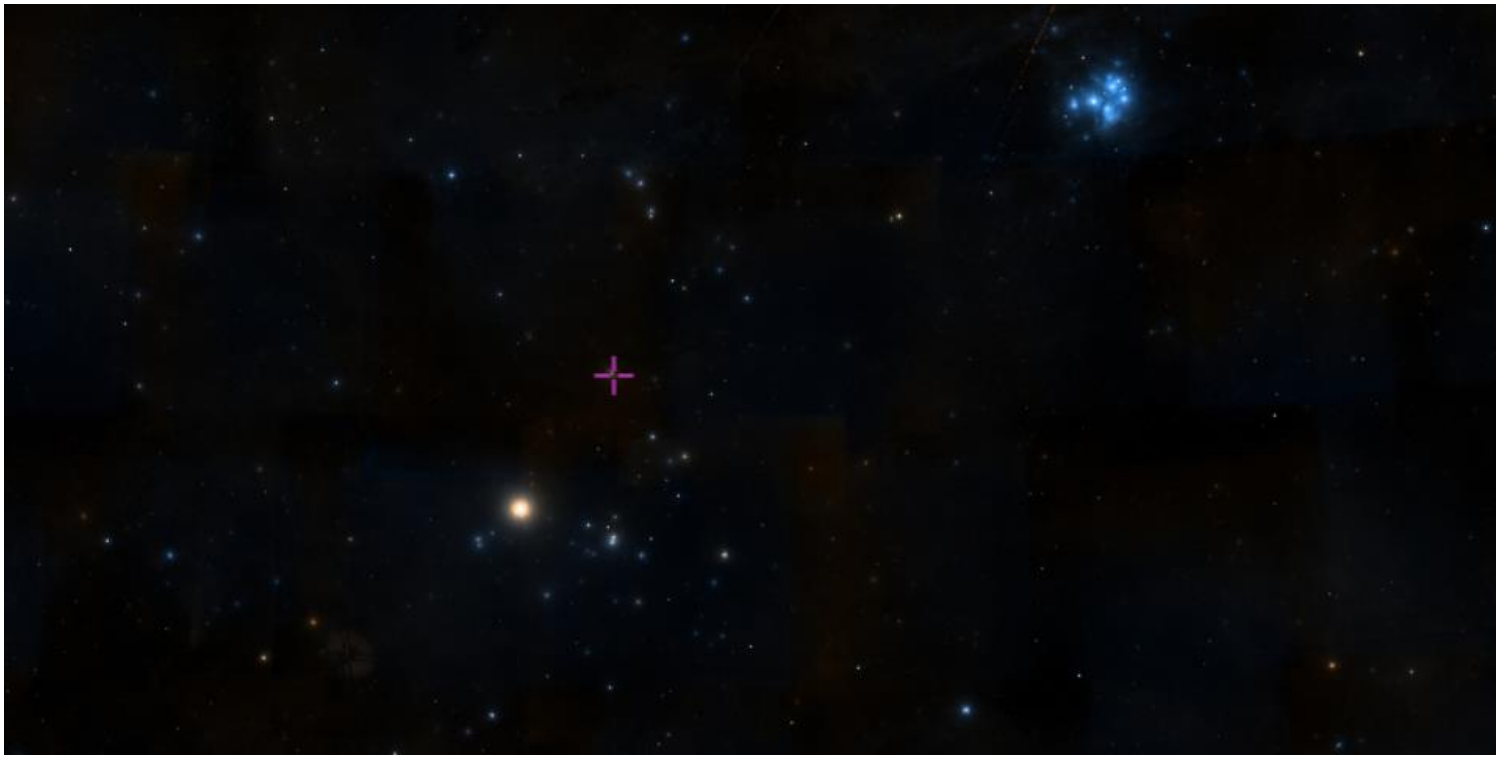
THE EXOPLANET HOST STAR EPSILON TAU



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Asteroseismology of the Hyades red giant and planet host ϵ Tau*

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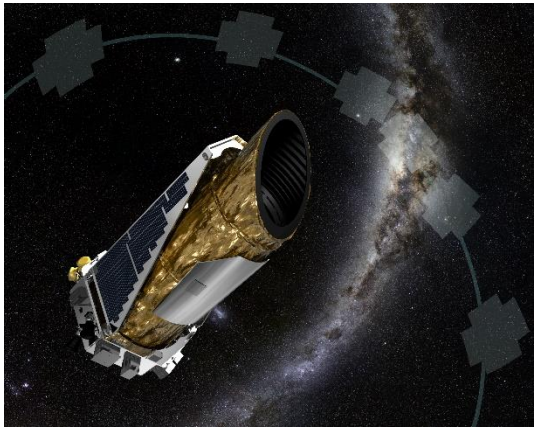
SONG key publication

With data from:

- SONG Tenerife
- SONG Delingha
- NASA K2
- PAVO / CHARA
  (White et al., in prep)

Combine high S/N spectroscopic data with uninterrupted spacebased data

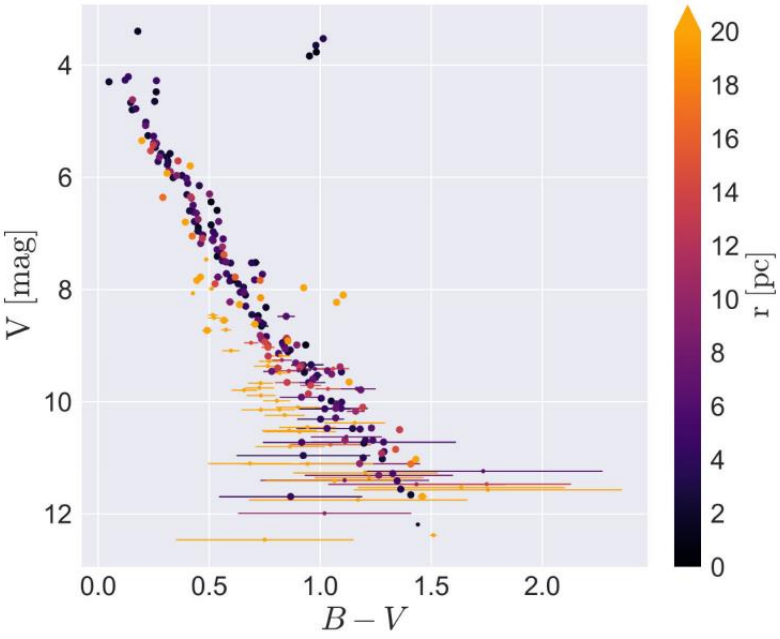


The Hyades Open Cluster:

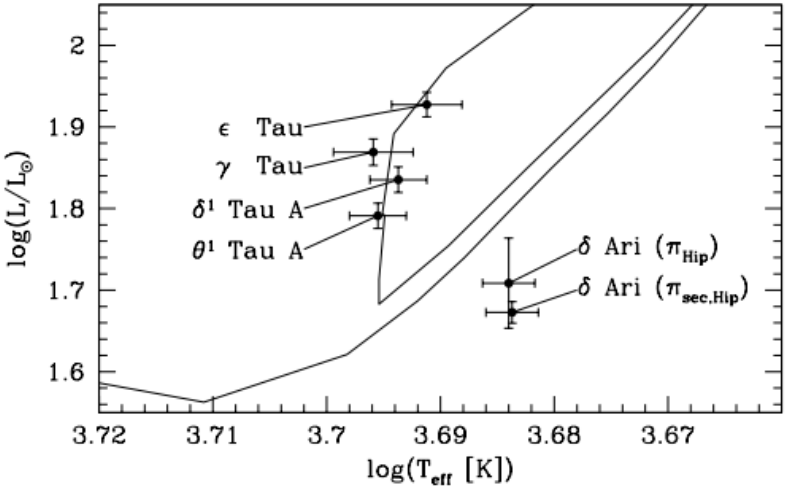
- Distance ~ 47 pc
  Age ~ 650 Myr
  Fe/H ~ 0.14

- Four red giant stars thought to be RC stars

- Oscillations in four giants
  (White et al., in prep., Beck et al. 2015)
  and in two MS stars
  (Lund et al. 2016)



(*Gaia*, Raino et al. 2018)



(de Bruijne et al. 2001)

Basic parameters for eps Tau:

- and the first exoplanet in an open cluster

TABLE 1

STELLAR PARAMETERS FOR ϵ TAU

Parameter	Value
Spectral type	K0 III
π (mas)	21.04 ± 0.82
V	3.53
$B - V$	1.014
$T_{\rm eff}$ (K)	4901 ± 20
$\log g$ (cm s^{-2})	2.64 ± 0.07
v_t (km s^{-1})	1.49 ± 0.09
[Fe/H]	0.17 ± 0.04
R ($R_\odot$)	13.7 ± 0.6
L ($L_\odot$)	97 ± 8
M ($M_\odot$)	2.7 ± 0.1
$v \sin i$ (km s^{-1})	2.5

Sato et al. (2007)

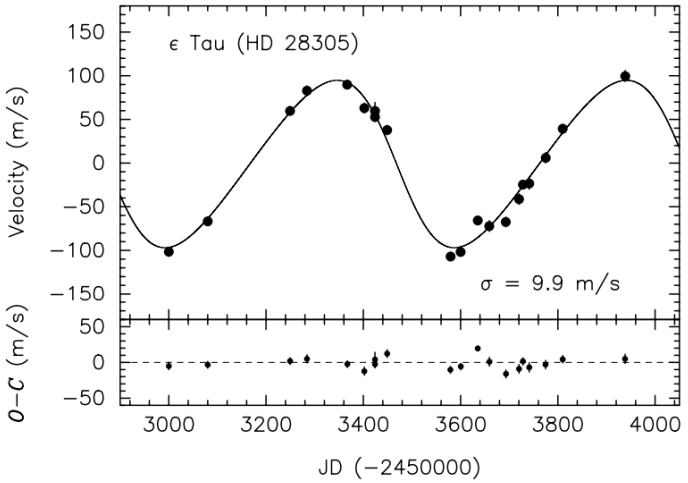


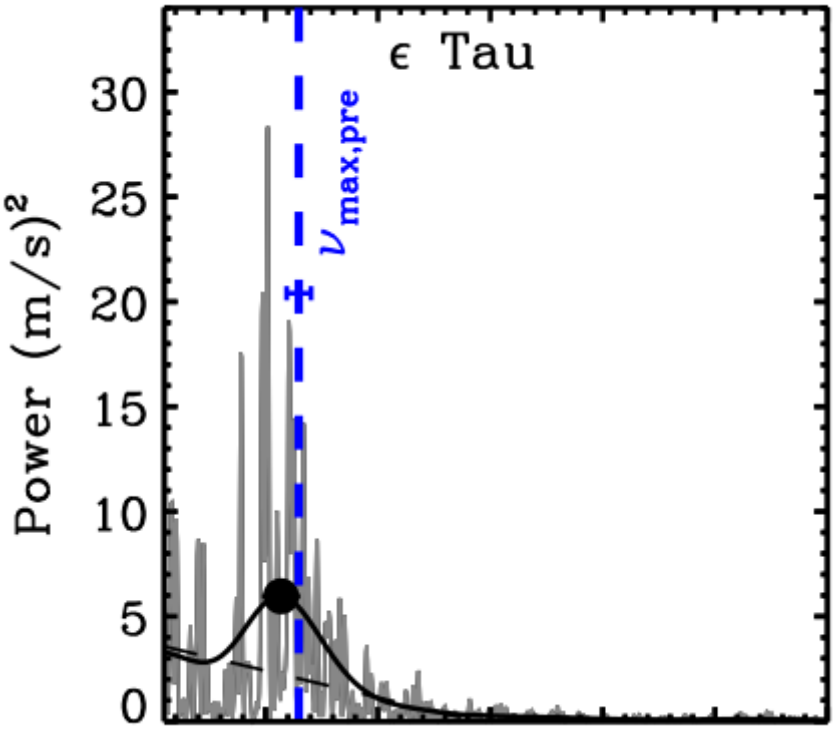
TABLE 3

ORBITAL PARAMETERS FOR ϵ TAU

Parameter	Value
P (days)	594.9 ± 5.3
K_1 (m s^{-1})	95.9 ± 1.8
e	0.151 ± 0.023
ω (deg)	94.4 ± 7.4
T_p (JD−2,450,000)	2879 ± 12
$a_1 \sin i$ (10^{-3}AU)	5.192 ± 0.097
$f_1(m)$ (10^{-8} $M_\odot$)	5.27 ± 0.28
$m_2 \sin i$ ($M_{\rm J}$)	7.6 ± 0.2
a (AU)	1.93 ± 0.03
$N_{\rm obs}$	20
rms (m s^{-1})	9.9
Reduced χ^2	4.5

Basic parameters for eps Tau:

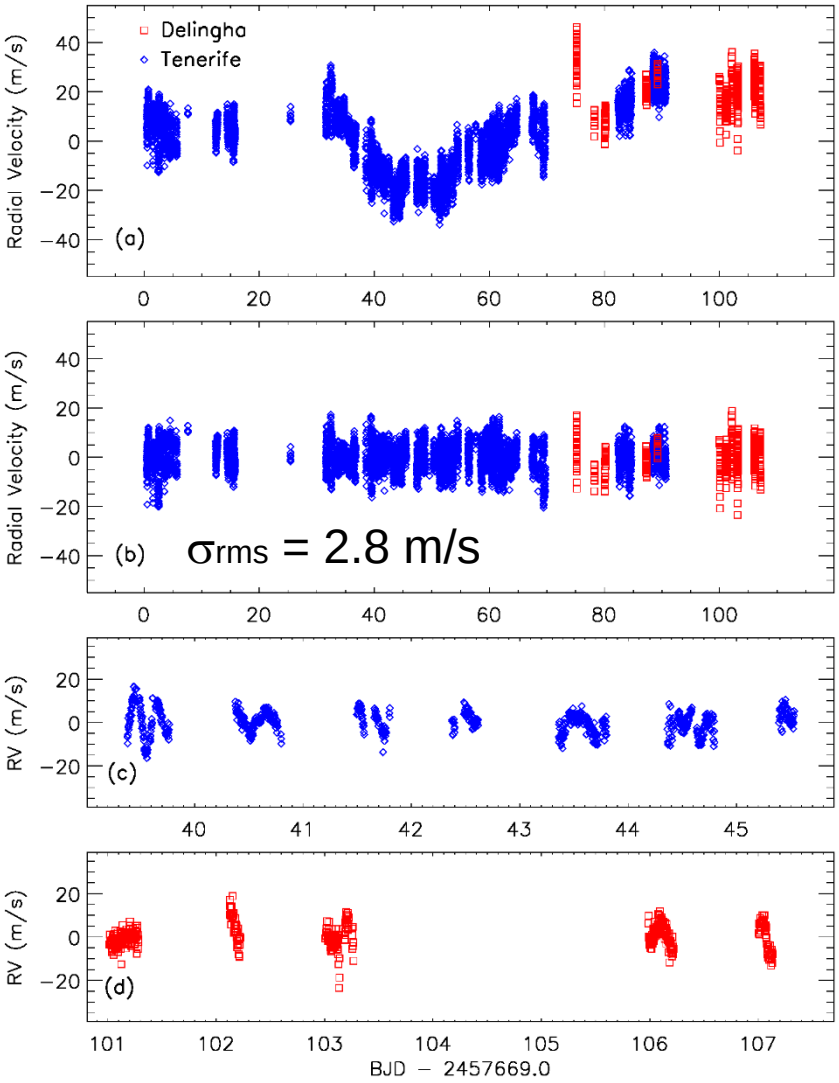
- asteroseismic measurements with SONG

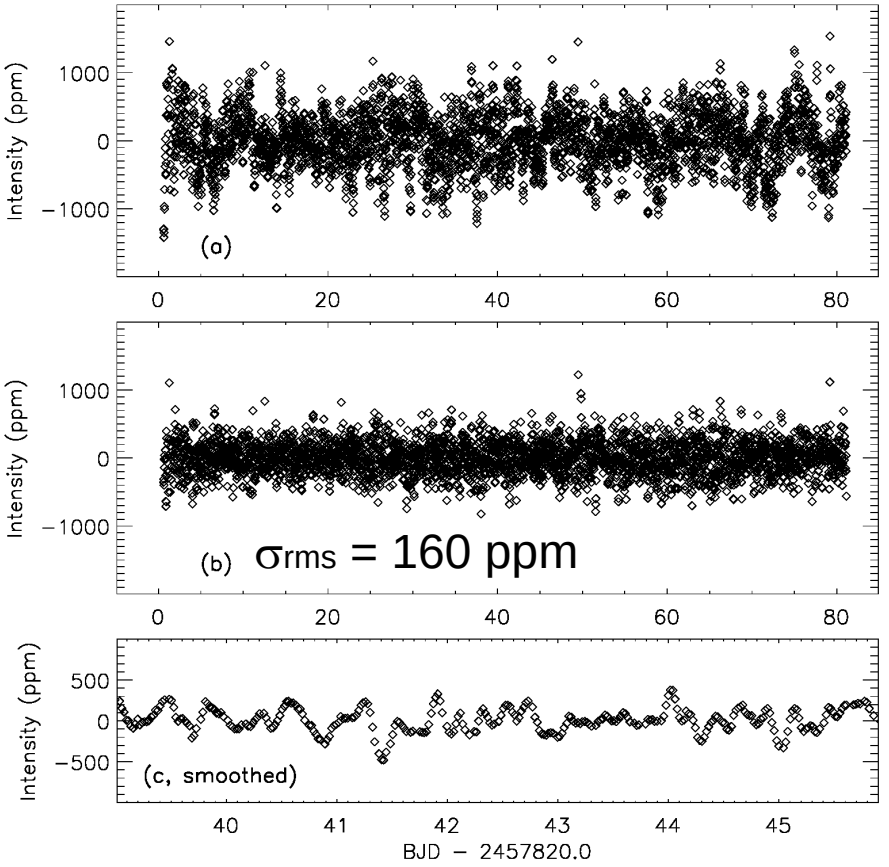


Asteroseismology		
$\nu_{max,\,obs}$ (μHz)^h (11)	log g (dex) (12)	M ($M_\odot$) (13)
56.9(8.5)	2.67(8)	2.40(36)
84.5(12.7)	2.84(8)	1.73(27)

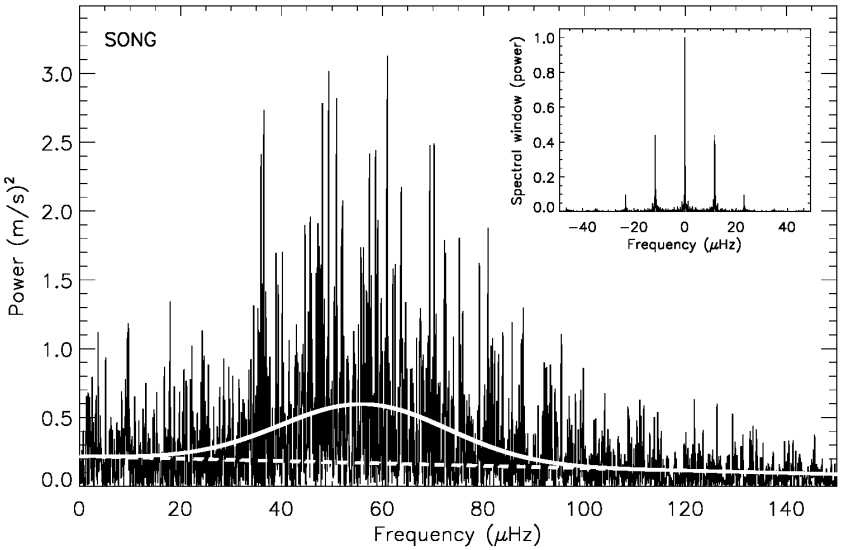
Stello et al. (2017)

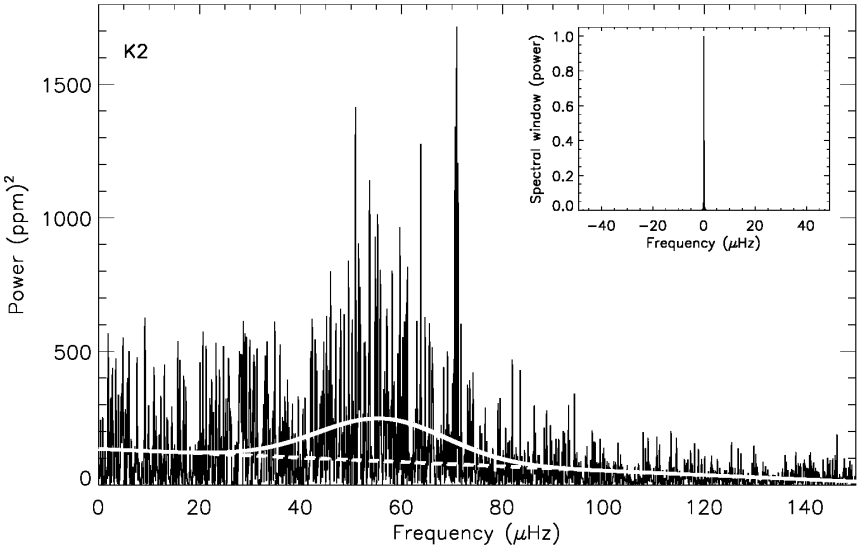
New time series data from SONG and K2

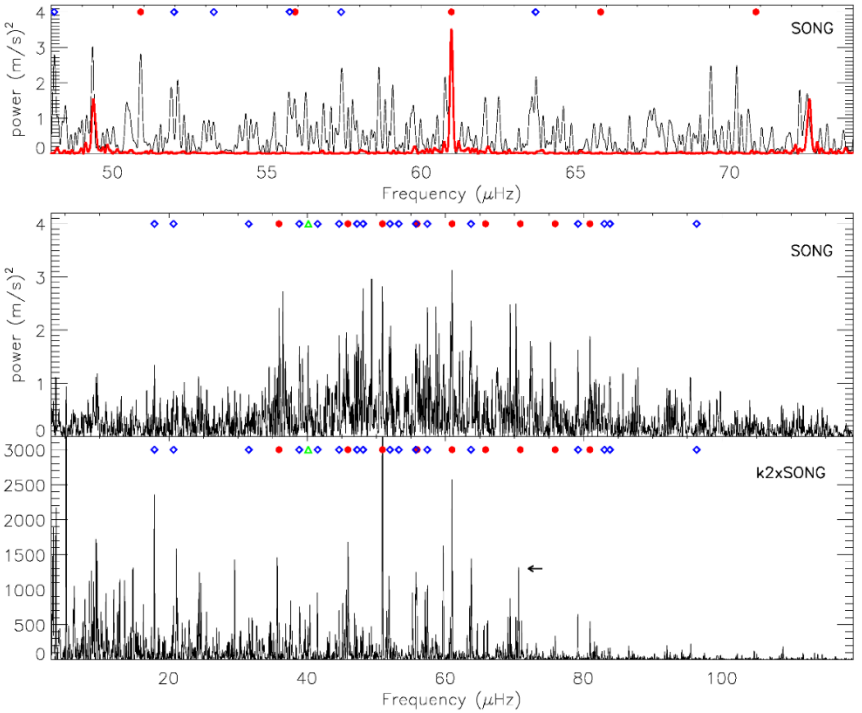




(30 min cadence, lower panel smoothed)

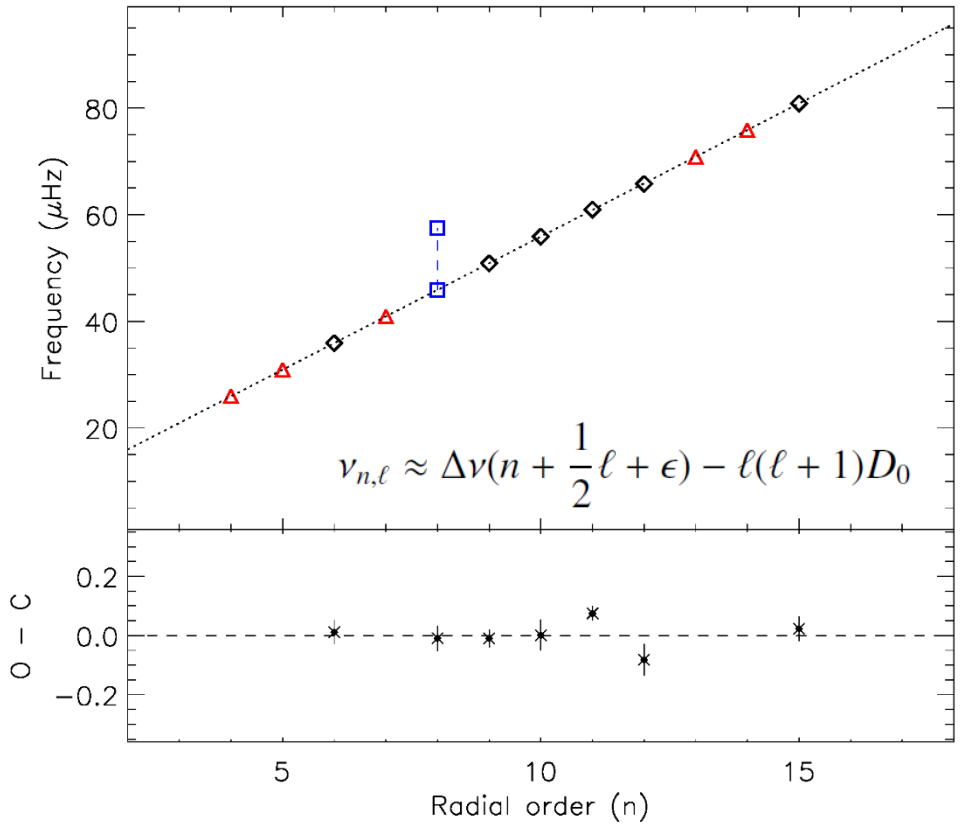


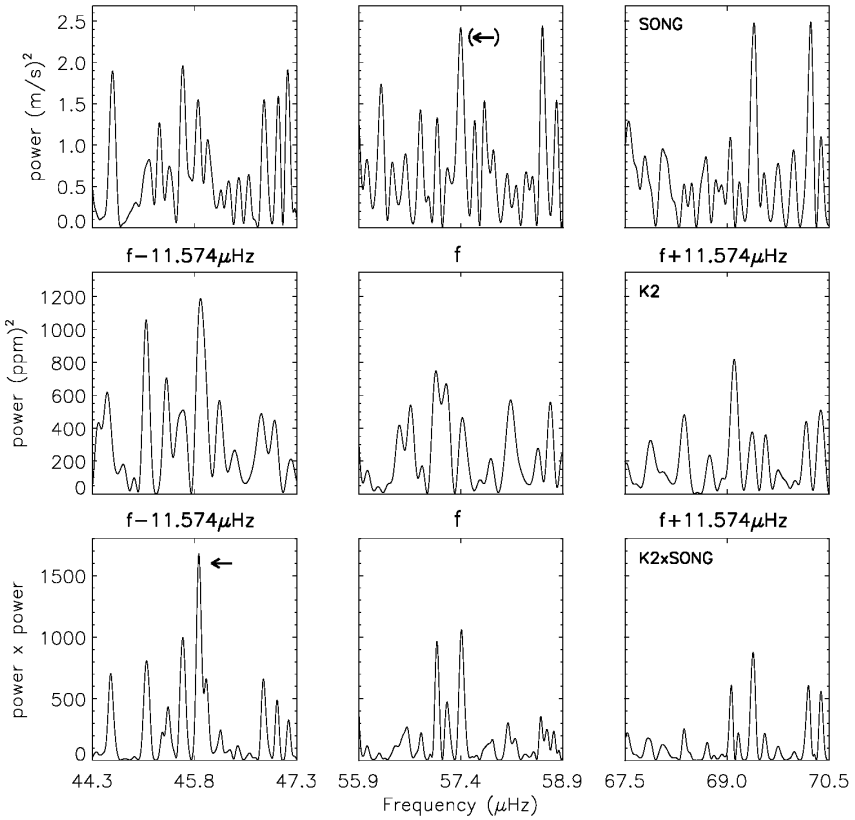


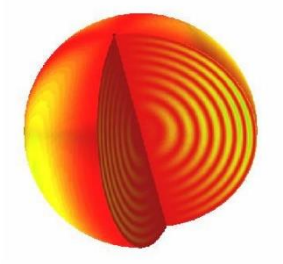


Frequency analysis based on SONG data supported by the better spectral window of K2

Looking for *l* = *0* by combining the SONG and K2 data…







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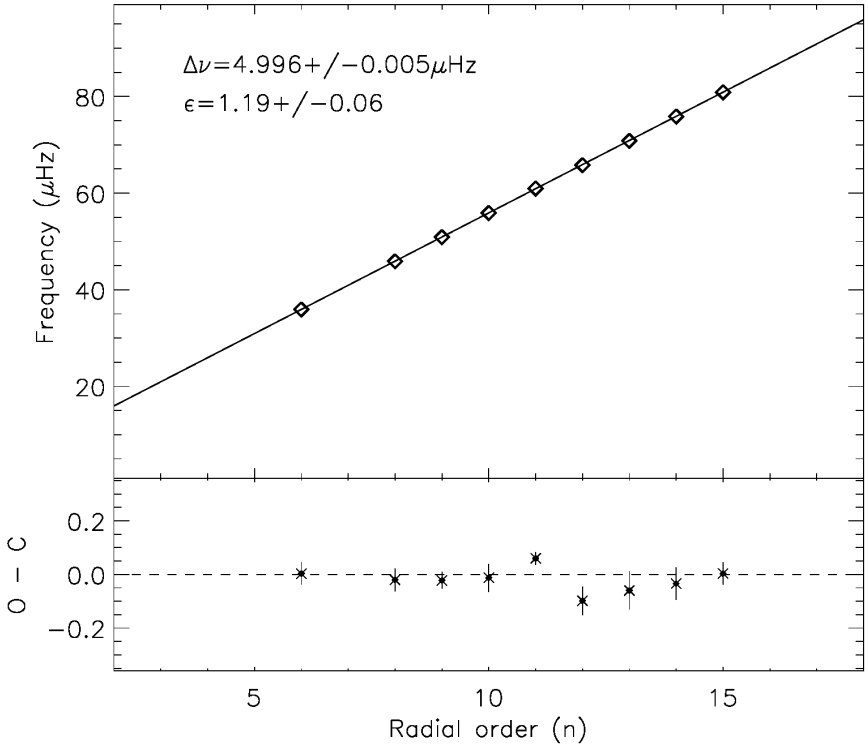
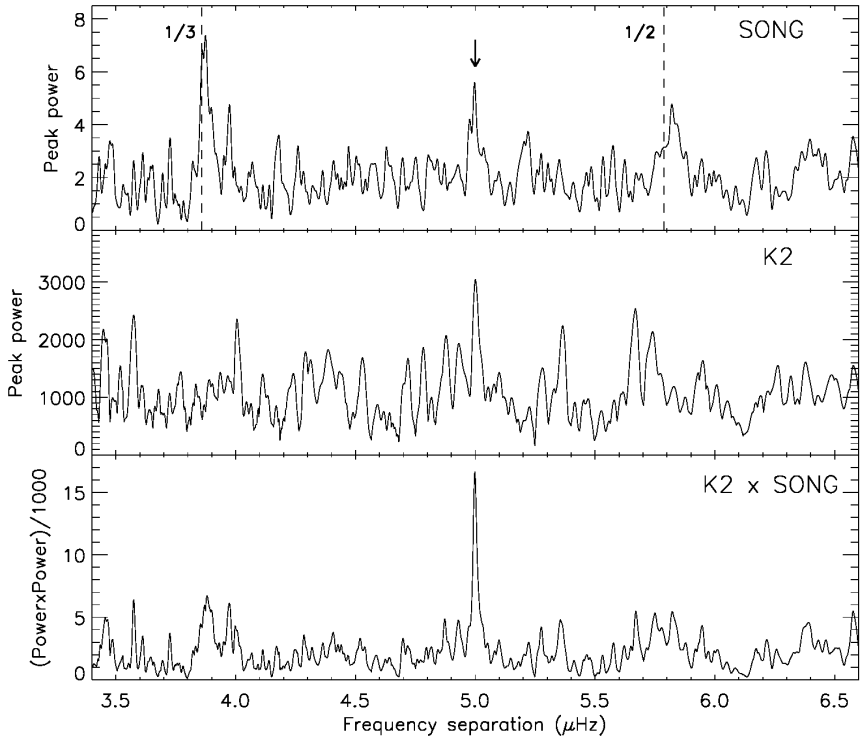
Determining the large frequency spacing:

Using the *l = 0* modes:



Using ”Powersum”:



See Christensen-Dalsgaard et al. (2008) / Arentoft et al. (2017, 2018) for details about ”Powersum”

Asteroseismic results:

Table 2. Global asteroseismic parameters for ϵ Tau

Parameter	SONG	K2
ν_{max}	56.4±1.1 μHz	56.1 μHz
$\Delta\nu$	5.00±0.01 μHz	5.00 μHz
$\delta\nu_{02}$	0.76±0.05 μHz	
ϵ	1.19±0.06	

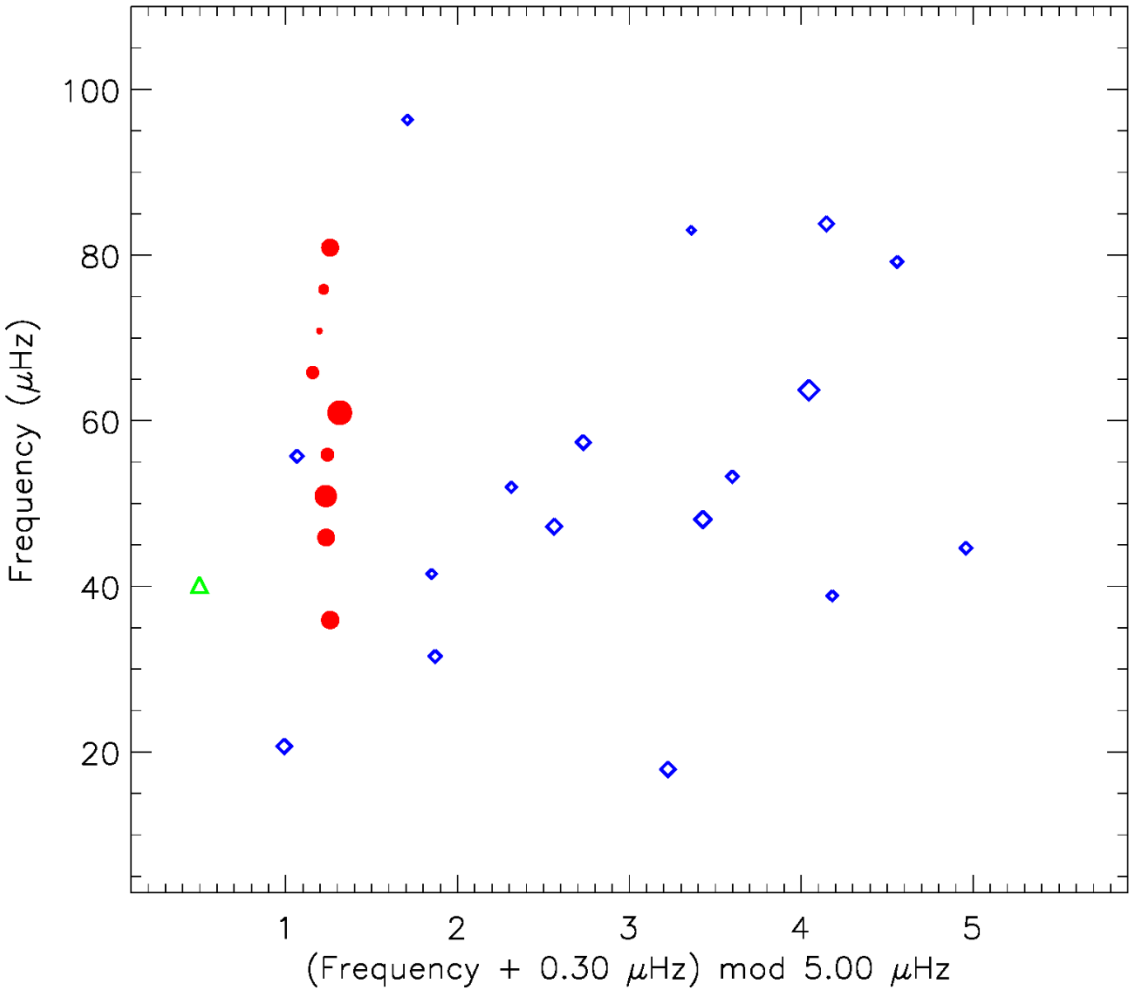
Further analysis based on the results from SONG

Table 3. A list of the 27 mode frequencies (with uncertainties) in ϵ Tau, their amplitude, S/N value in amplitude (not power), and mode-identification (ℓ, n) for the ℓ=0,2 modes. The last column lists the abscissa coordinate used in the échelle diagram in Fig. 8.

f (μHz)	$\sigma(f)$	a (m/s)	S/N (a)	Mode ID	Échelle abs.
17.92	0.05	1.12	6.12		3.23
20.68	0.06	0.93	5.08		0.99
31.55	0.06	0.94	5.13		1.87
35.93	0.04	1.37	7.52	ℓ=0,n=6	1.26
38.86	0.06	0.78	4.26		4.18
40.17	0.05	1.20	6.59	ℓ=2,n=6	0.50
41.52	0.06	0.72	3.93		1.85
44.63	0.06	0.89	4.89		4.96
45.90	0.04	1.32	7.25	ℓ=0,n=8	1.23
47.23	0.05	1.17	6.40		2.56
48.10	0.04	1.26	6.88		3.43
50.90	0.03	1.68	9.20	ℓ=0,n=9	1.23
51.98	0.06	0.78	4.27		2.31
53.26	0.06	0.87	4.79		3.60
55.73	0.05	1.18	6.48		1.07
55.90	0.05	1.01	5.56	ℓ=0,n=10	1.24
57.39	0.05	1.07	5.84		2.73
60.97	0.02	1.87	10.26	ℓ=0,n=11	1.32
63.70	0.04	1.52	8.34		4.04
65.81	0.05	0.98	5.35	ℓ=0,n=12	1.16
70.85	0.07	0.46	2.52	ℓ=0,n=13	1.20
75.87	0.06	0.79	4.32	ℓ=0,n=14	1.22
79.20	0.06	0.84	4.60		4.56
80.90	0.04	1.34	7.34	ℓ=0,n=15	1.26
83.00	0.07	0.59	3.25		3.36
83.79	0.05	1.09	5.98		4.15
96.34	0.06	0.73	3.98		1.71

The remaining modes:

- Most are likely *l* = *1*
- Some may be *l* = *3*
- Some may be daily aliases (e.g., of *l* = *2*)



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$v \sin i$ (km s^{-1})	2.5

Updated parameters from asteroseismology (scaling), spectral analysis and Interferometry:

4950 +/- 22 K

2.67 (seismology), 2.72 +/- 0.07 (fit)

0.15 +/- 0.02

12.06 +/- 0.16

2.458 +/- 0.073

Sato et al. (2007)

Planet mass $m_2 \sin i$ 7.6 +/- 0.2 M_J 7.1 +/- 0.2 M_J

Evolutionary stage of eps Tau:

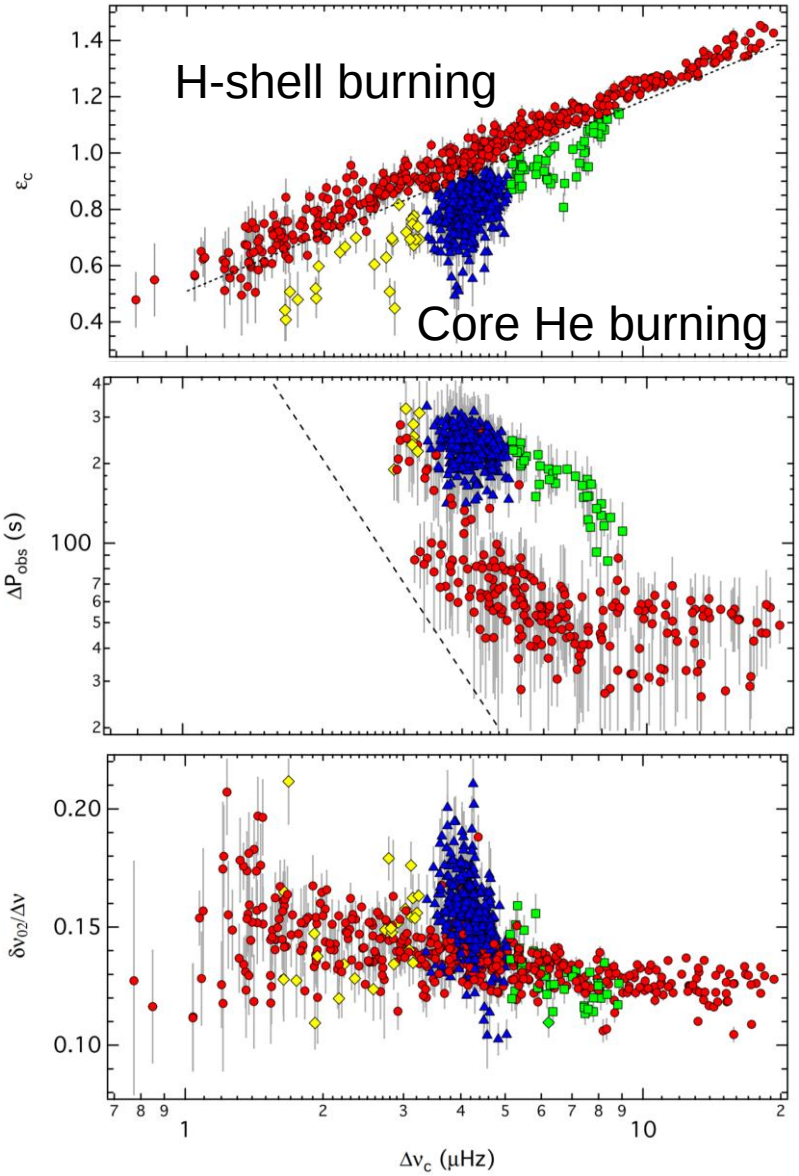
- The asymptotic relation:

$$\nu_{n,\ell} \approx \Delta\nu(n + \frac{1}{2}\ell + \epsilon) - \ell(\ell+1)D_0$$

- Kallinger et al. (2012) / Kepler: *Three central radial modes*

- For eps Tau (l = 0, n = 9 – 11)

$$\Delta\nu_c = 5.04\ \mu Hz, \varepsilon_c = 1.09$$



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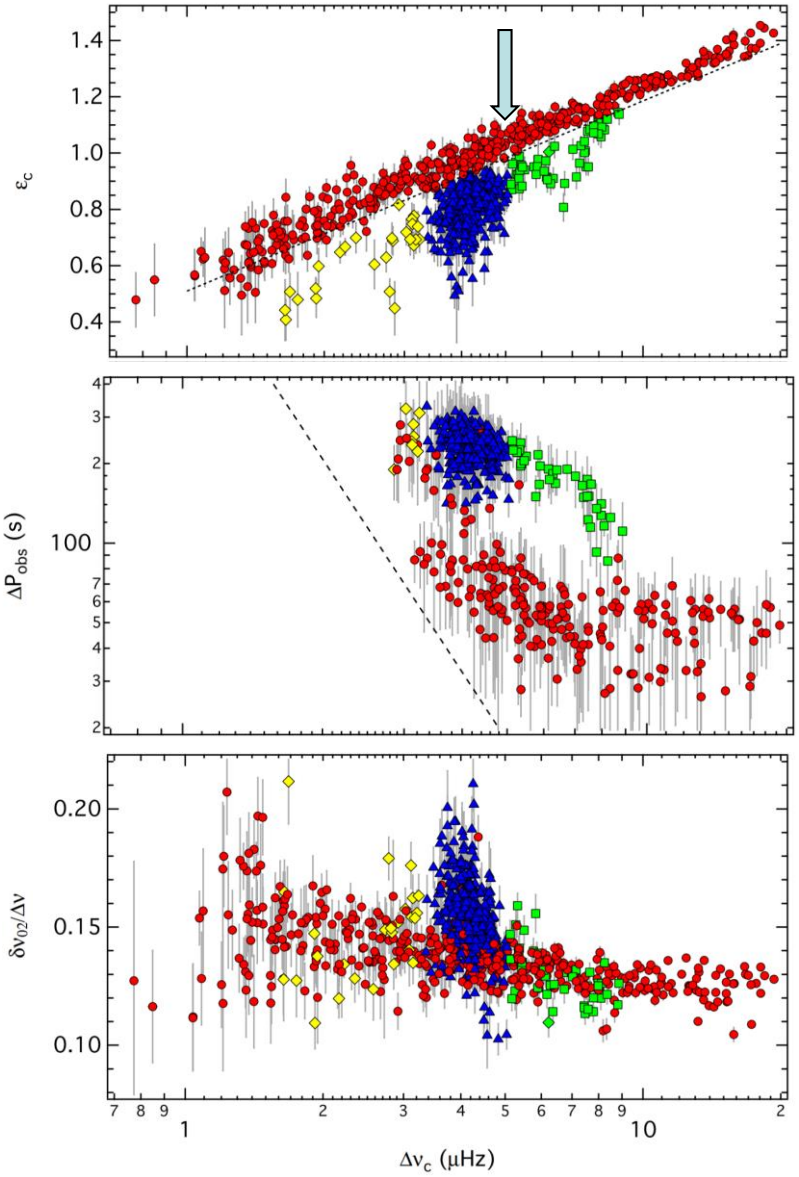
- This places eps Tau among the H-shell burning RGB stars…



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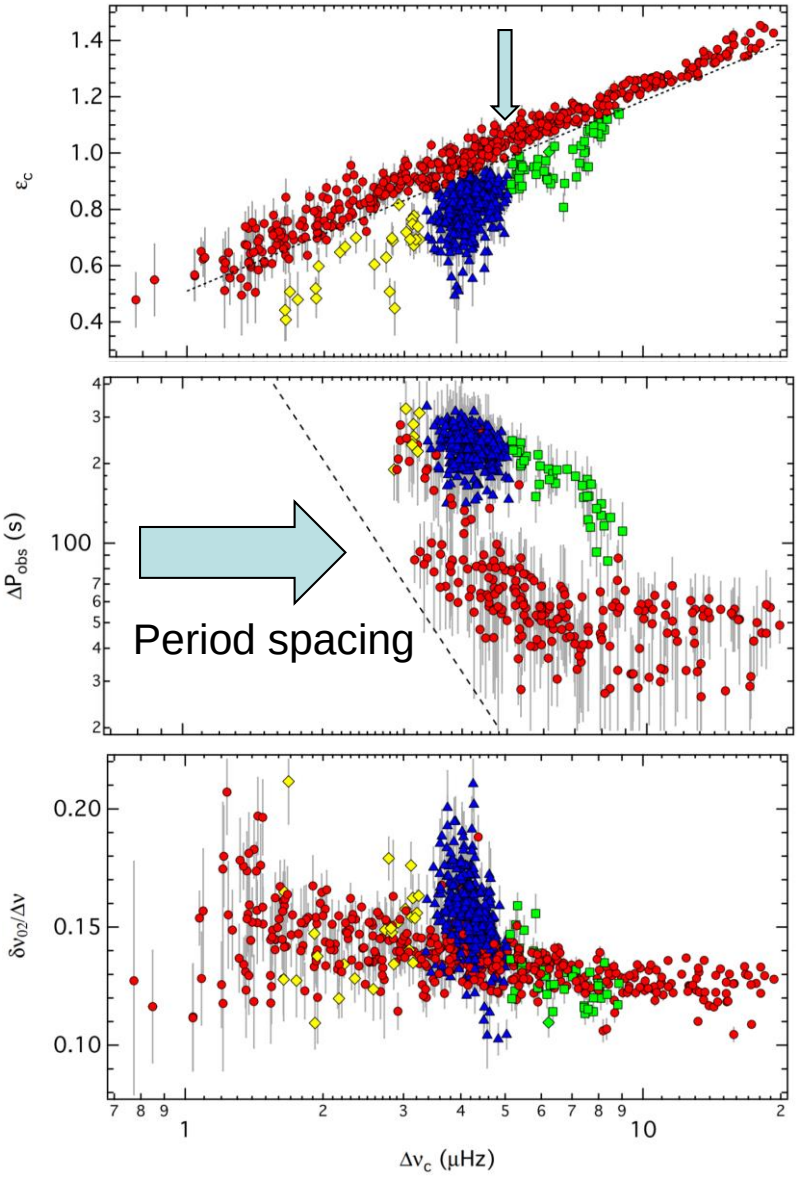
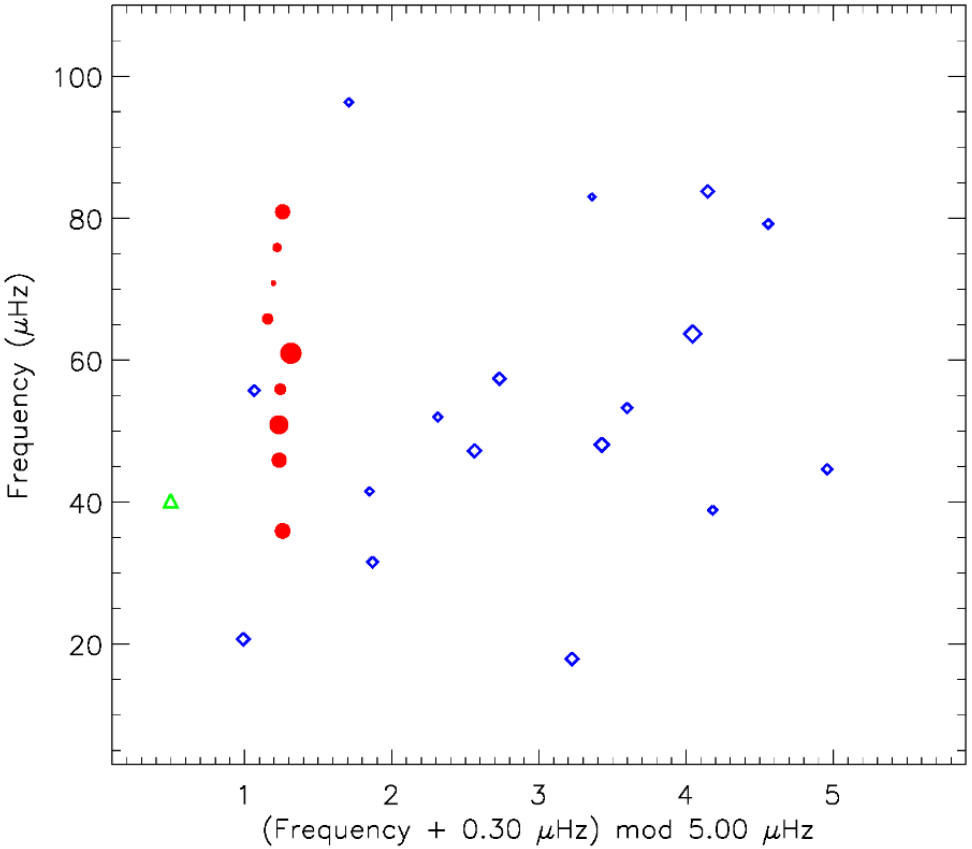
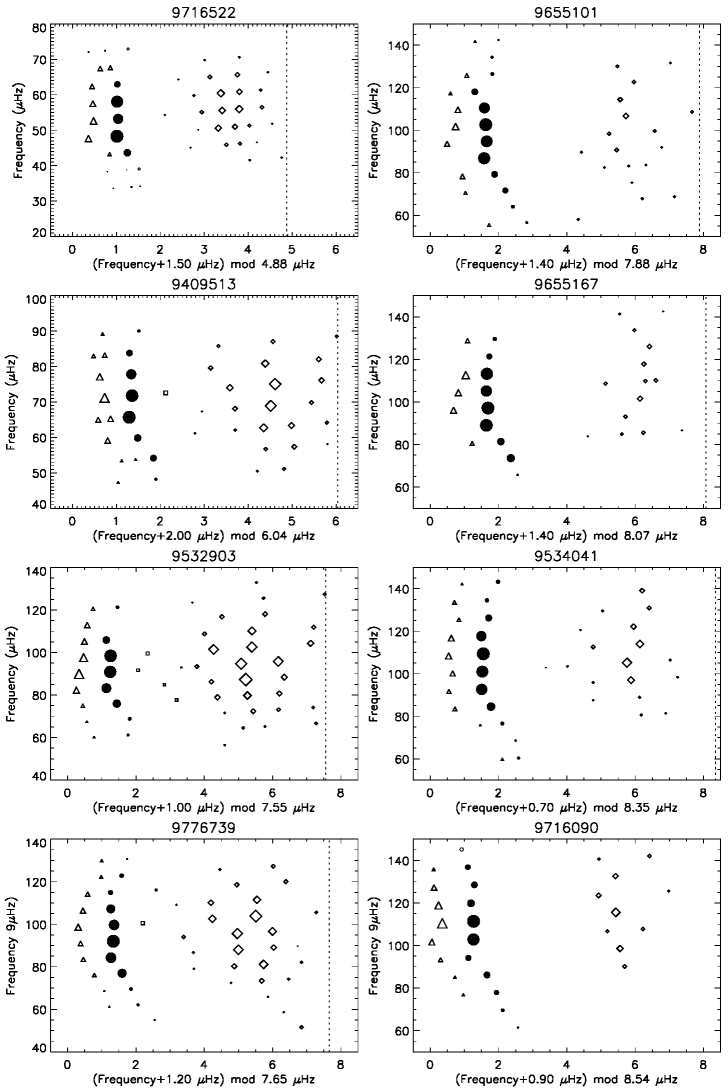


Kallinger et al. (2012)

Period spacing:

Observe the remaining 3 giants to determine the period spacing?





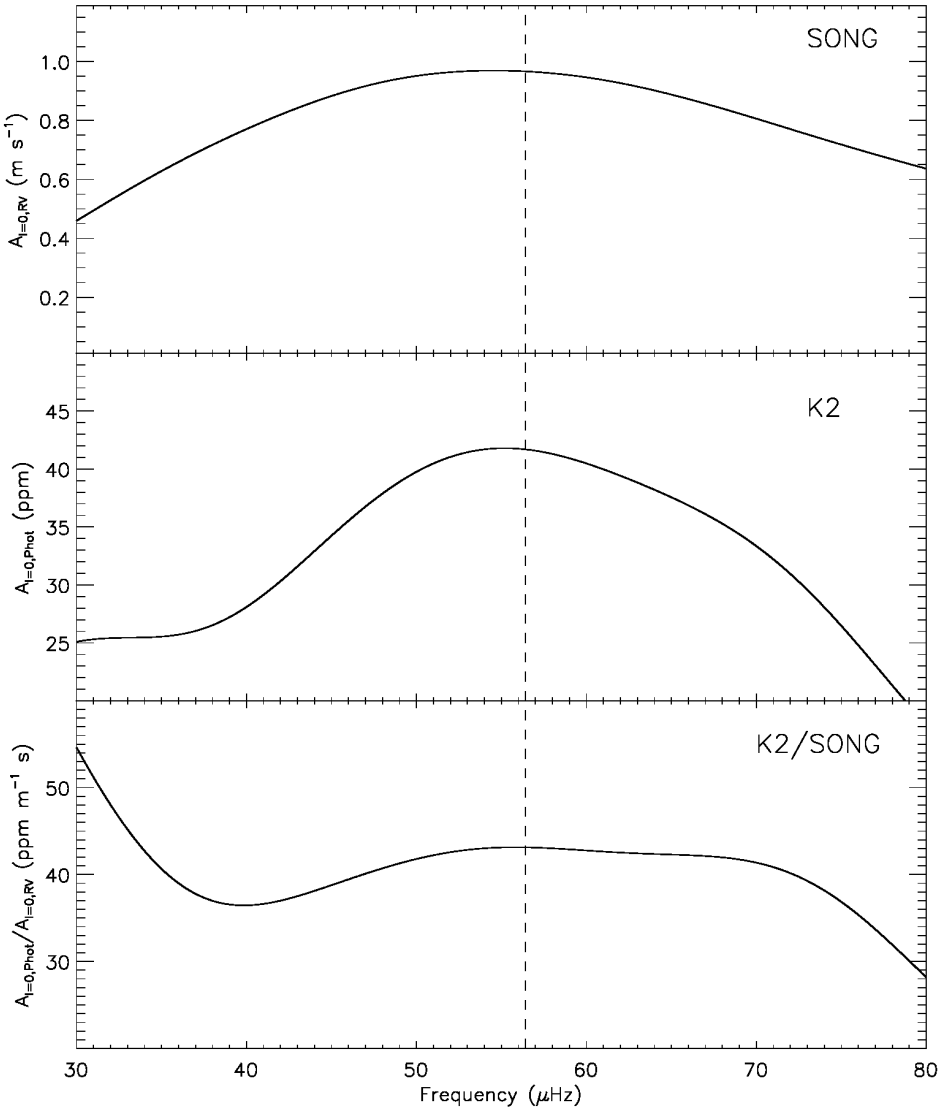
Eight clump stars in NGC6811 (Arentoft et al. 2017)

Amplitude ratio between photometry and spectroscopy:

Amplitude per radial mode
(Kjeldsen et al. 2008)

Amplitude ratio as a function of frequency;
Procyon (Huber et al. 2011), Sun

Note: SONG and K2 data non-simultaneous…



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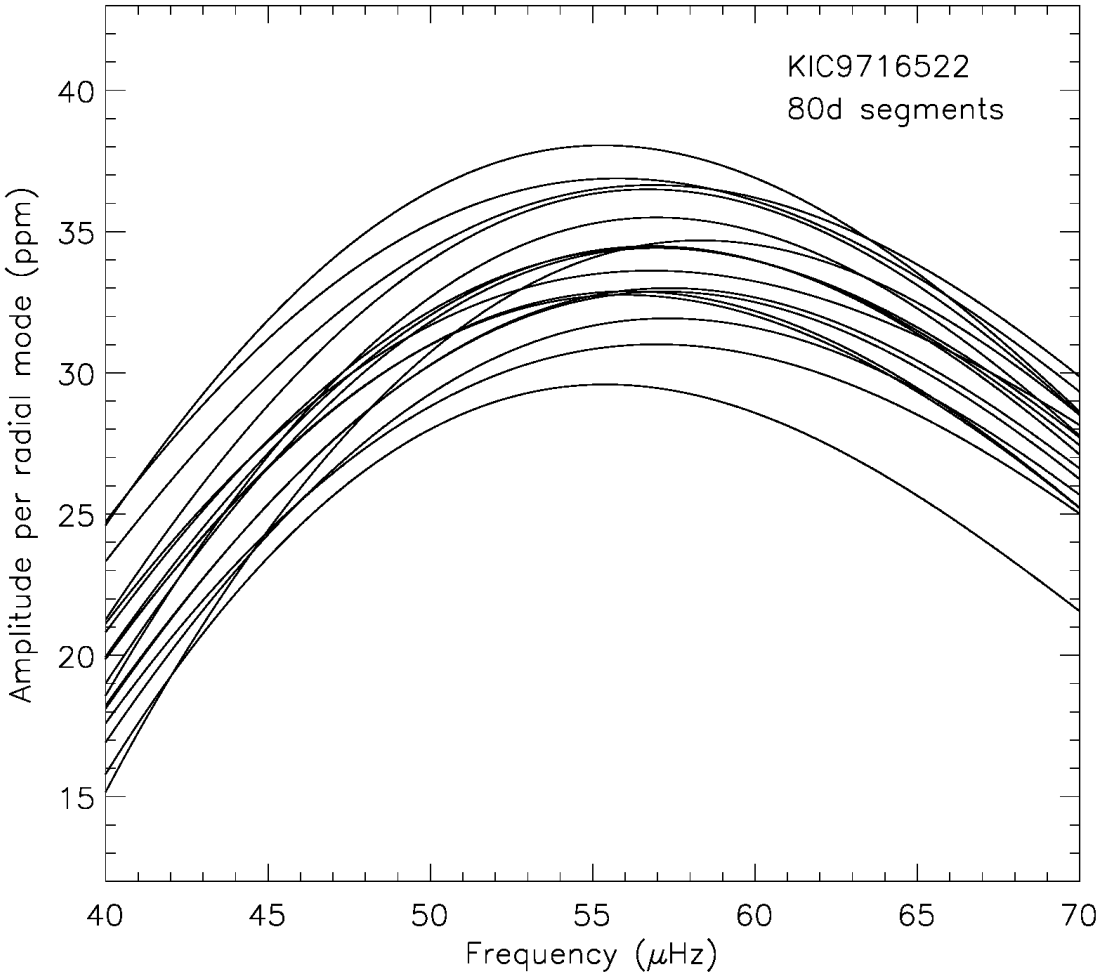

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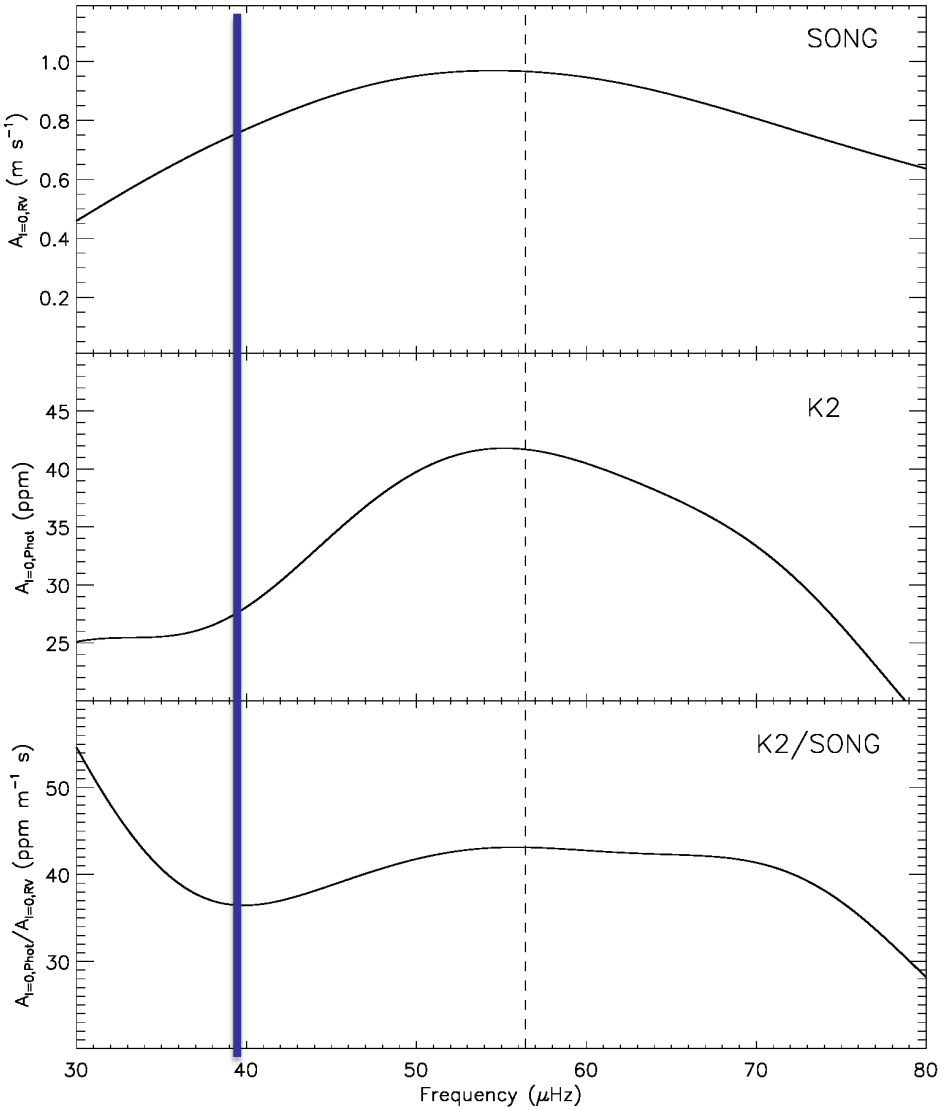

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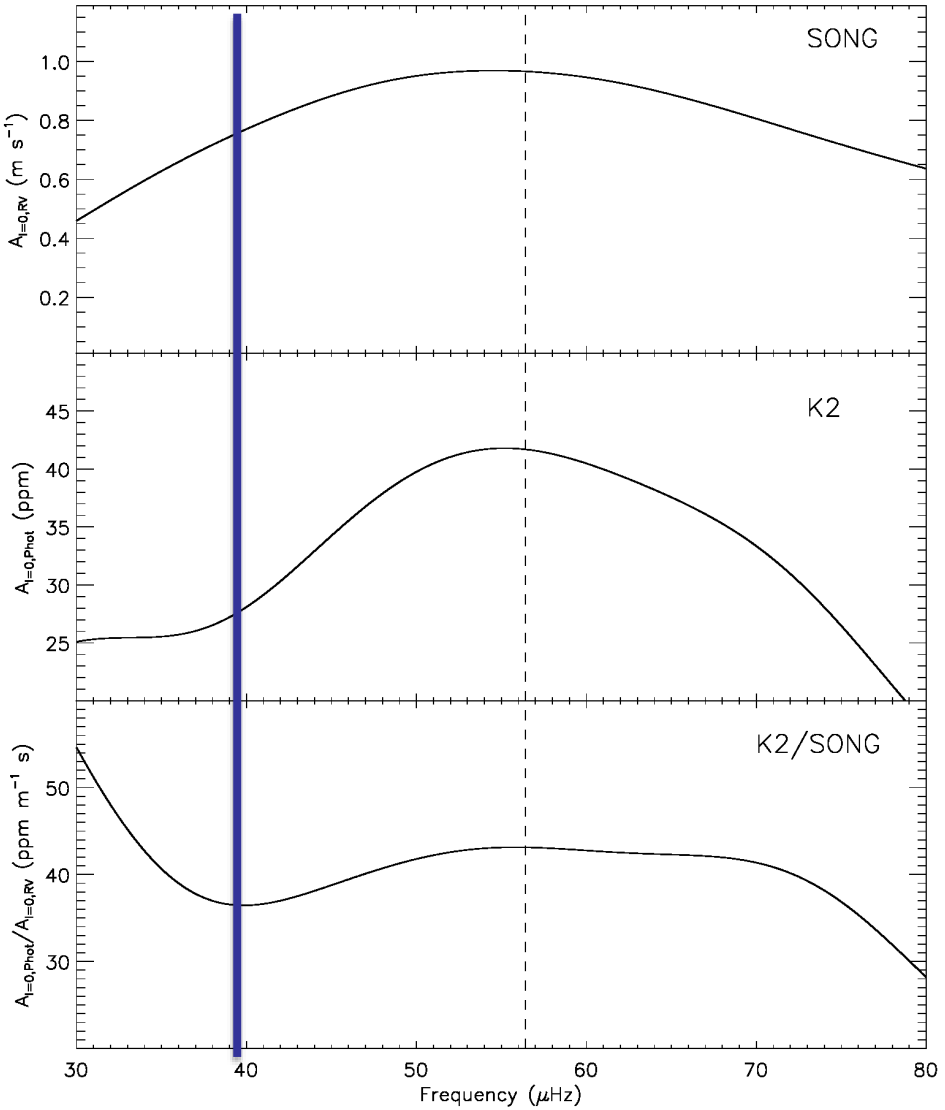

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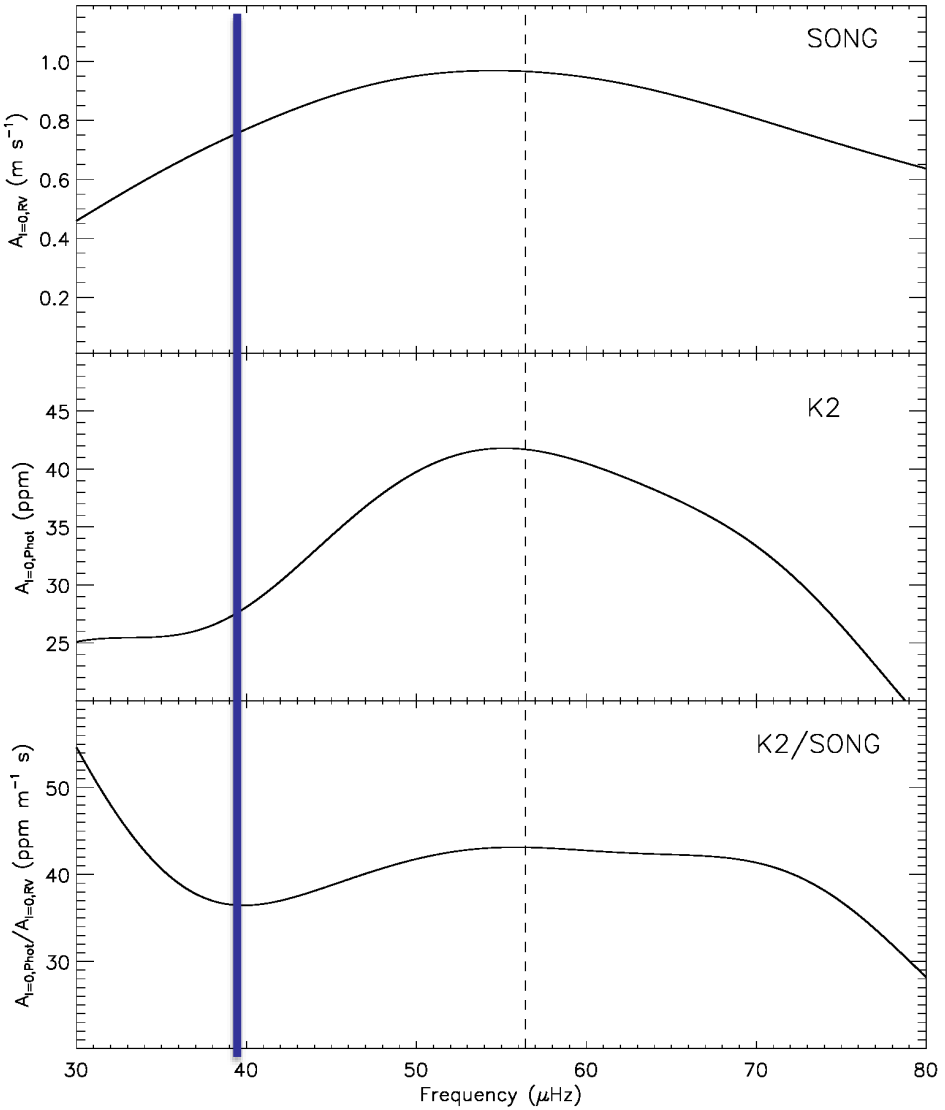

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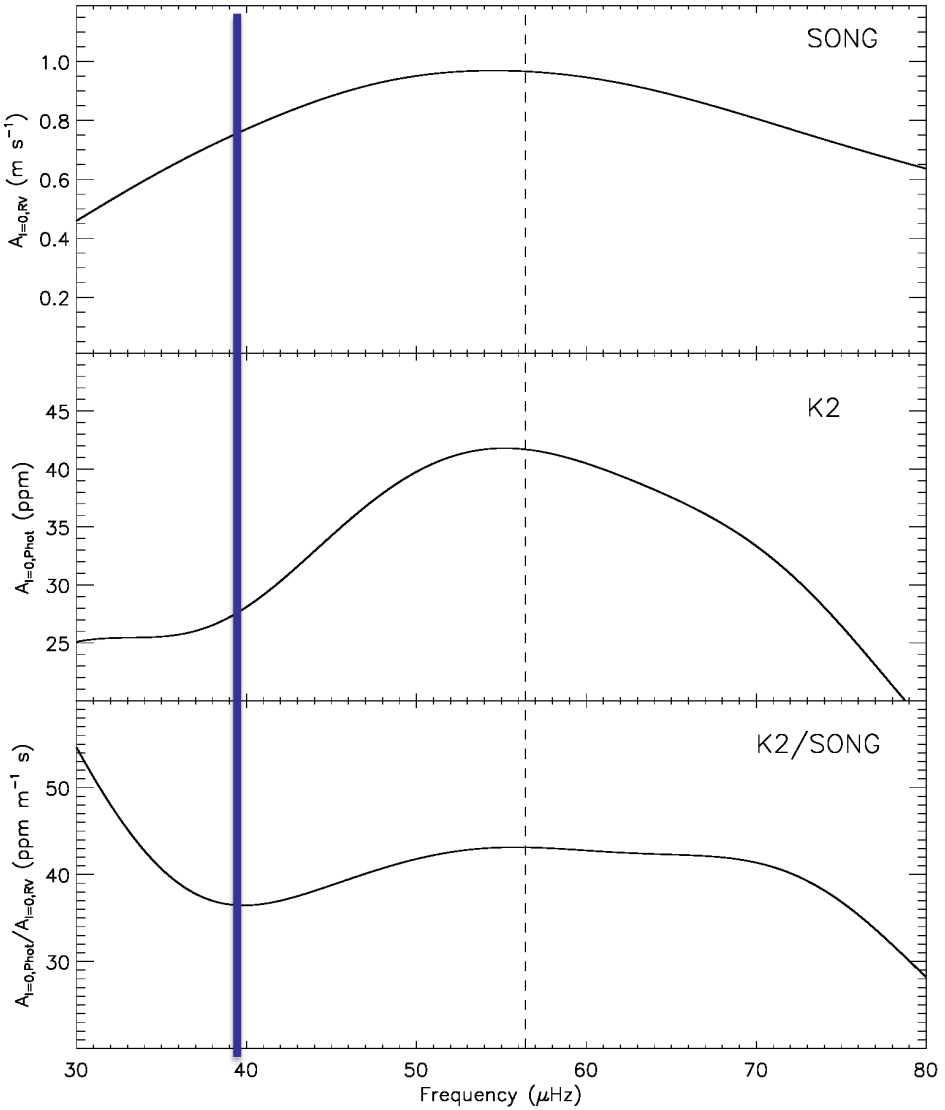
See Günthers talk this afternoon..



Fresh model results from Victor Silva Aguirre (Aarhus),
Fitting asteroseismic parameters + existing photometry
with BASTA models:

Distance: 44.287 pc *(cluster distance ~ 47 pc)*

Radius: 12.16 R_{sun} *(interferometry: 12.06 +/- 0.16 R_{sun})*

Age: $600^{+100}_{-50}\ Myr$ *(cluster age ~ 650 Myr)*

Evolutionary stage: Most likely RGB

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Thank you for your attention and stay tuned for the paper!