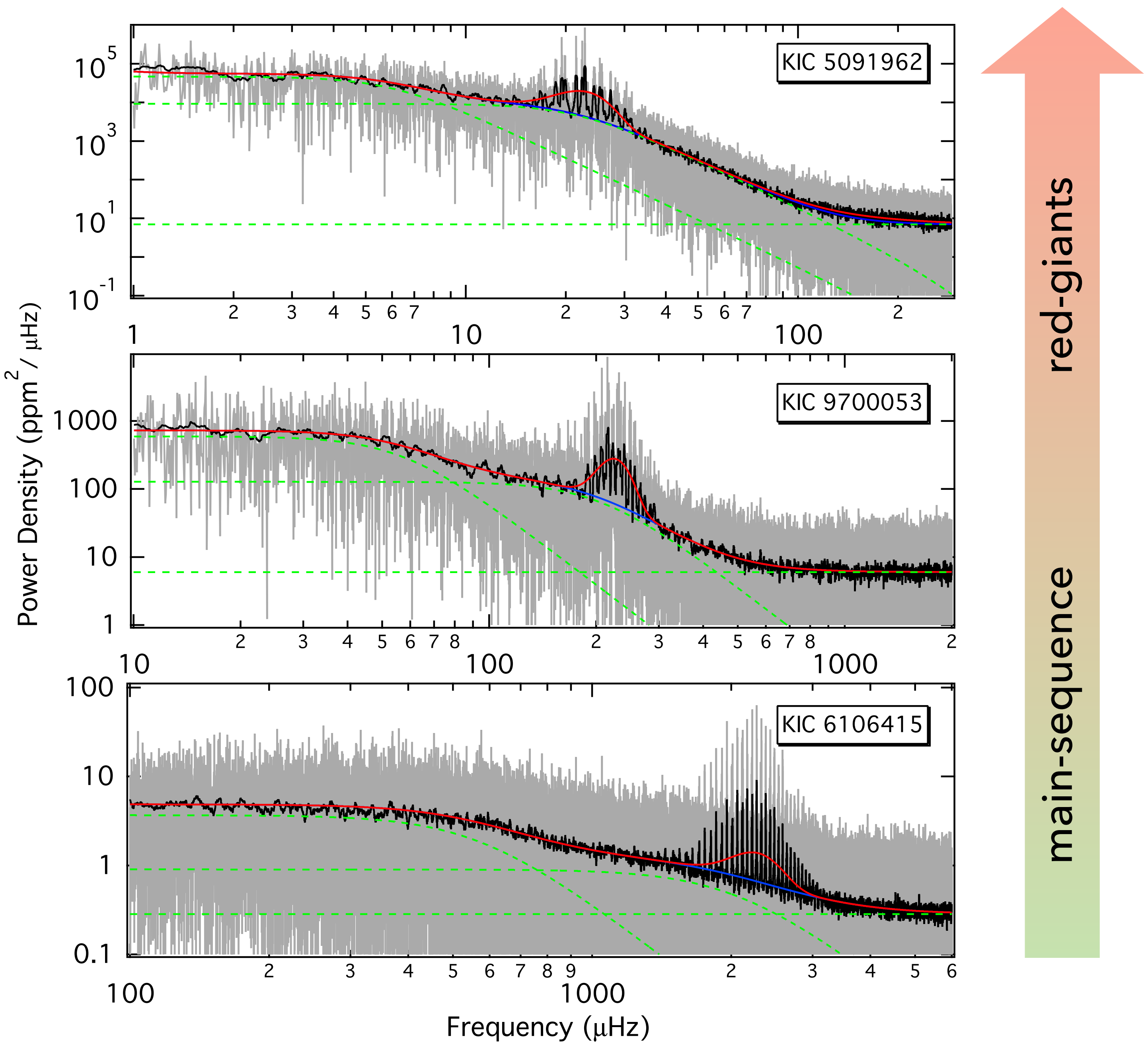


Bayesian analysis tells us...

- the original Harvey model is obsolete

- reliably fitting α is difficult (even with the long Kepler time series)

- a simple super-Lorentzian works for ALL stars and gives reliable parameters



UNIFORM SCALING

granulation parameters almost perfectly scale with pulsation frequencies

timescales/frequencies

high-freq. component: $\nu \sim 0.98\nu_{max}^{0.99}$

low-freq. component: $\nu \sim 0.32\nu_{max}^{0.97}$

$\nu_{high}/\nu_{low} \sim 3.06$

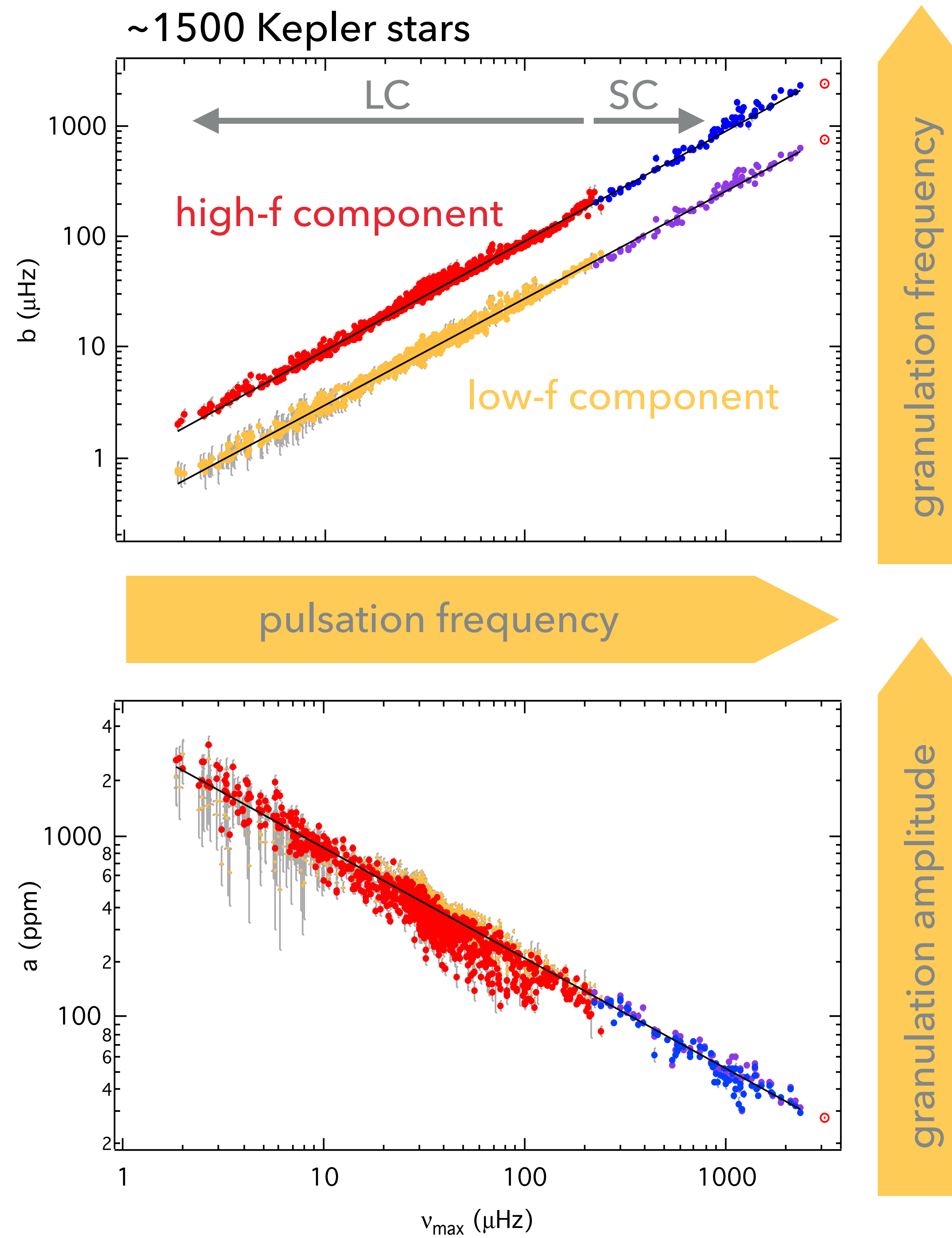
combined timescale: $\tau \sim g^{-0.85}T_{eff}^{-0.4}$

amplitudes

$a \sim \nu_{max}^{0.6}$

$a \sim \nu_{max}^{0.6} M^{-0.25}$

~1500 Kepler stars



ENERGY PARTITION

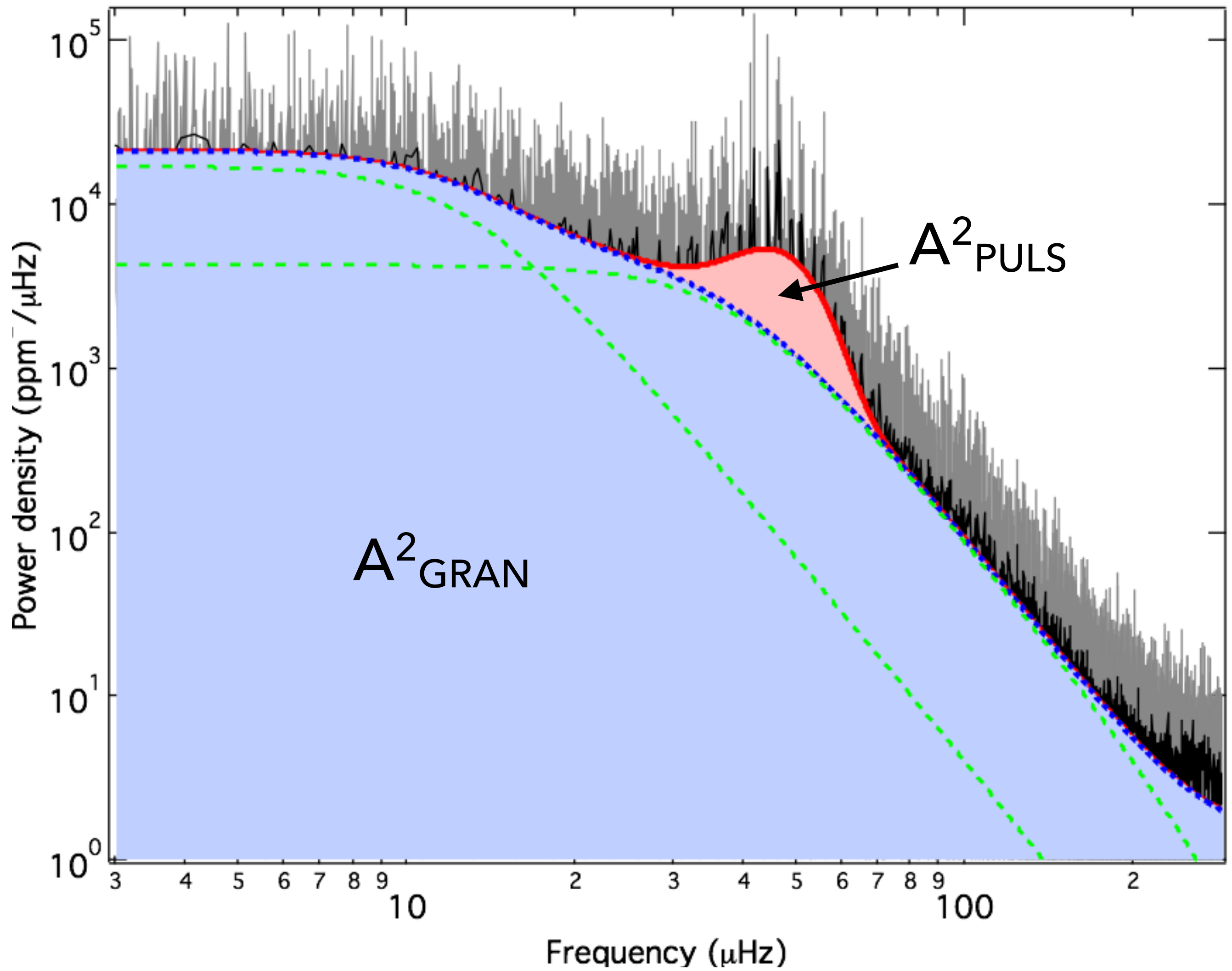
∫spectrum ⇔ variance of the time series

pulsation energy (A^2_{PULS})

$$A^2_{\rm PULS} = \int {\rm Gaussian} = \sqrt{2\pi} P_g \sigma$$

granulation energy (A^2_{GRAN})

$$A^2_{\rm GRAN} = \sigma_1^2 + \sigma_2^2$$



ENERGY PARTITION

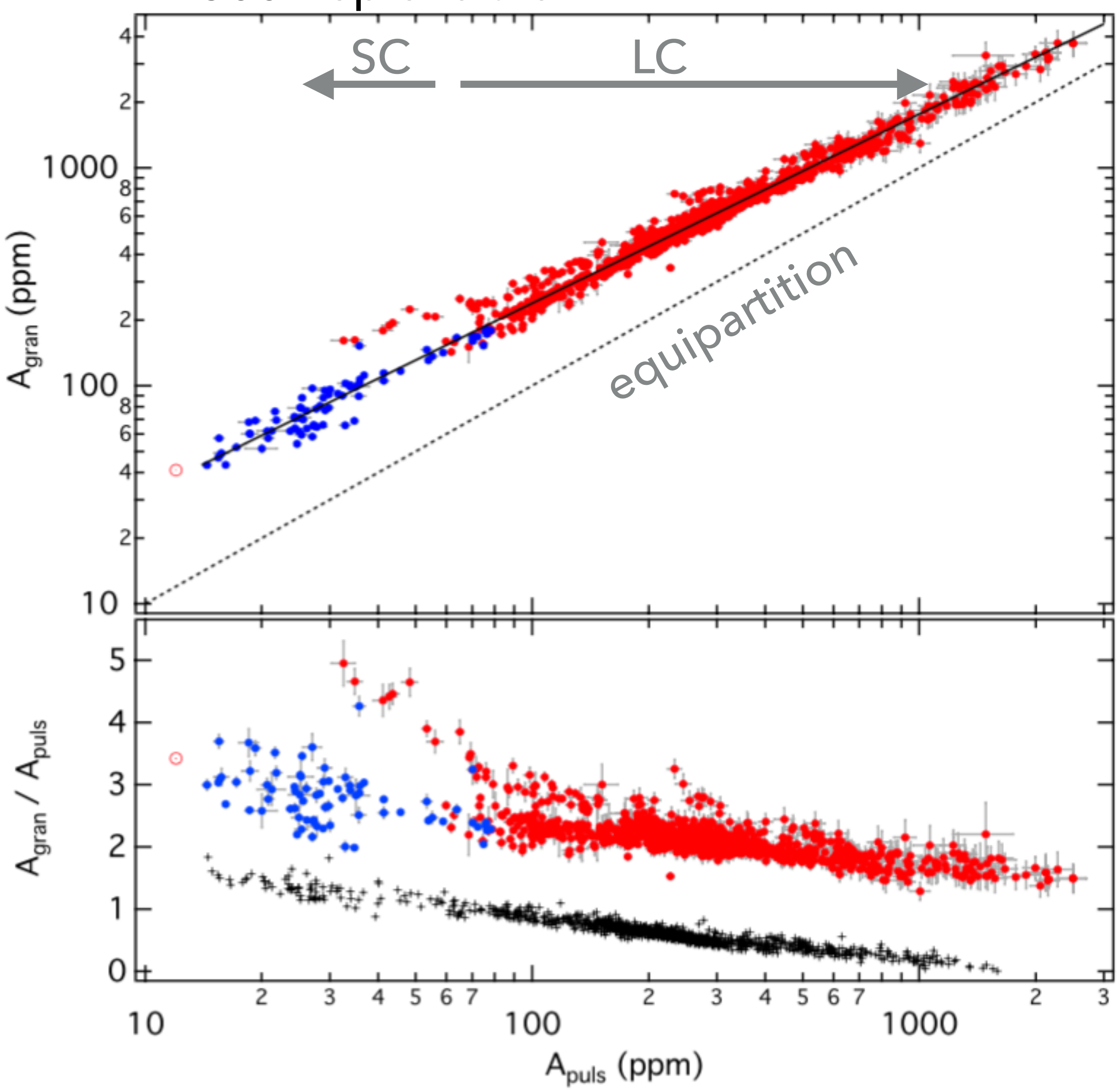
$A_{GRAN} \sim A_{PULS}^{0.86}$

dependence on surface gravity (g) and mass (M)

$A_{GRAN} \approx g^{-1/2}M^{-1/4}$

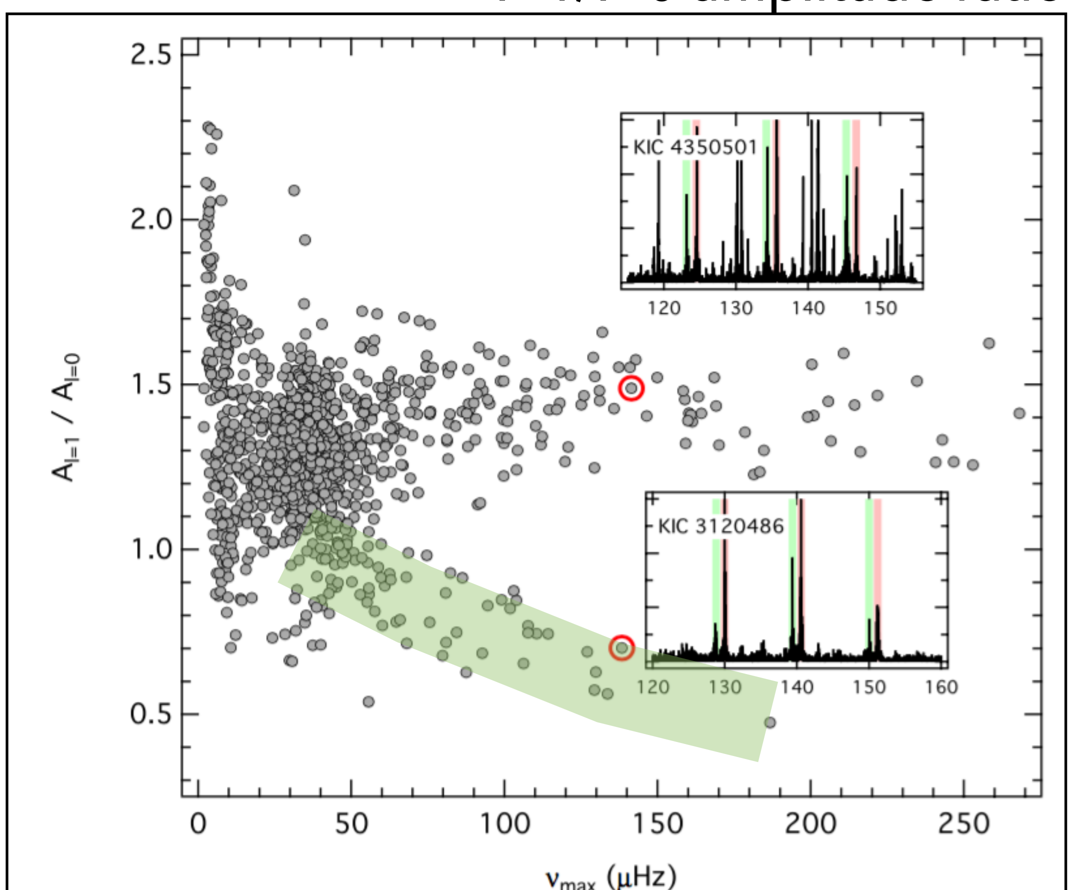
$A_{PULS} \approx g^{-2/3}M^{-1/3}$

~1500 Kepler stars

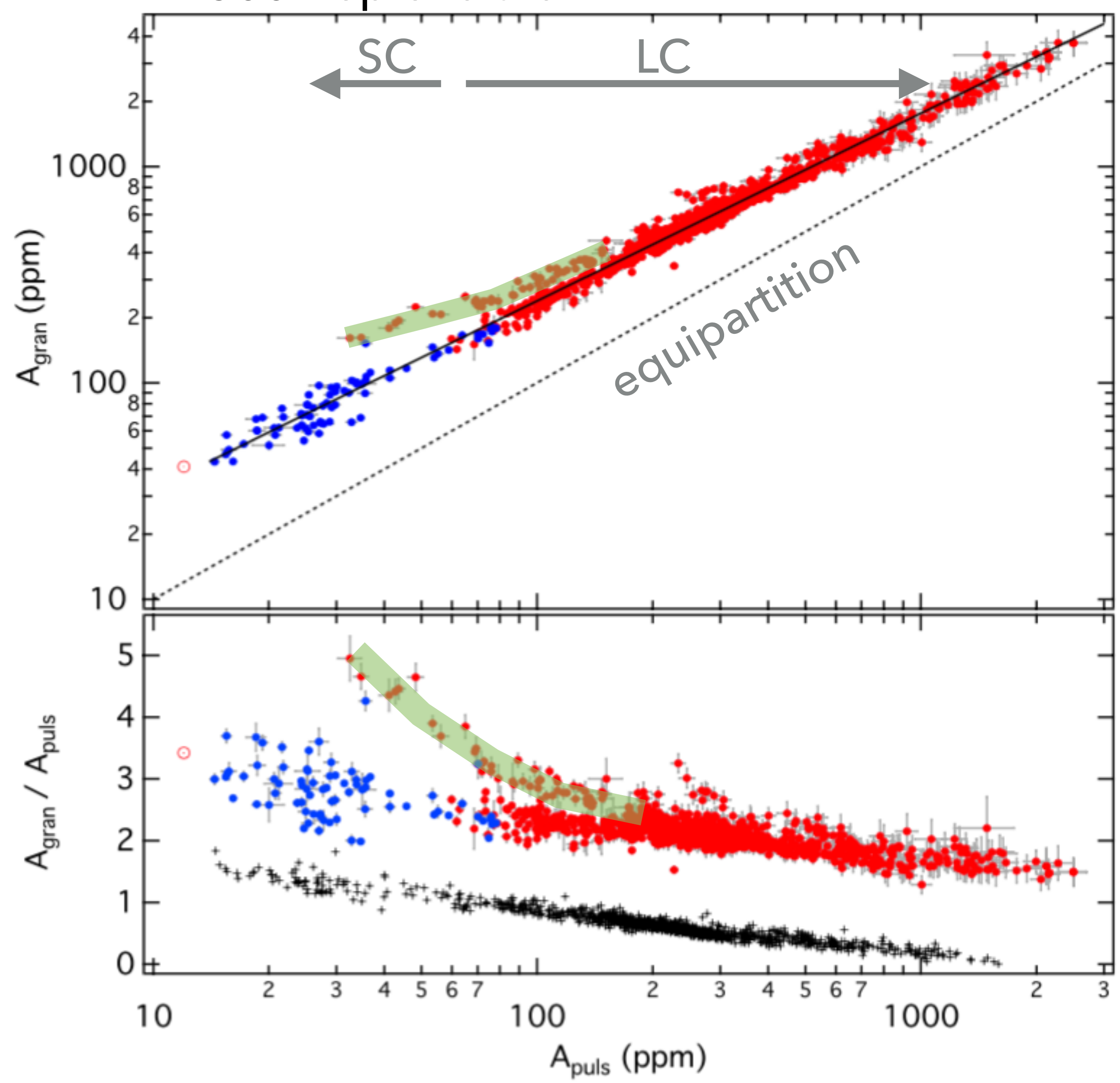


DEPRESSED DIPOLE MODES

l=1/l=0 amplitude ratio

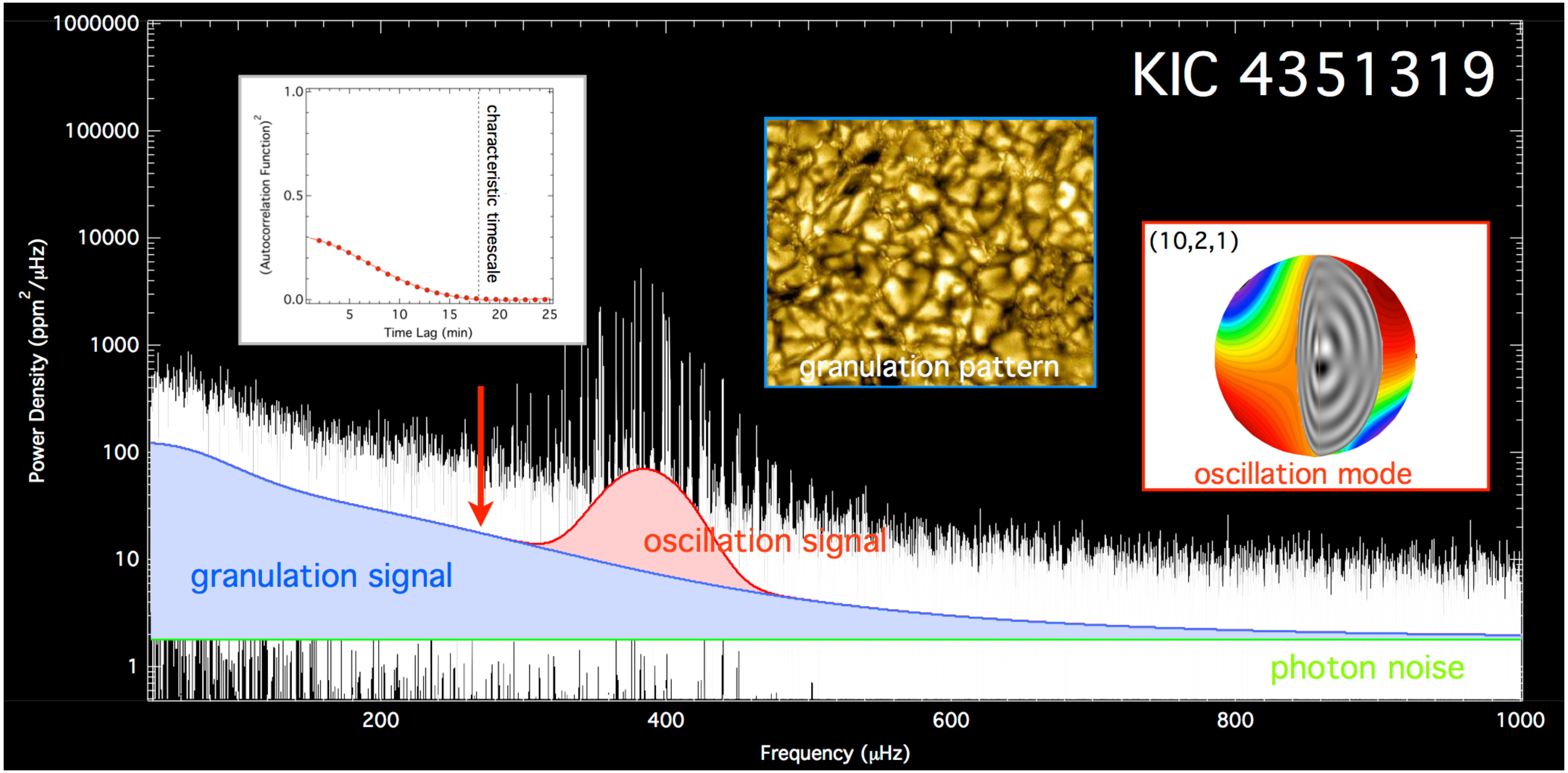


~1500 Kepler stars

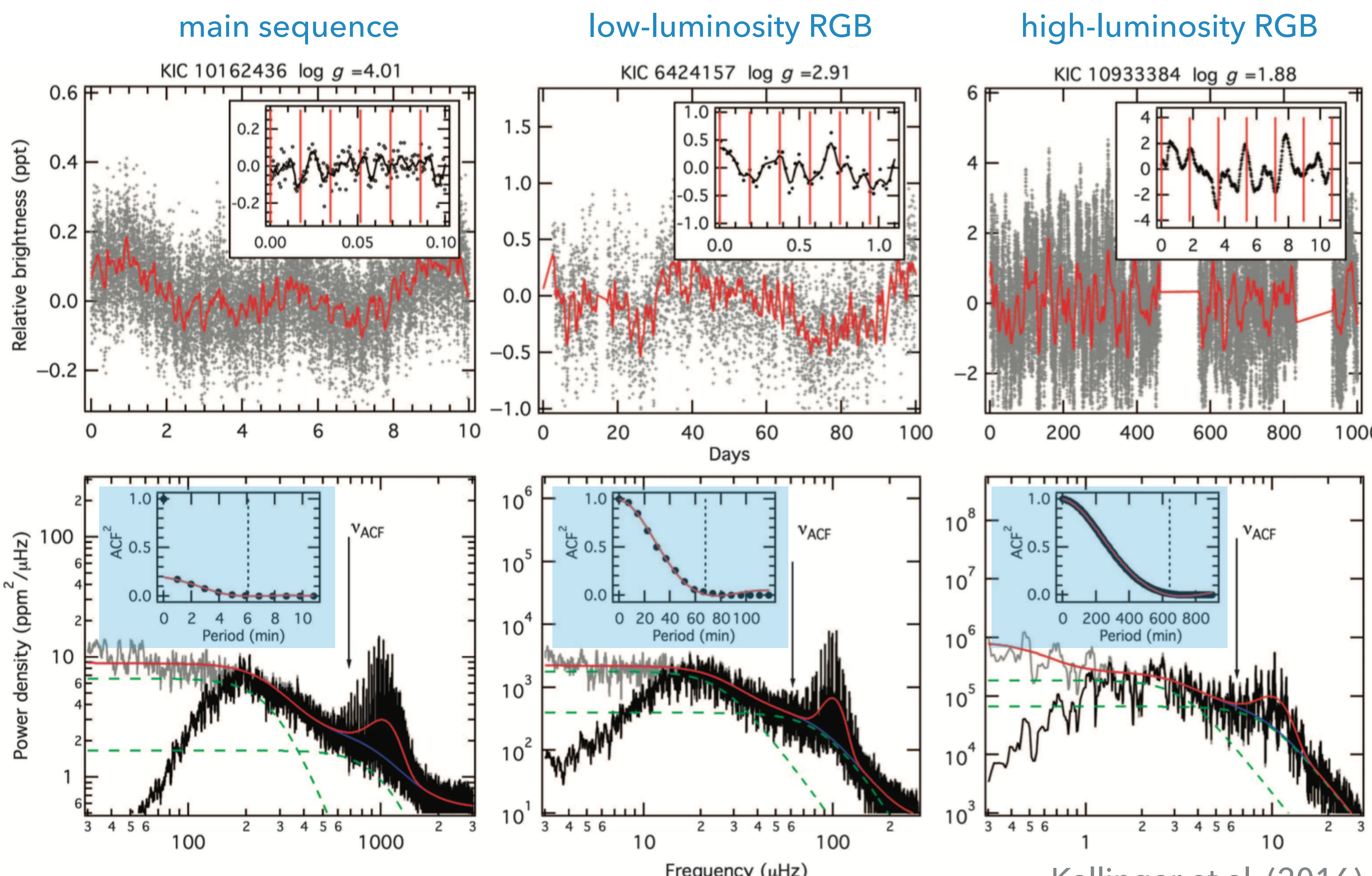


IMPLICATIONS FOR FUNDAMENTAL PARAMETER ESTIMATES

A NEW WAY TO MEASURE SURFACE GRAVITY



AUTOCORRELATION TIMESCALE



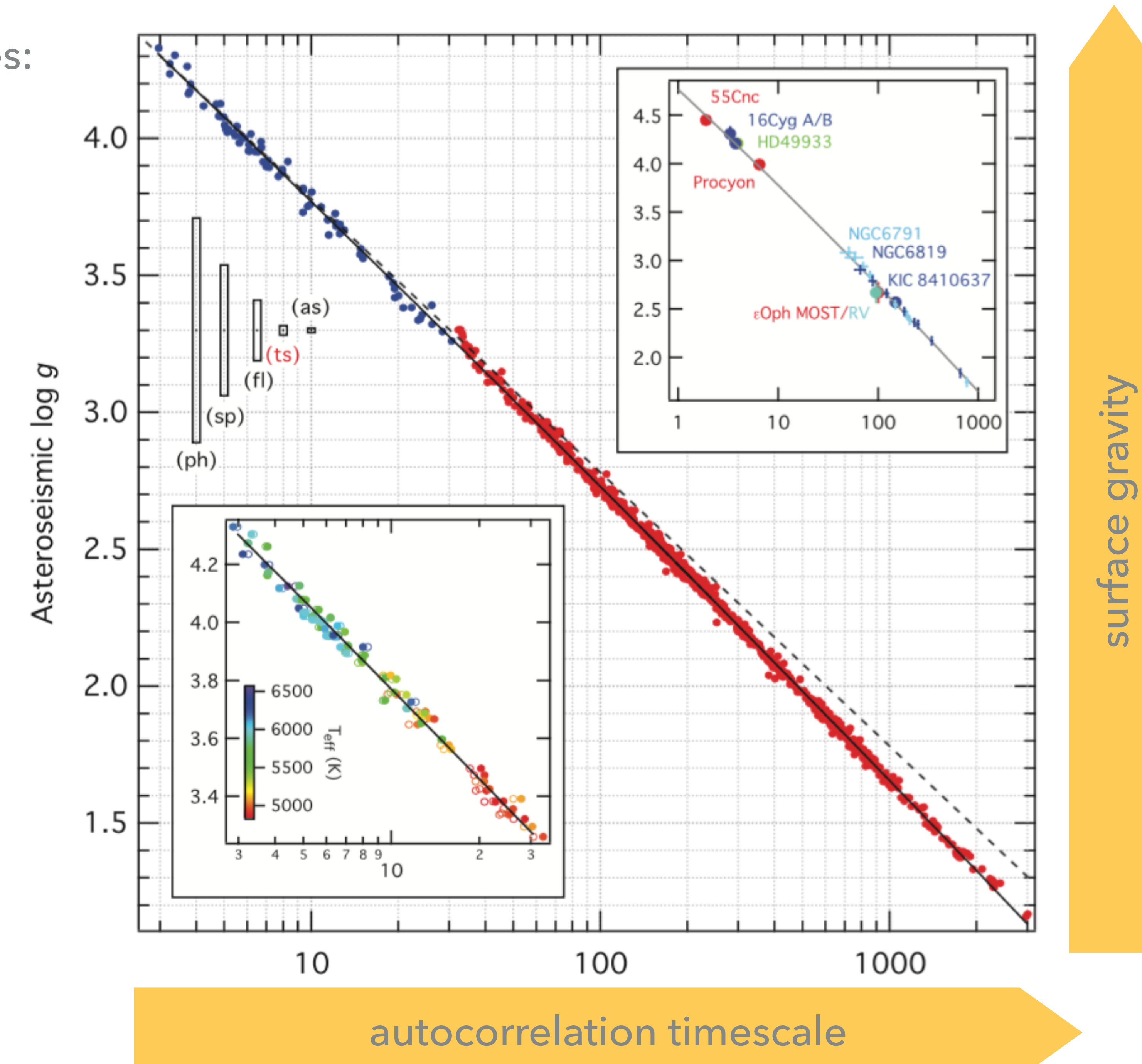
Kallinger et al. (2016)

AUTOCORRELATION TIMESCALE

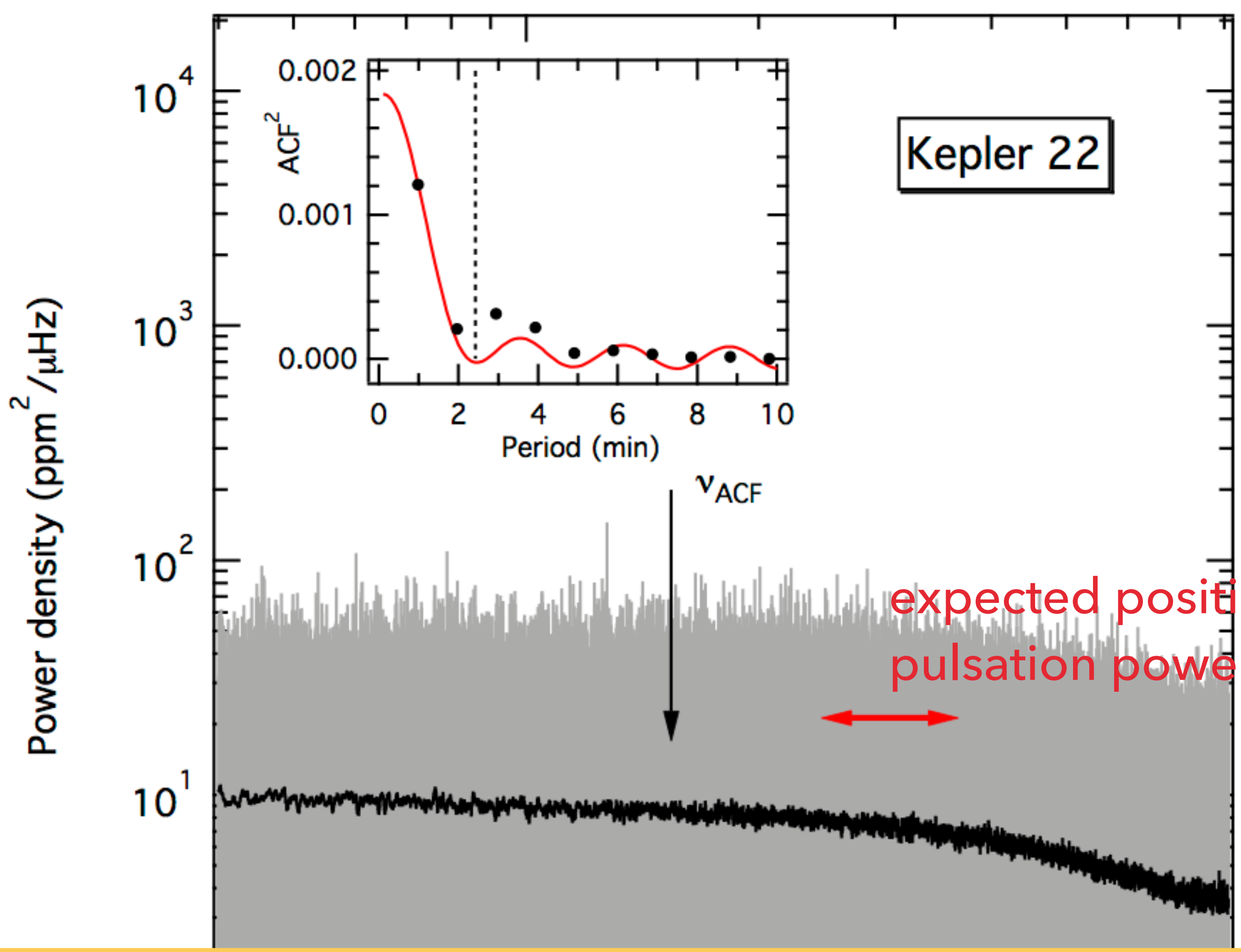
calibration with seismic surface gravity gives:

$$\log g = 4.766 \pm 0.007 - 0.962 \pm 0.007 \log(\tau_{ACF}) - 0.026 \pm 0.002 \log(\tau_{ACF})^2$$

accurate to ± 0.017 (or~4%)



WORKS ALSO FOR “NOISY” STARS



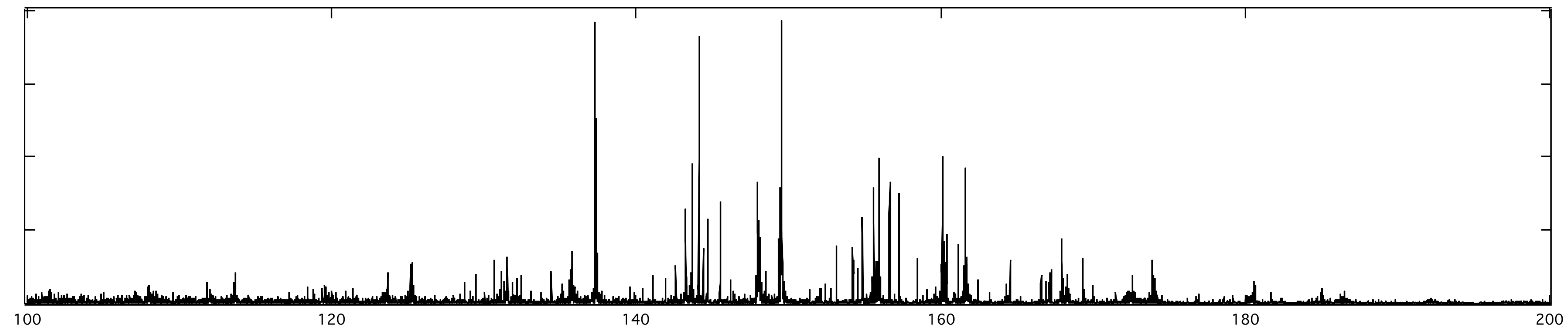
ACF technique: log*g* = 4.39±0.04

spectroscopy: log

large potential for future missions (e.g. TESS)

MODE LIFETIMES ON THE RGB

PROBLEM



large number of modes

due to mixed nature of nonradial modes the total number of modes rapidly exceeds 100

rotationally split modes

rotation splits nonradial modes into multiplets with an a priori unknown structure (single peak/duplet/triplet for l=1 modes)

lifetime effects

is a more resolved or not? does a peak belong to a poorly resolve Lorentzian profile or is it a individual mode?

mode identification

unknown spherical degree

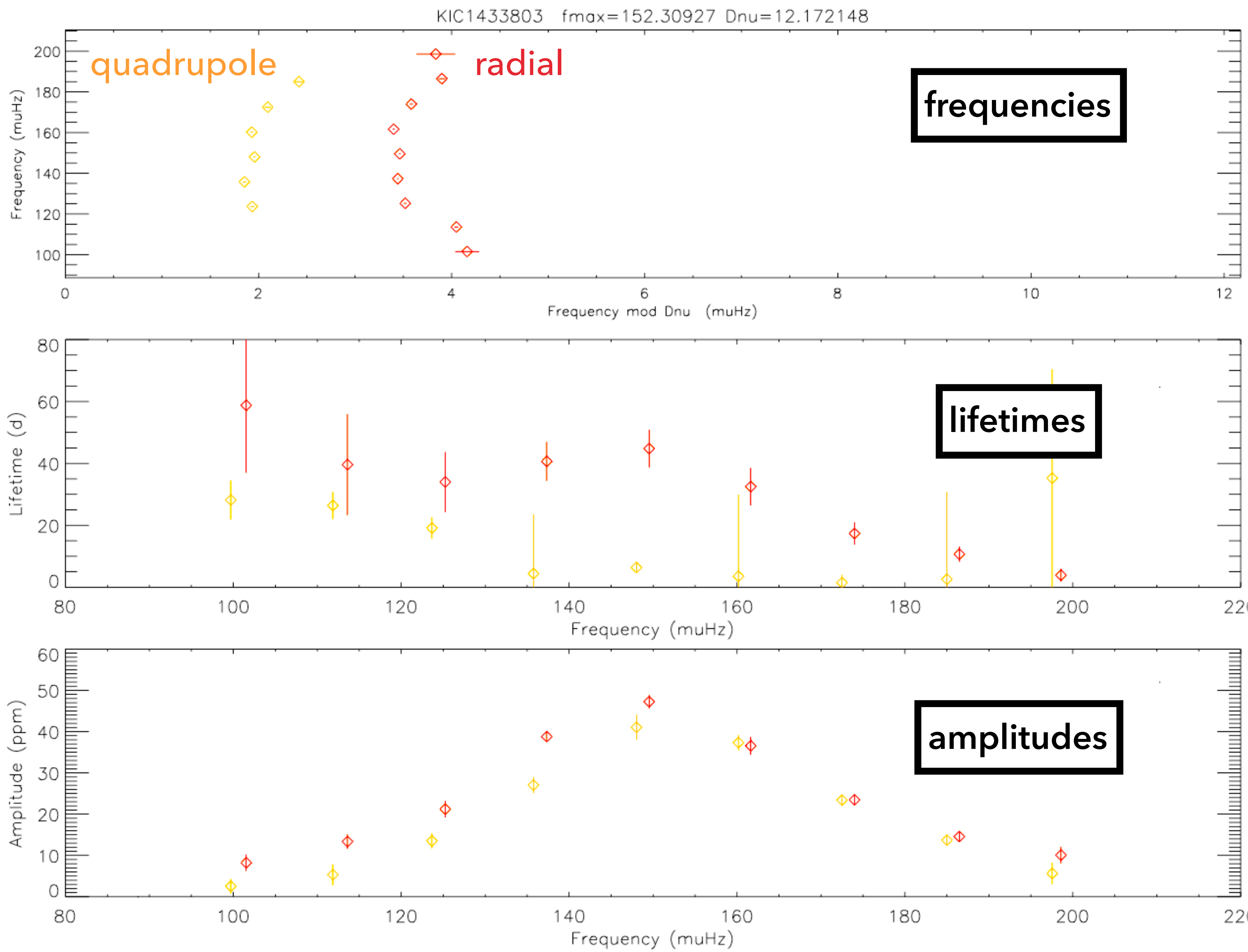
mode significance

is a peak due to noise?

for thousands of star ➠ automatic approach

I SPARE YOU THE DETAILS (BUT ITS COMPLICATED)

L = 0 AND 2 MODES

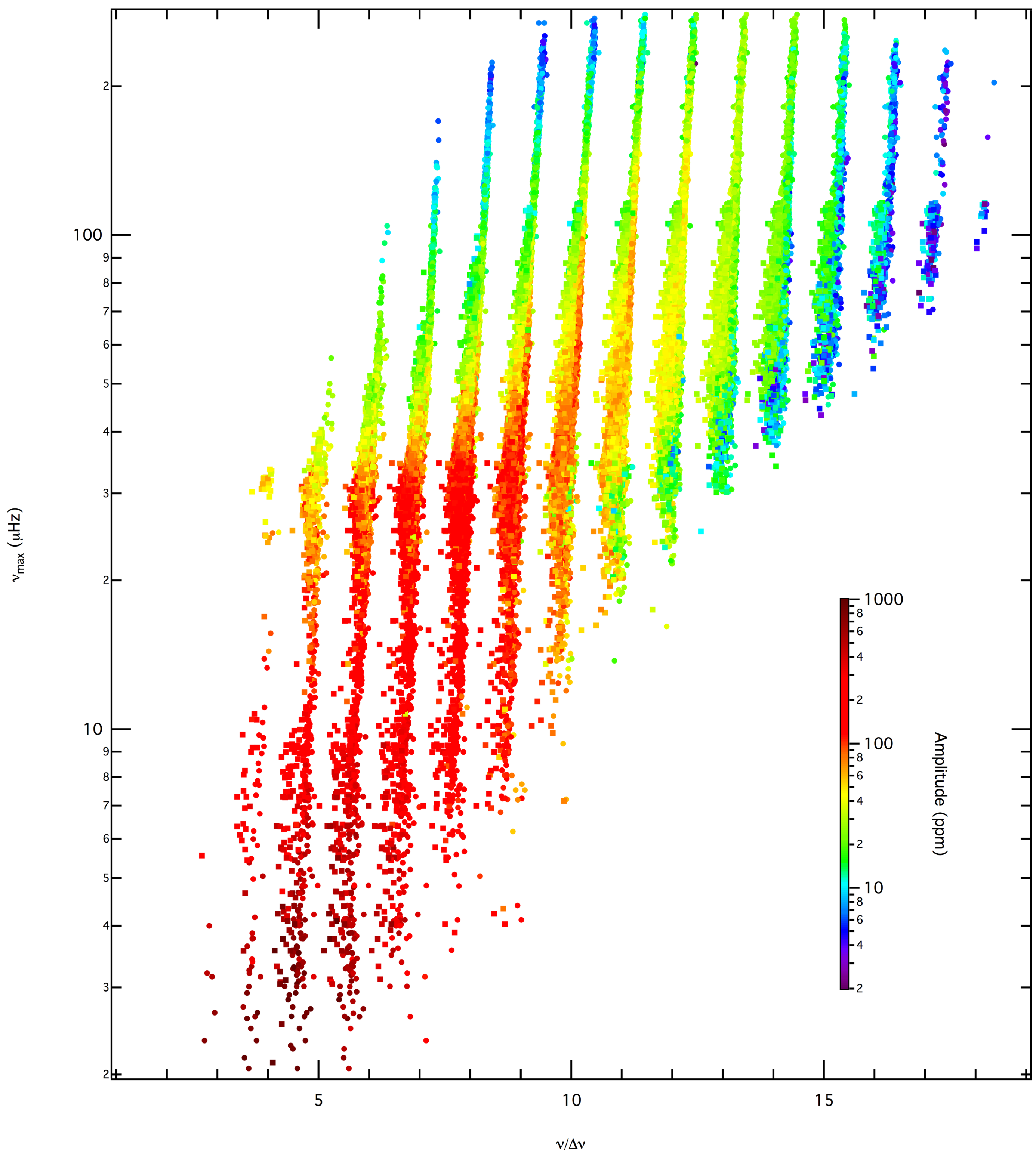


σ ≃ 20nHz

σ ≃ 28%

σ ≃ 8%

APOKASC SAMPLE



radial modes with Bayesian evidence > 0.95 of **6300** stars

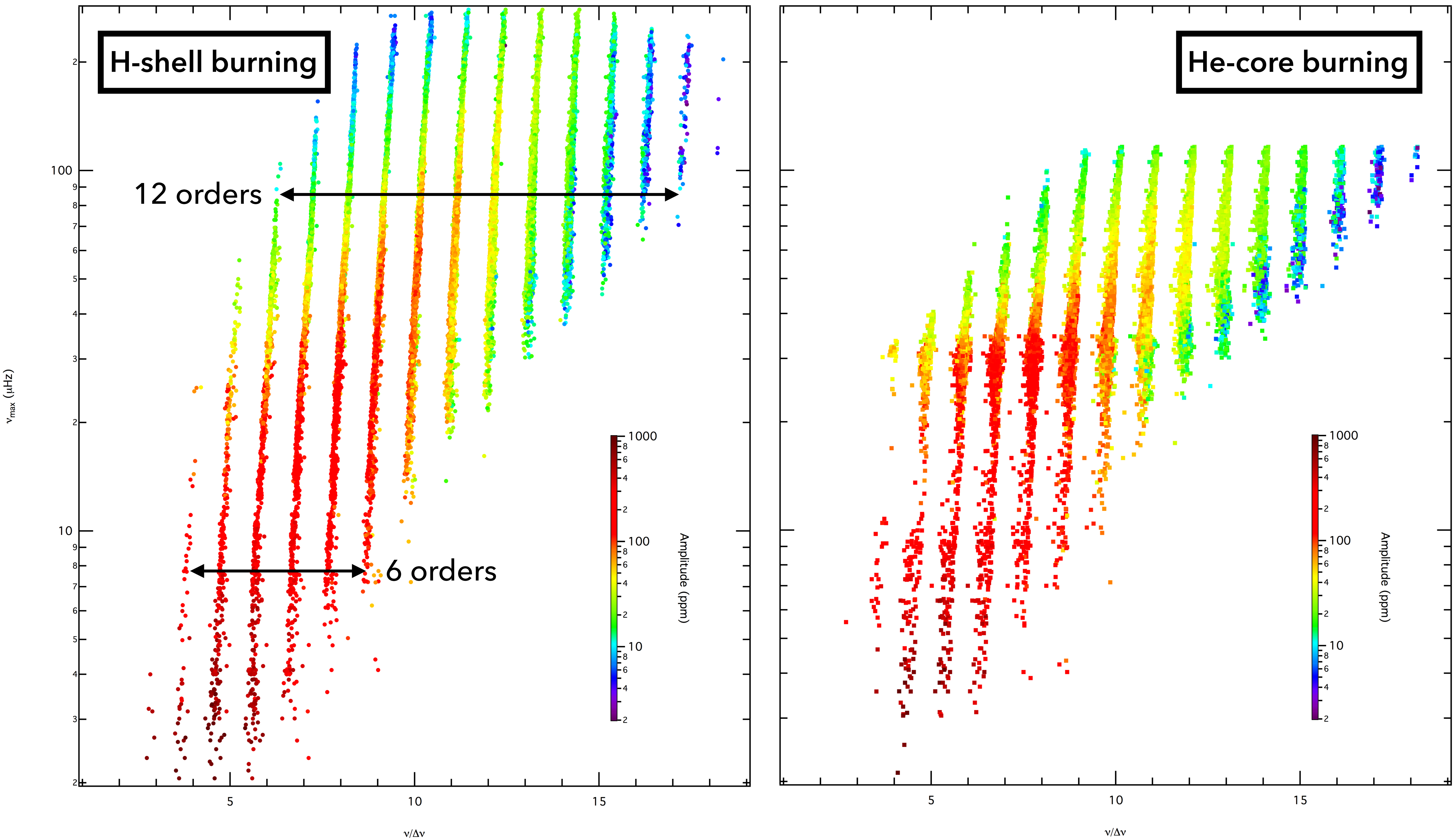
(~42,000 modes)

APOKASC SAMPLE

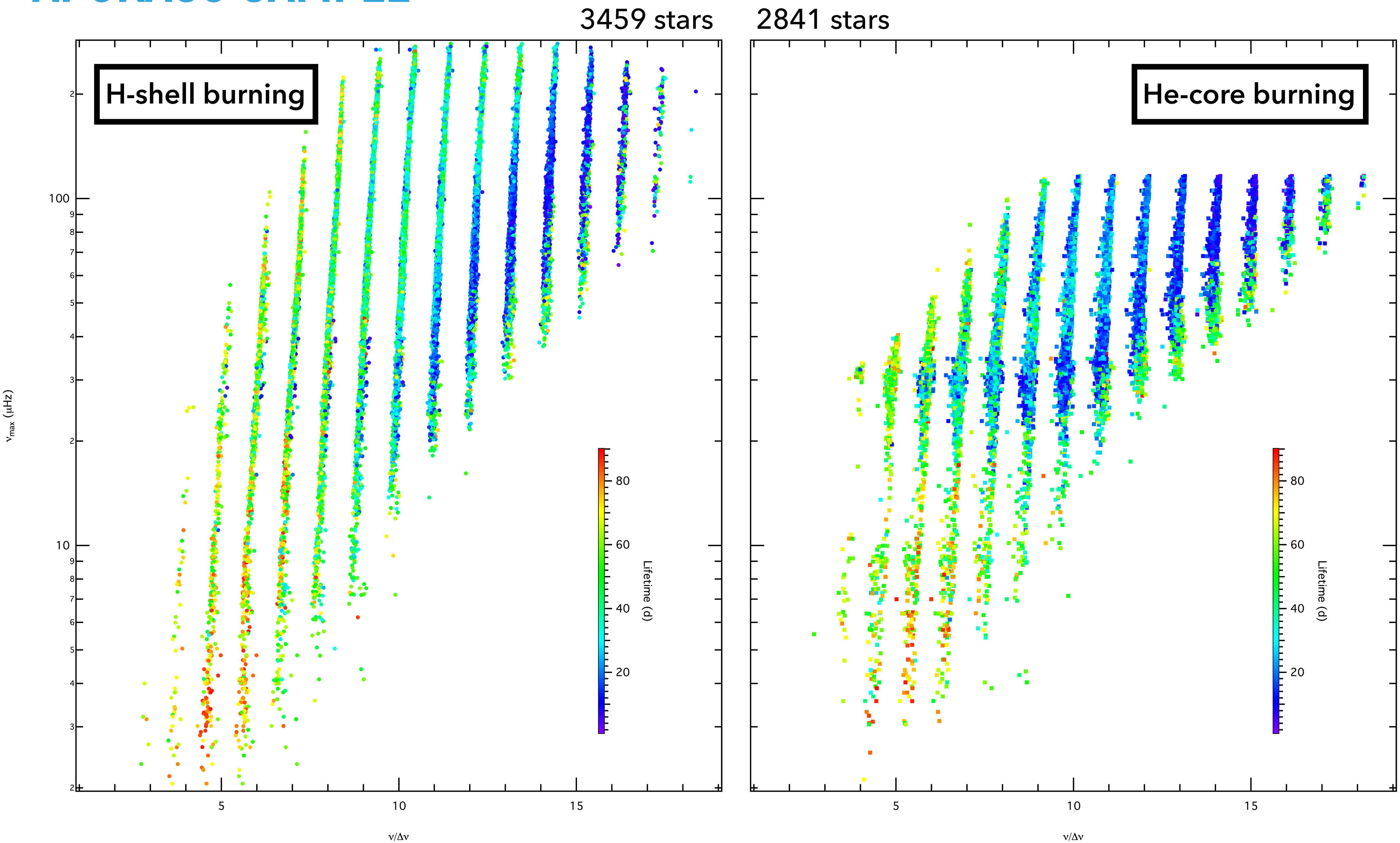
3459 stars

2841 stars

120,000+ individual modes

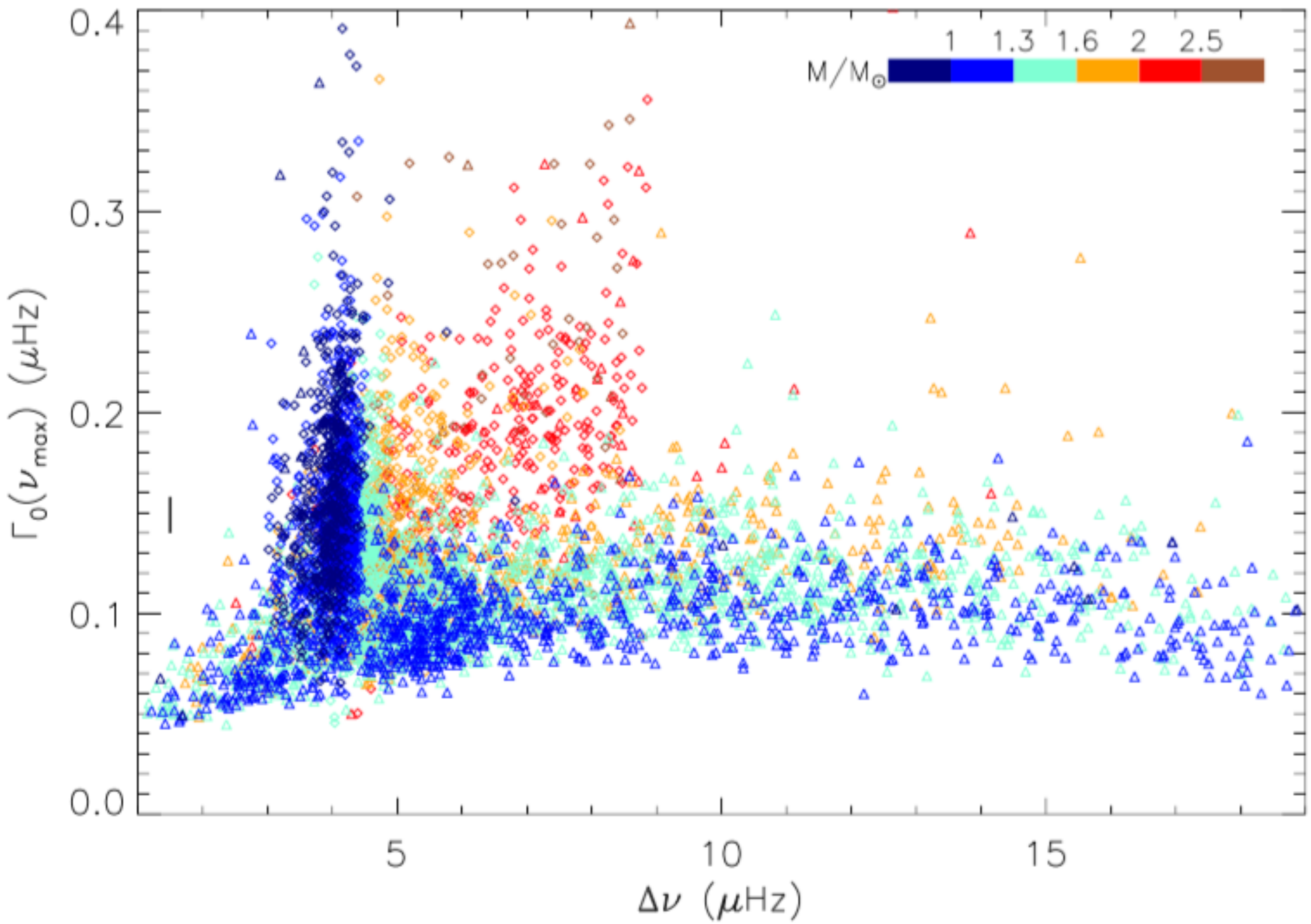


APOKASC SAMPLE

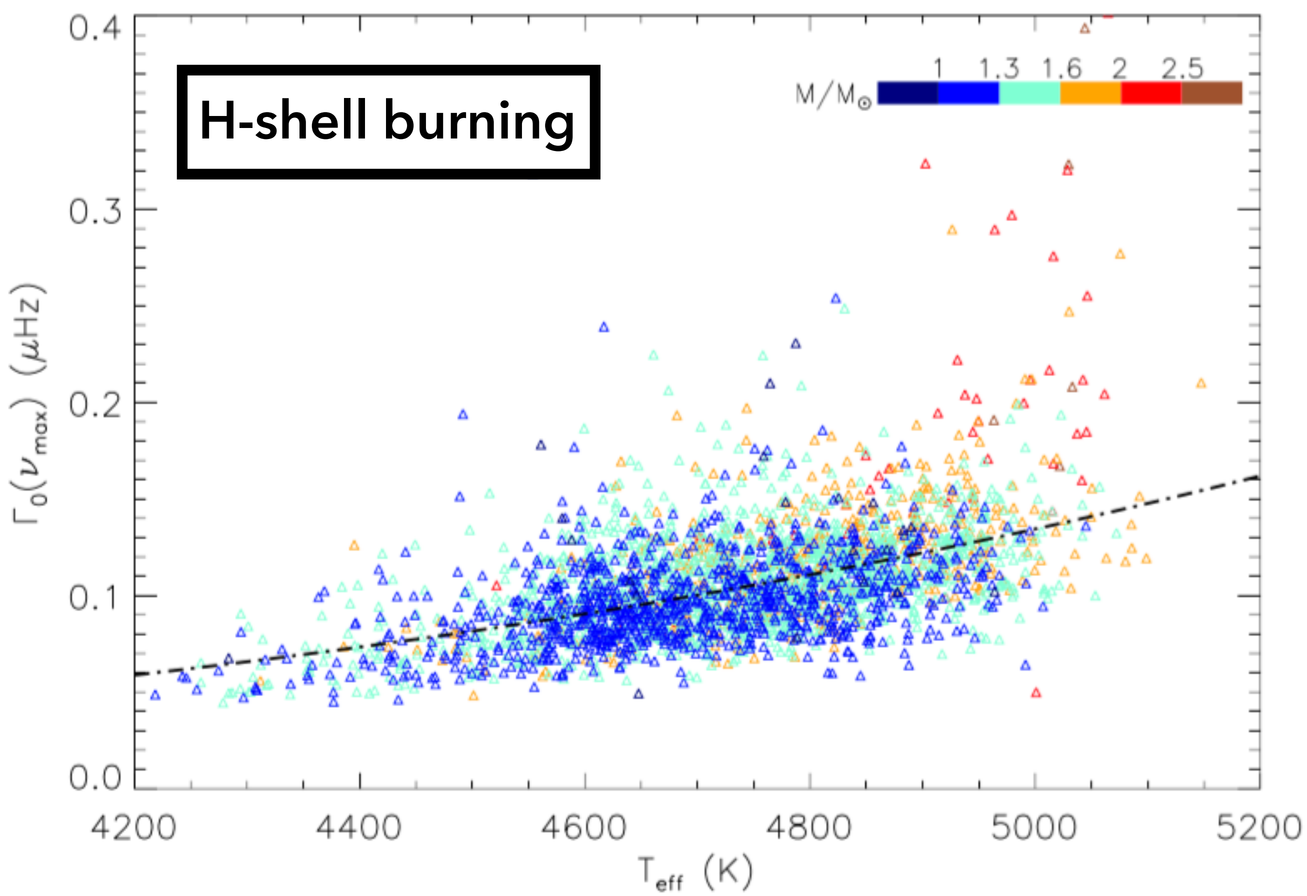


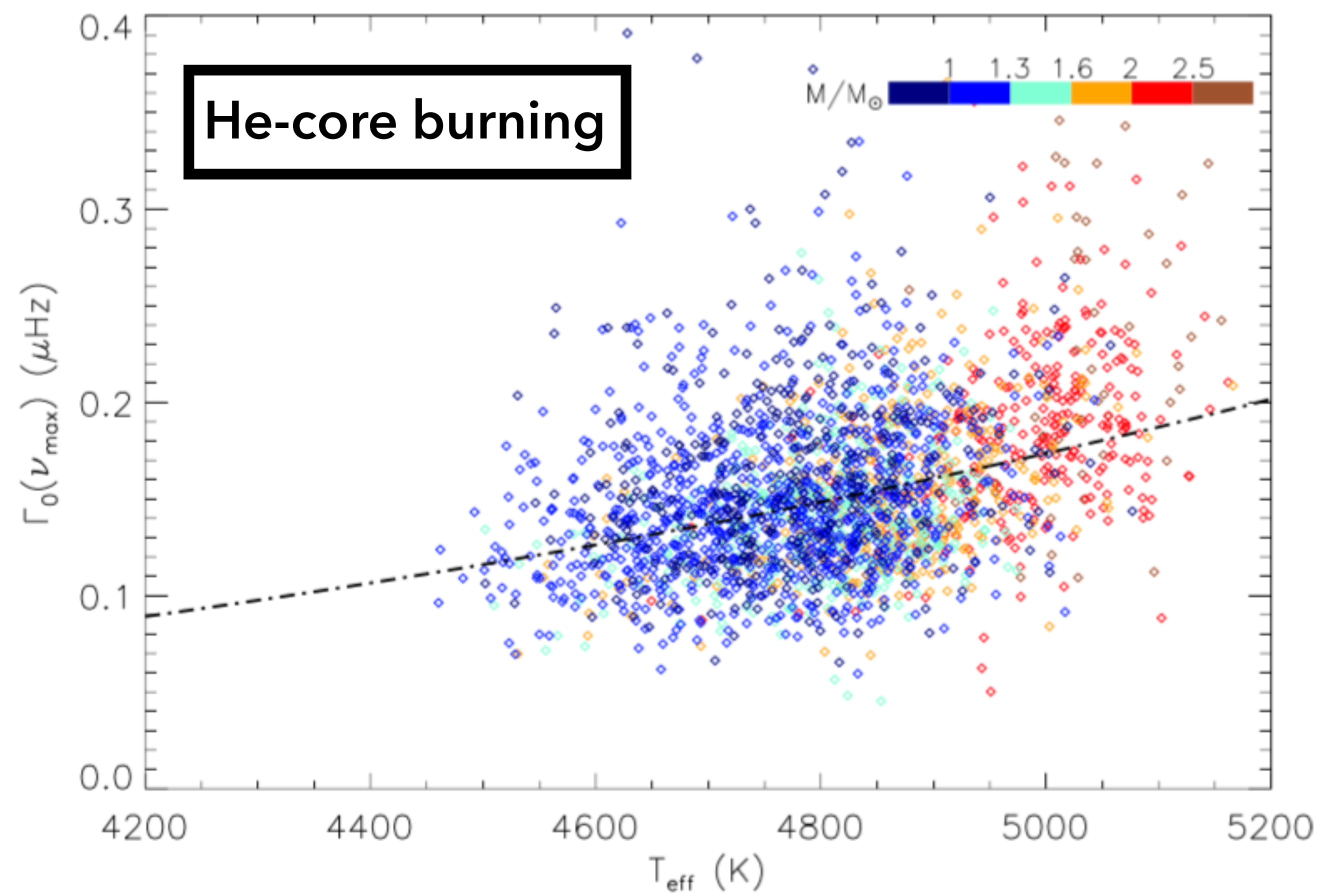
LINE WIDTHS IN THE CENTRE OF THE POWER EXCESS

Vrard & Kallinger (in prep)



TEMPERATURE SCALING



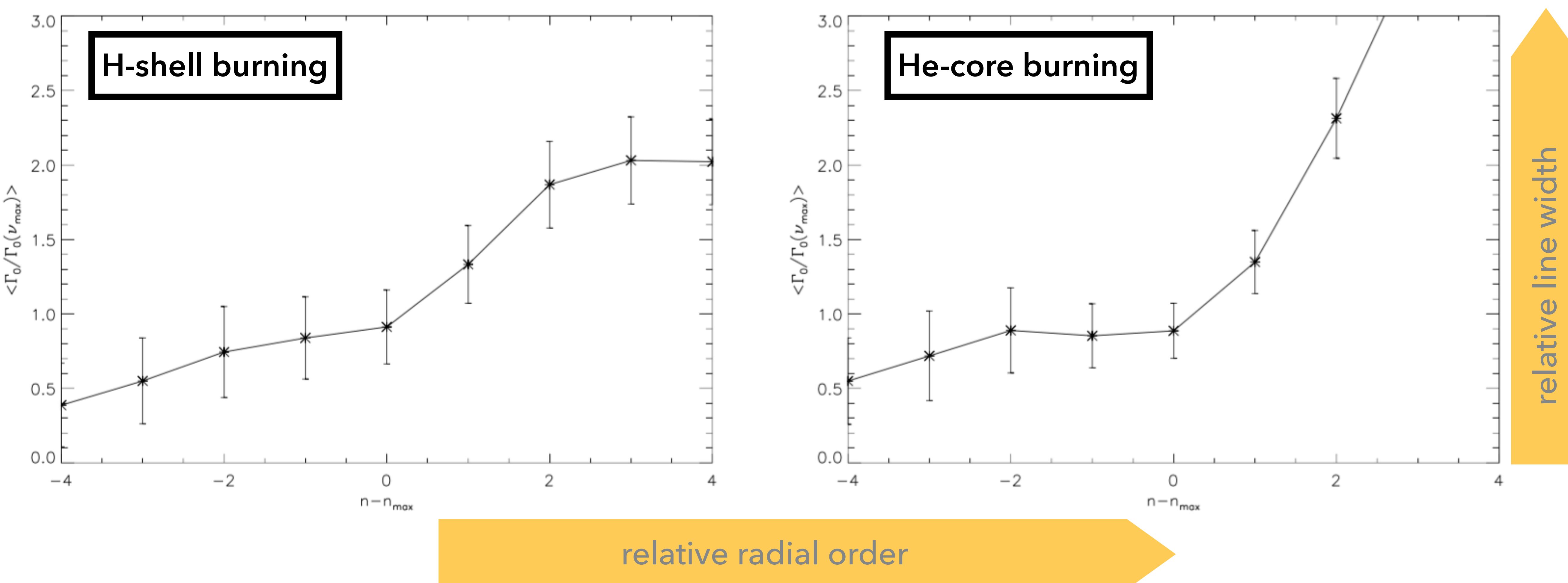


$\Gamma(\nu_{max}) \sim T_{eff}^{4.8}$

$\Gamma(\nu_{max}) \sim T_{eff}^{3.8}$

FREQUENCY DEPENDENCE

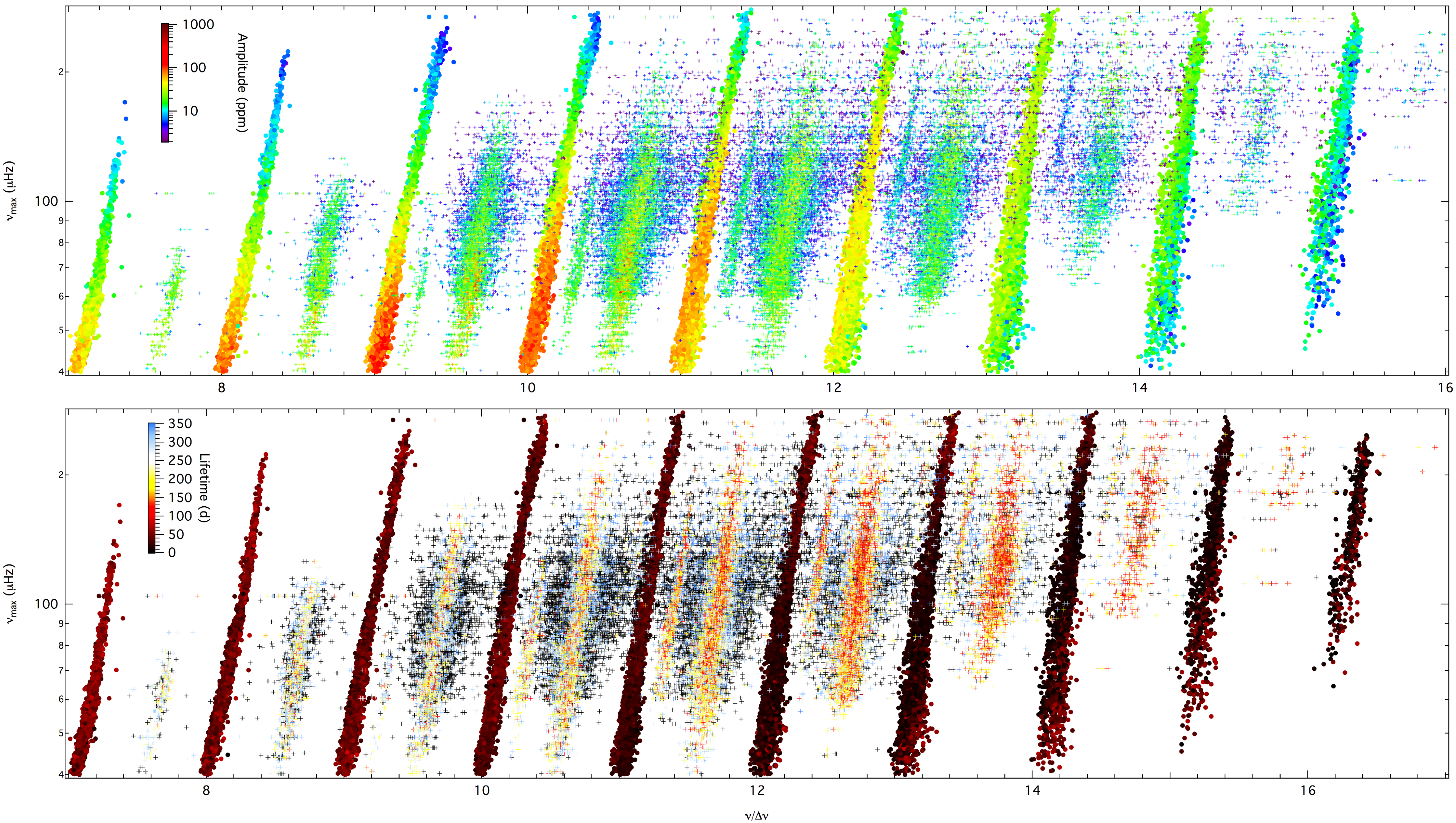
collapsograms of all stars



NON-RADIAL MODES

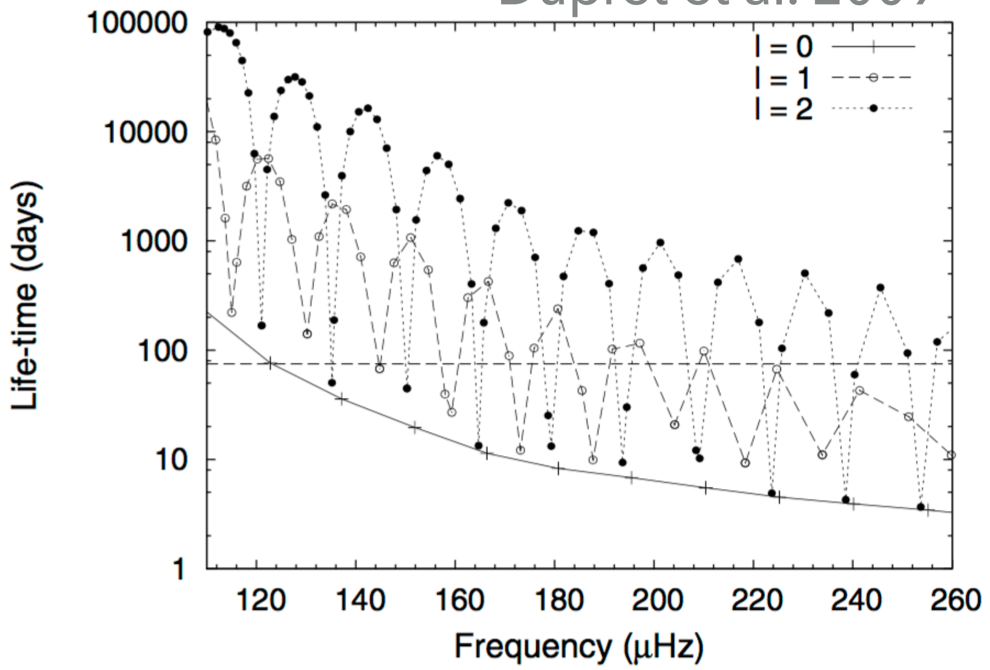
APOKASC SAMPLE

~2800 RGB stars with ν_{max} > 30μHz



THEORETICAL - OBSERVED

Dupret et al. 2009



60,000+ individual modes