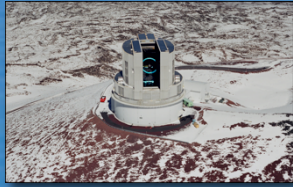




# G型巨星の星震学

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坪井優介  
神戸栄治  
佐藤文衛

2009年8月20日



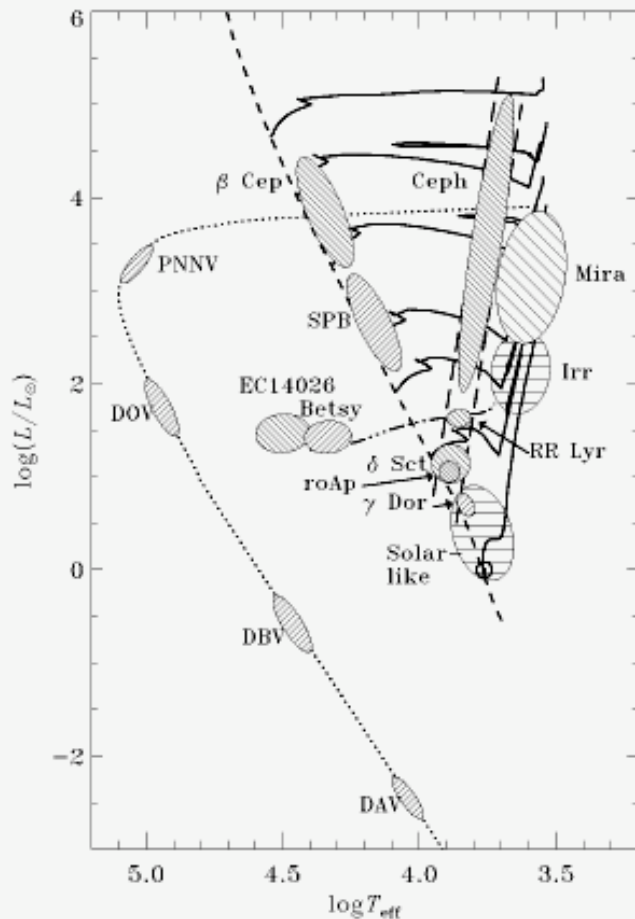
# 目的

## 振動情報から内部構造を知る

太陽から太陽型矮星 ( $\alpha$  Cen A,B, 70 Oph)  
準巨星、巨星へ

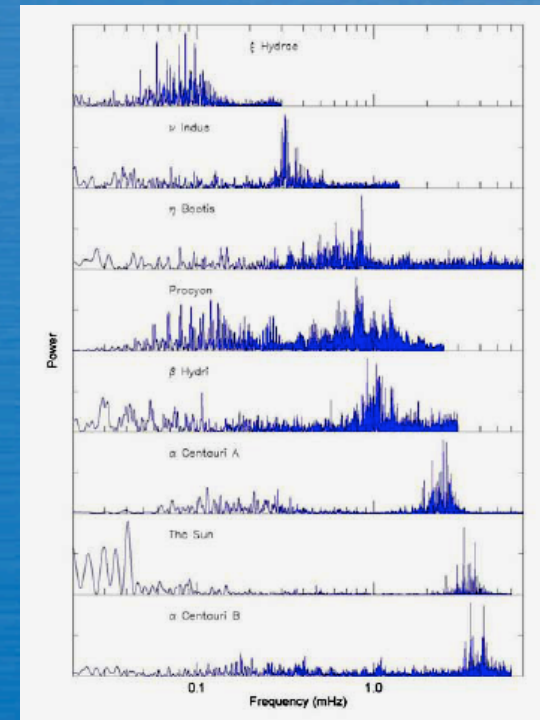
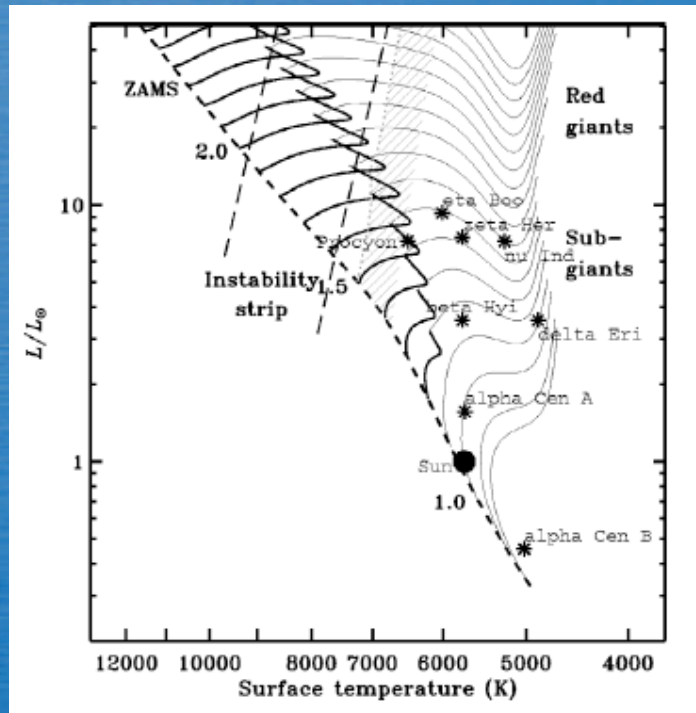
## 励起機構の究明

乱流運動による励起は巨星でも有効か





# 晩期型星の振動観測の現状



giants

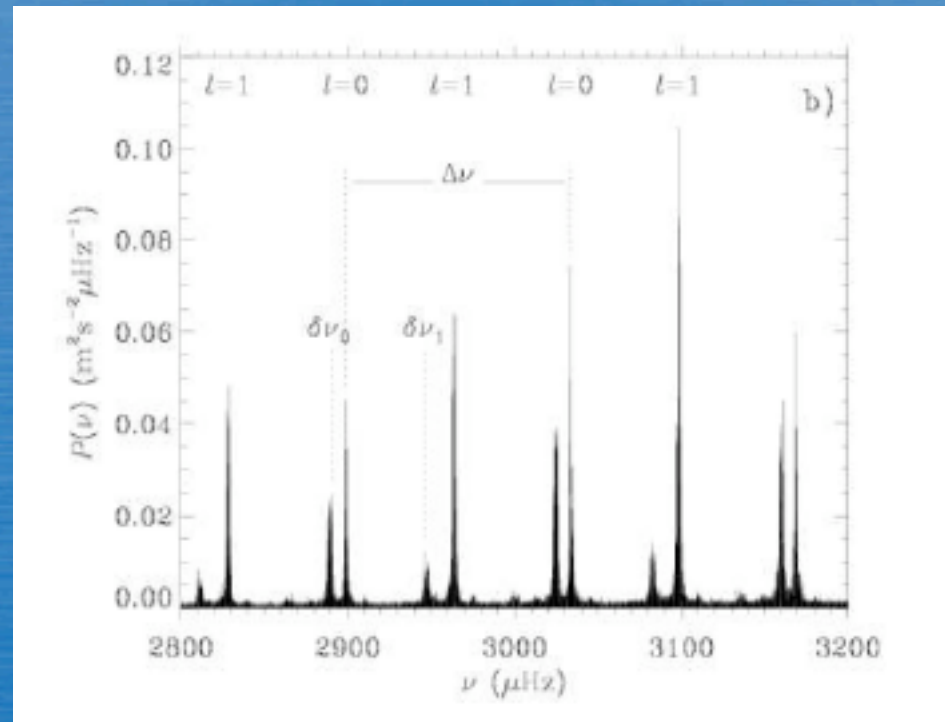
subgiants

dwarfs

G型巨星(中質量星)の観測提案



## 振動の特徴



$$\nu_{nl} = \Delta\nu_0 \left( n + \frac{l}{2} + \epsilon \right) - l(l+1)D_0$$



# $\alpha$ Cen A at VLT and AAT (Butler et al. 2004)

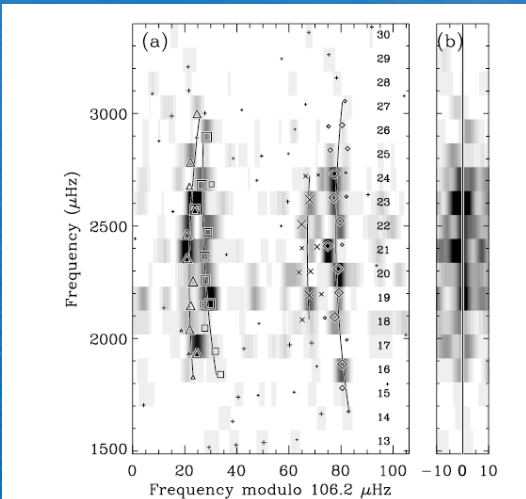
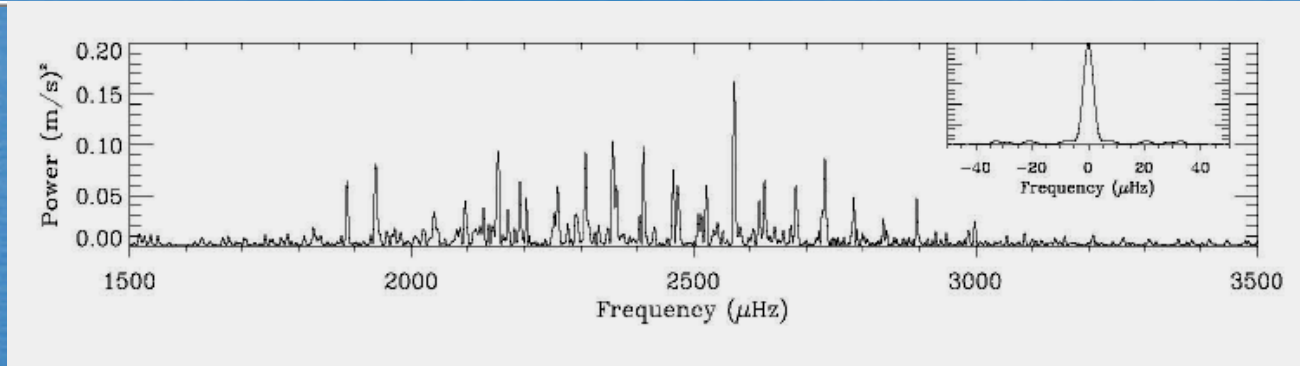
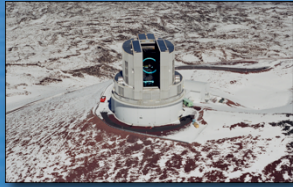
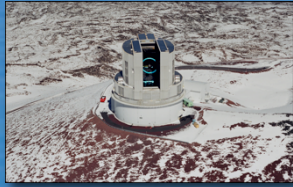


FIG. 4.—(a) Gray scale shows the power spectrum in echelle format (without smoothing), and the symbols show the peaks extracted by iterative sine-wave fitting:  $l = 0$  (squares),  $l = 1$  (diamonds),  $l = 2$  (triangles),  $l = 3$  (crosses), and other peaks (plus signs). The sizes of the symbols are proportional to the amplitudes of the peaks. The curves show fits to the frequencies, as described in the text, and the numbers up the right side show the  $n$ -value of each order. (b) The power summed over the four ridges ( $l = 0-3$ ) after first subtracting from each one the frequency predicted by eqs. (4)–(7).



## 観測天体(G型巨星)

Parameter	$\zeta$ Hya	$\eta$ Her	11Com	$\kappa$ CrB	$\epsilon$ Tau
HD number	76294	150997	107383	142091	28305
Spectral type	G8III-IV	G8III-IV	G8III	K0III-IV	K0III
$V$	3.11	3.48	4.72	4.79	3.53
$M_V$	-0.24	0.75	-0.55	2.29	0.09
B-V	1.00	0.90	0.99	0.99	1.01
$\pi$ (mas)	21.6 $\pm$ 0.99	29.11 $\pm$ 0.52	9.04 $\pm$ 0.86	32.1 $\pm$ 0.61	21.0 $\pm$ 0.82
distance (pc)	46.2	34.3	112	31.1	47.5
[Fe/H]	-0.11	-0.15	-0.28	+0.10	+0.13
$T_{eff}$ (K)	4844 $\pm$ 20	5045 $\pm$ 20	4841 $\pm$ 15	4877 $\pm$ 25	4883 $\pm$ 30
log $g$	2.30 $\pm$ 0.06	2.79 $\pm$ 0.06	2.51 $\pm$ 0.05	3.21 $\pm$ 0.08	2.57 $\pm$ 0.09
$v_t$ (km/s)	1.41 $\pm$ 0.08	1.26 $\pm$ 0.08	1.38 $\pm$ 0.08	1.04 $\pm$ 0.09	1.46 $\pm$ 0.10
log $L$ ( $L_\odot$ )	2.12	1.70	2.25	1.11	1.99
log $R$ ( $R_\odot$ )	1.22 $\pm$ 0.03	0.97 $\pm$ 0.02	1.28 $\pm$ 0.05	0.70 $\pm$ 0.02	1.14 $\pm$ 0.03
$M$ ( $M_\odot$ )	2.93 $\pm$ 0.12	2.41 $\pm$ 0.14	3.14 $\pm$ 0.21	1.51 $\pm$ 0.16	2.84 $\pm$ 0.16
log age (yr)	8.60 $\pm$ 0.07	8.80 $\pm$ 0.13	8.49 $\pm$ 0.11	9.43 $\pm$ 0.21	8.62 $\pm$ 0.13



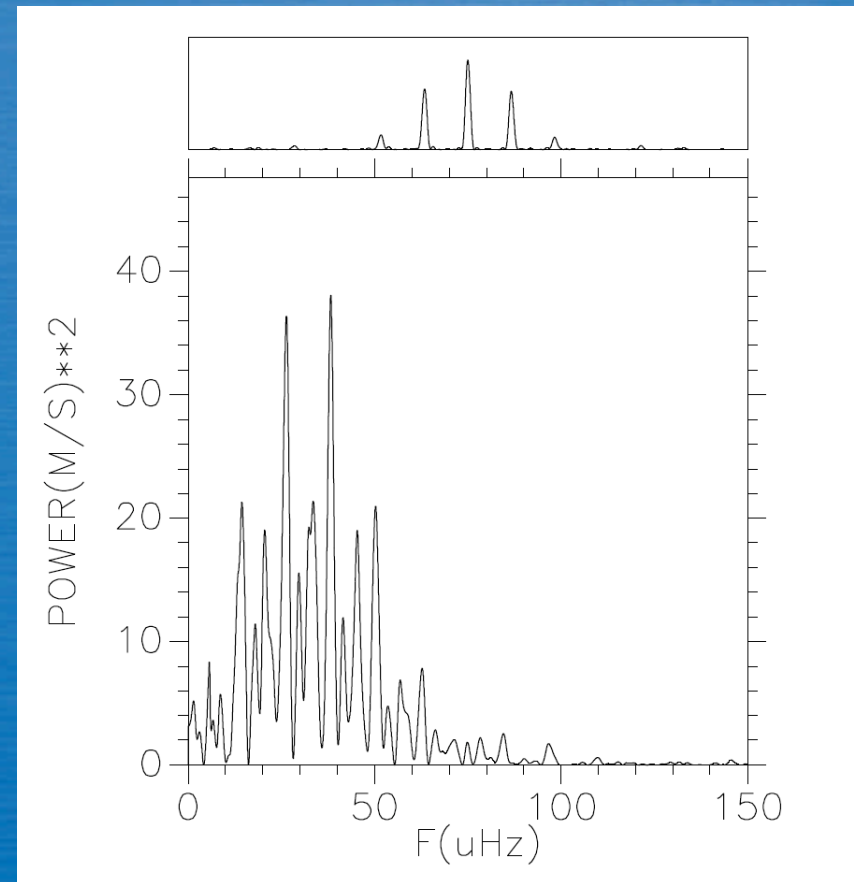
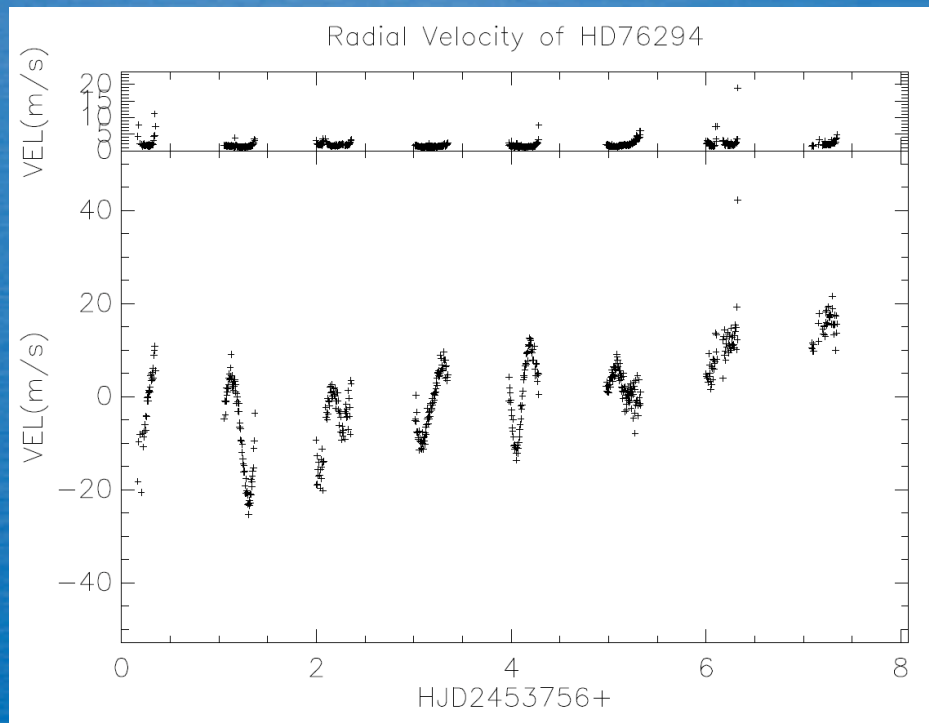
## 系外惑星を持つ天体

Parameter	11 Com	$\kappa$ CrB	$\epsilon$ Tau
P (days)	$326.03 \pm 0.32$	$1208 \pm 30$	$594.9 \pm 5.3$
e	$0.231 \pm 0.005$	$0.146 \pm 0.08$	$0.151 \pm 0.023$
a (AU)	$1.29 \pm 0.05$	27	$1.93 \pm 0.03$
$M_p \sin i (M_J)$	$19.4 \pm 0.05$	1.8	$7.6 \pm 0.2$

振動との関連を調べる



ζ Hya

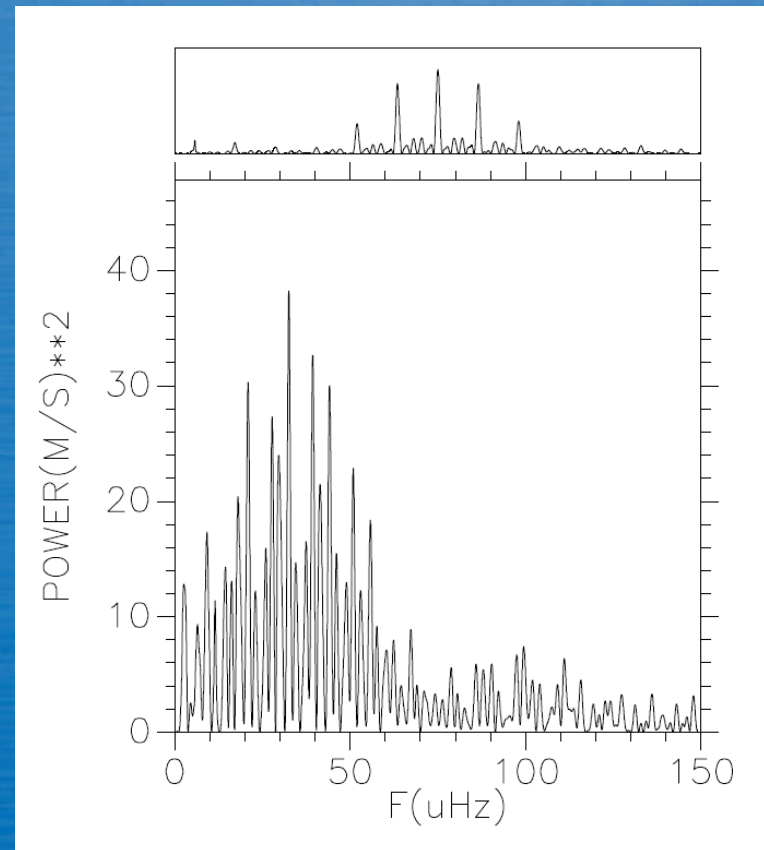
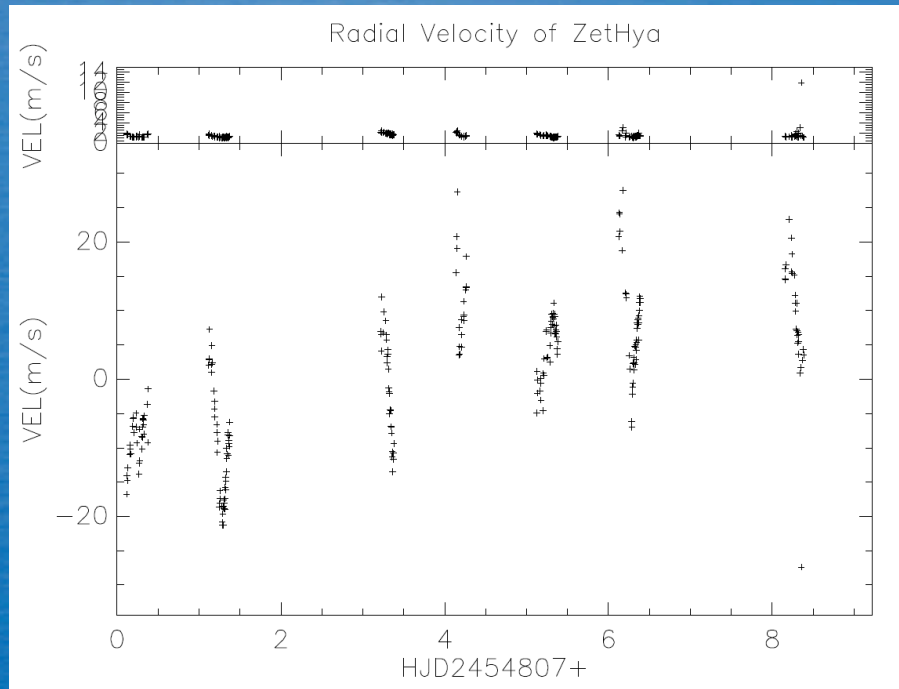


2006.01.20-27

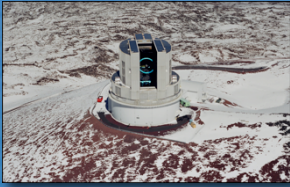




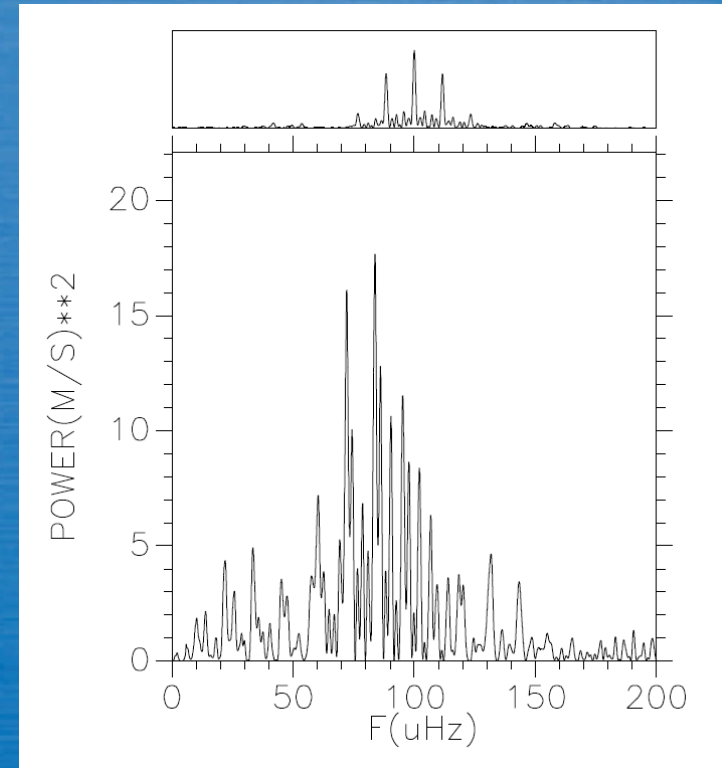
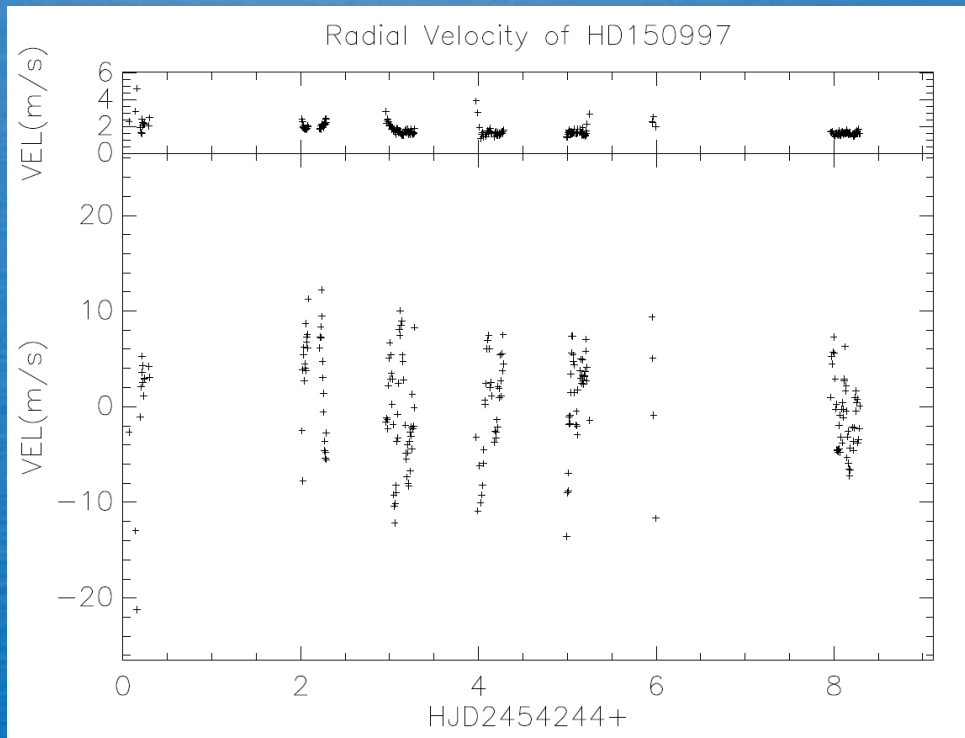
$\zeta$  Hya



2008.12.06-14



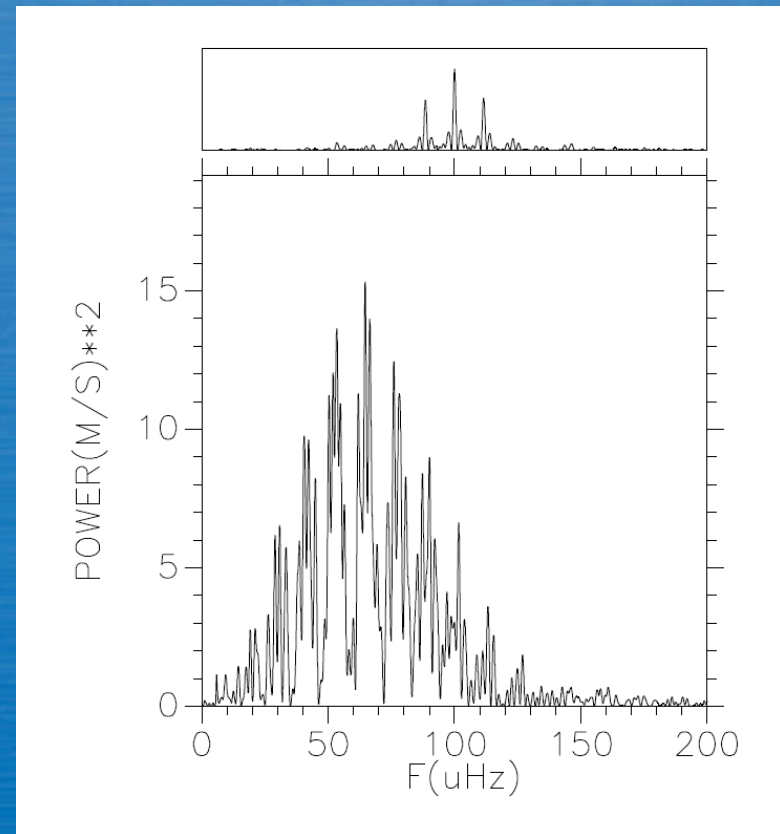
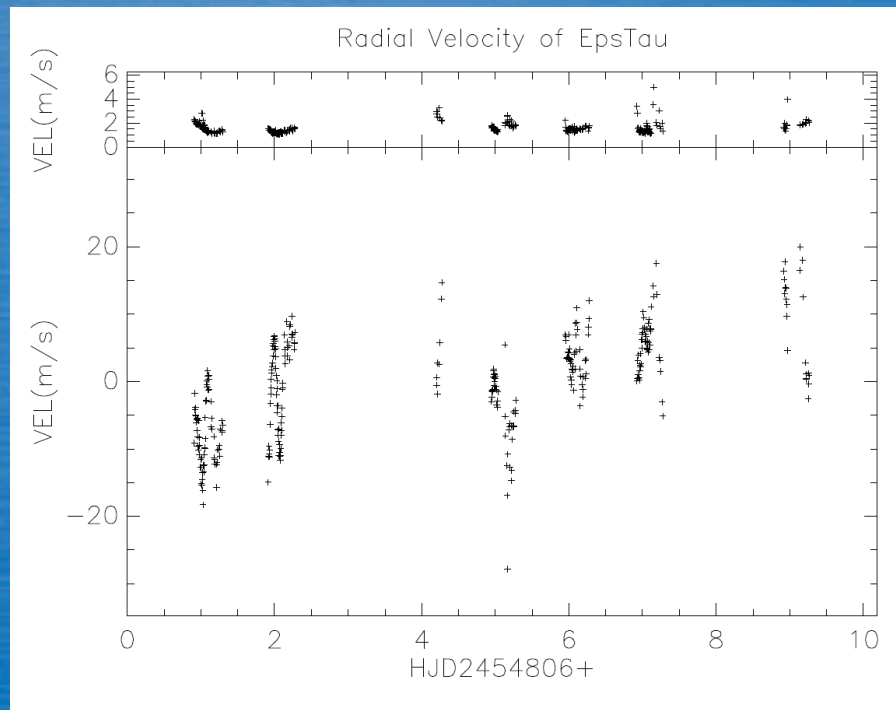
$\eta$  Her



2007.05.23-31



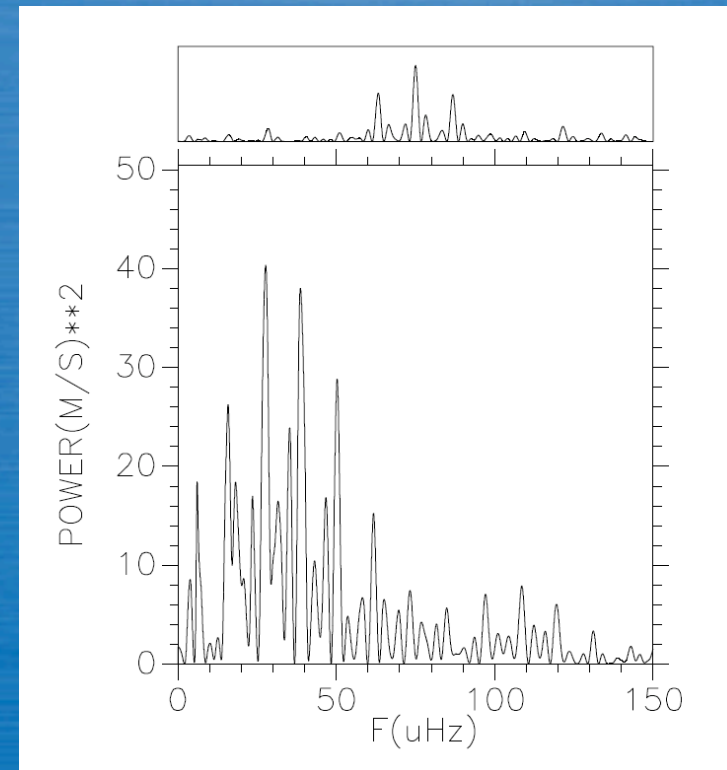
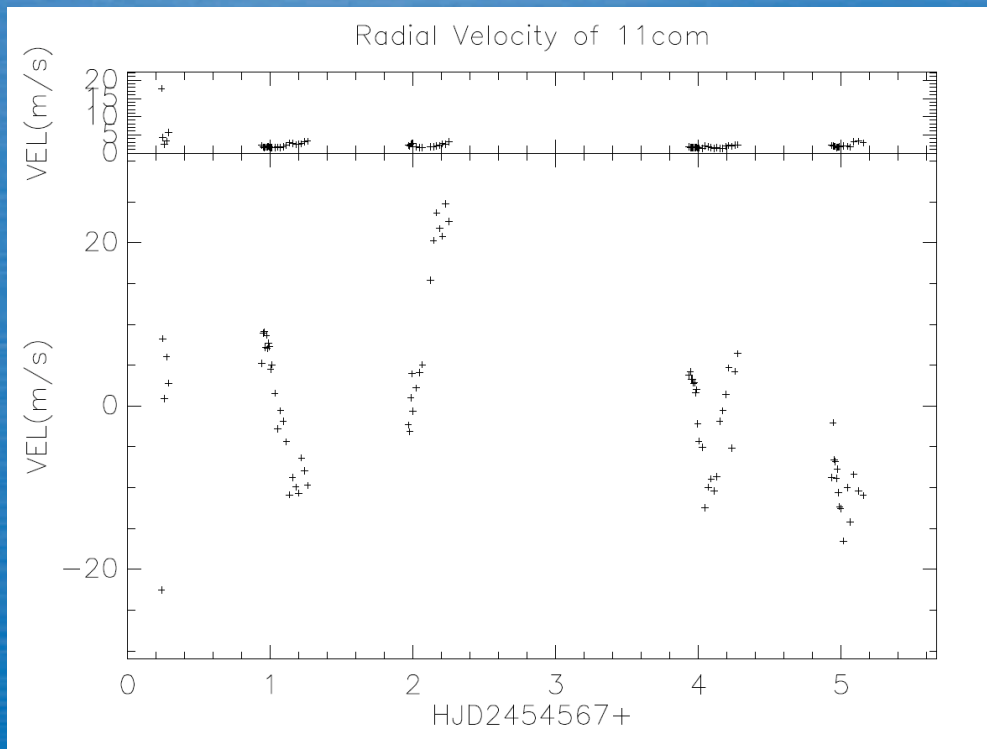
$\epsilon$  Tau



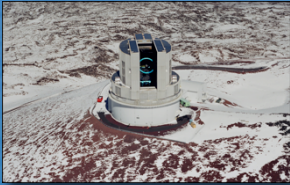
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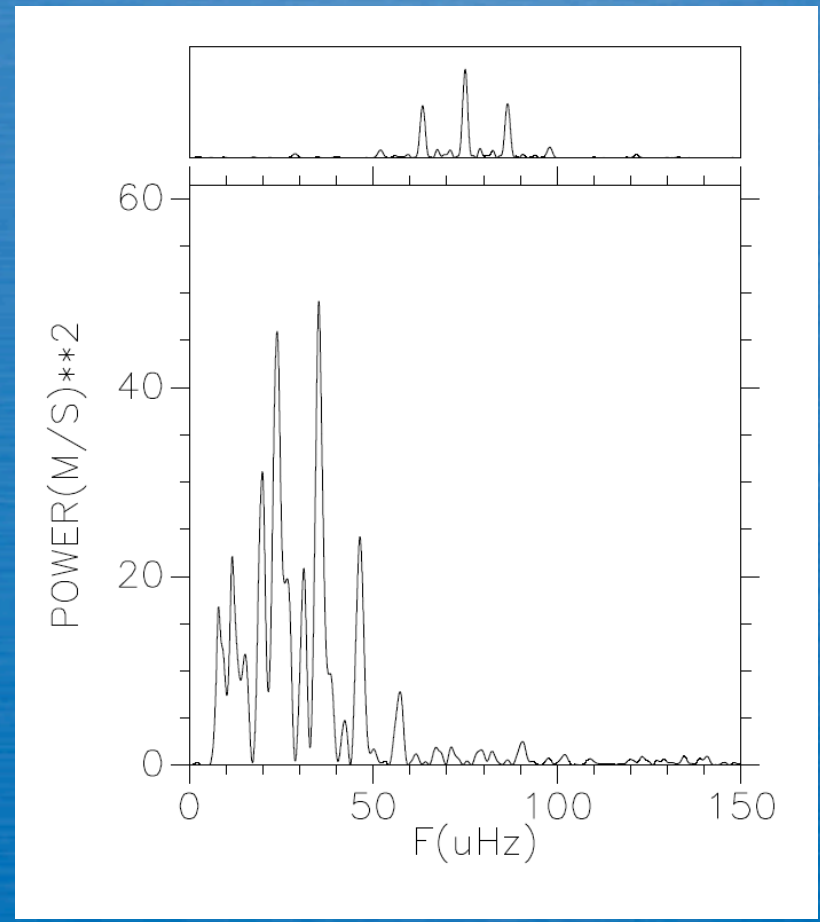
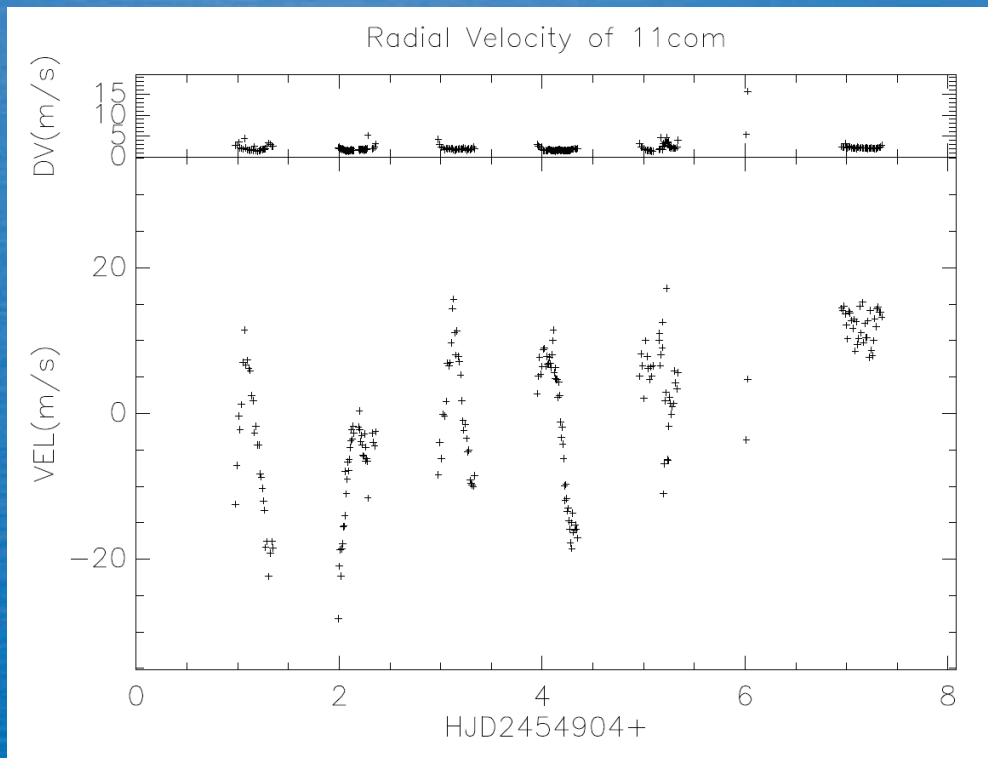
# 11 Com-a



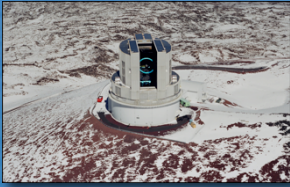
2008.04.10-15



# 11 Com-b



2009.04.14-20

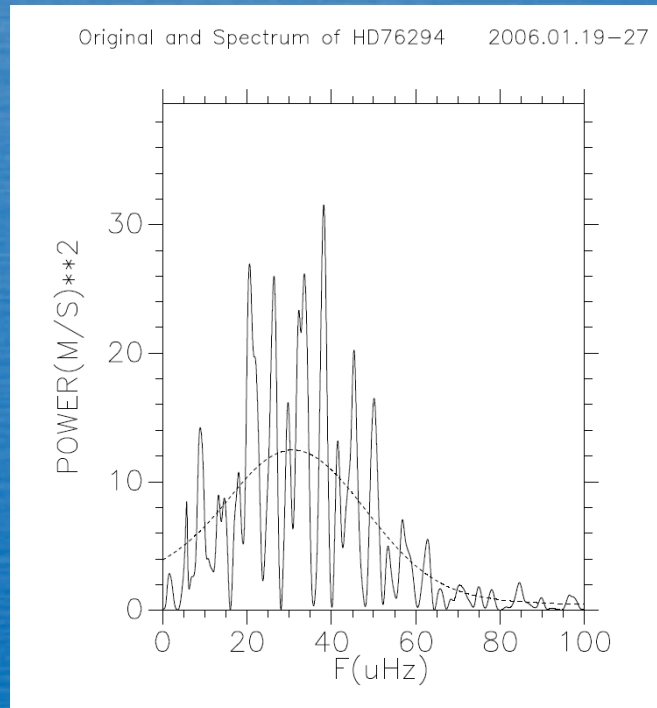


$v_{max}$

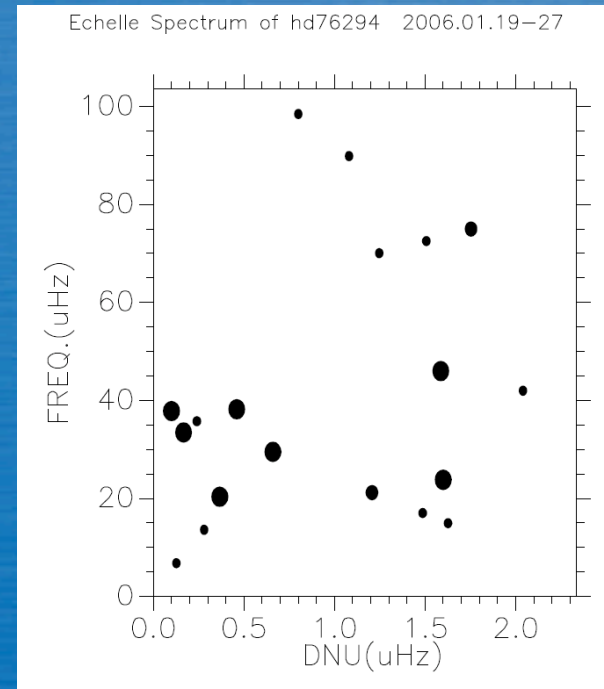
と

$\Delta\nu$

# $\zeta$ Hya -a



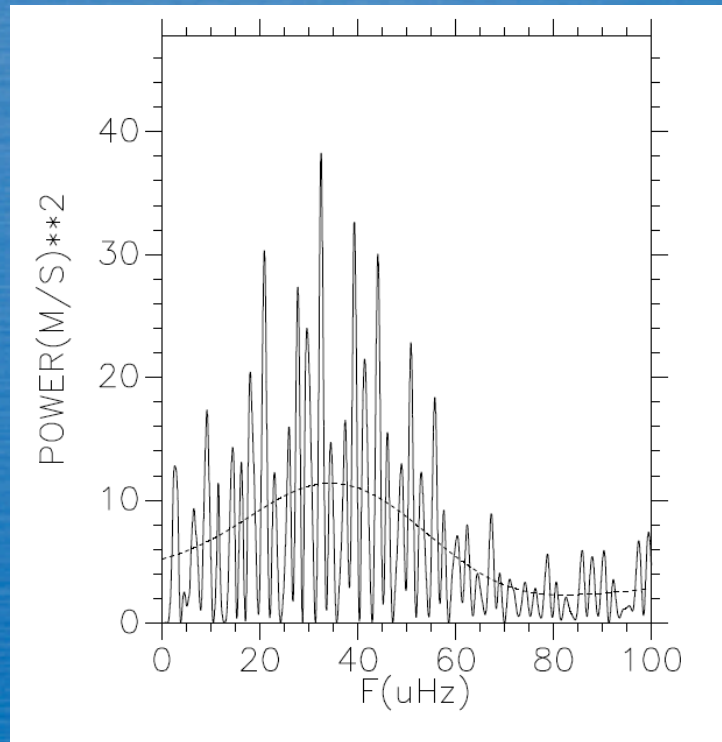
30.8  $\mu$ Hz



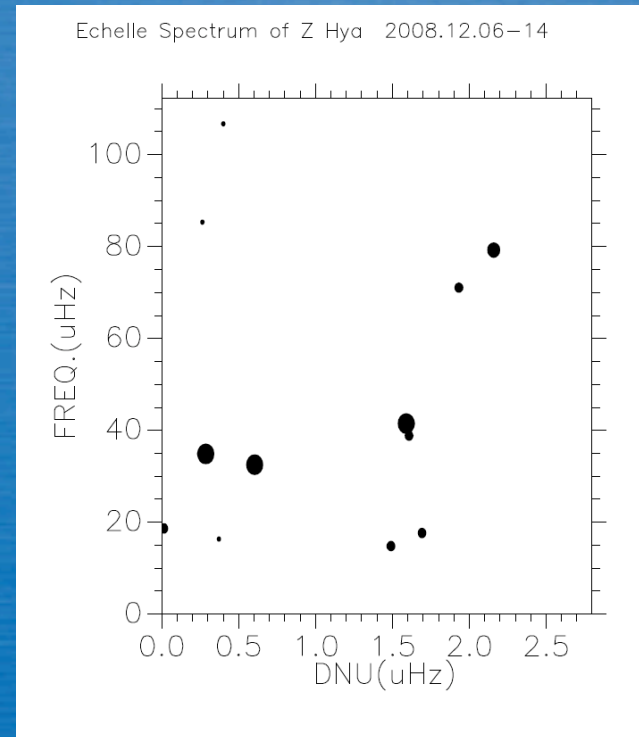
2.22  $\mu$ Hz



# $\zeta$ Hya -b



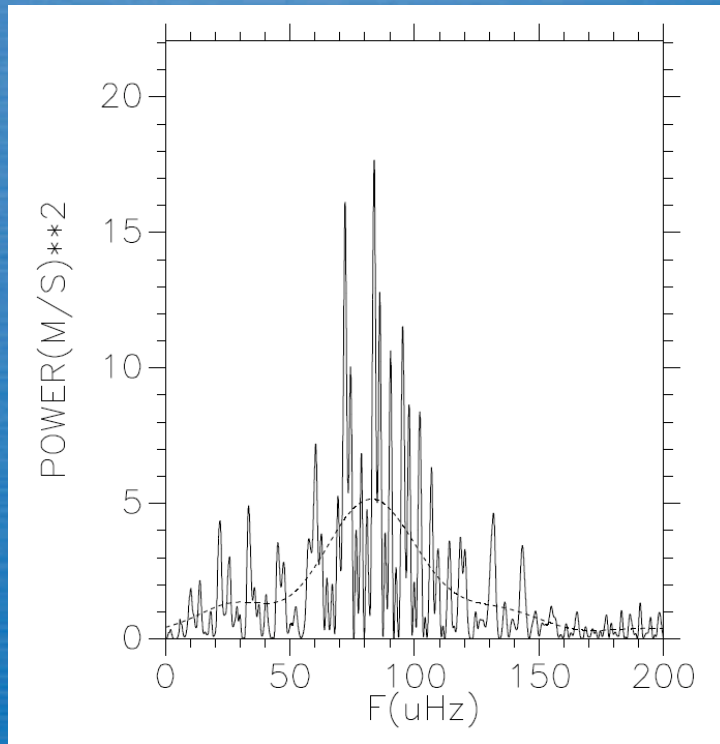
34.4 uHz



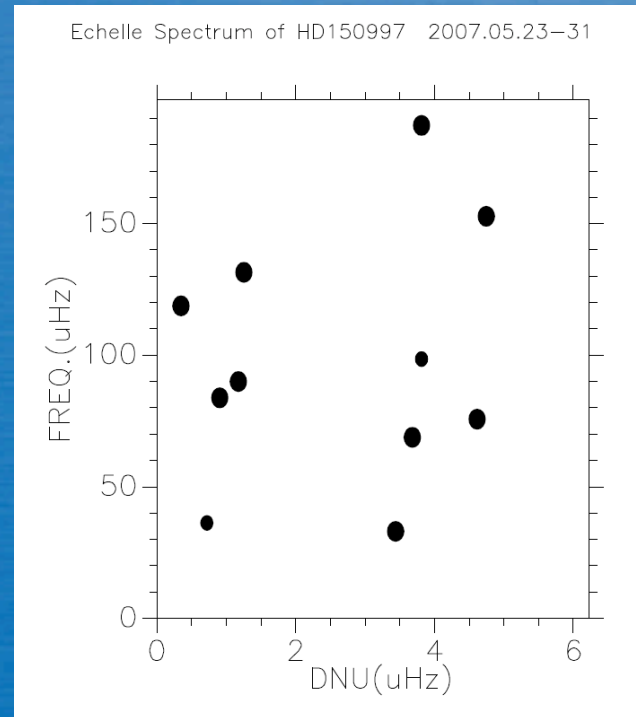
2.66 uHz



# $\eta$ Her



82.8 uHz



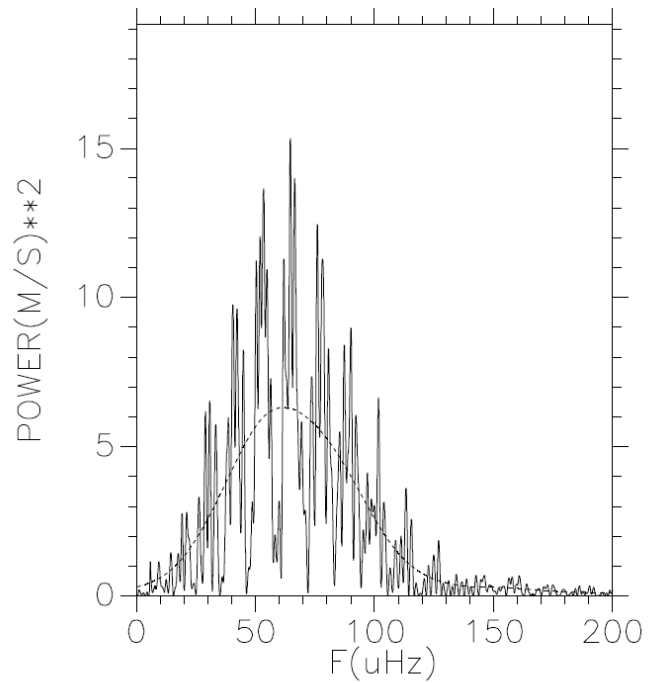
5.92 uHz





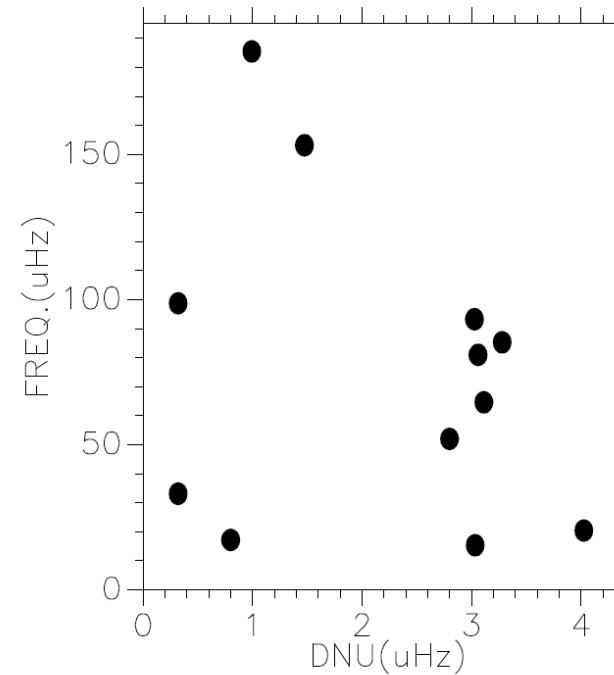
# $\epsilon$ Tau

Original and Spectrum of EpsTau 2008.12.06-14

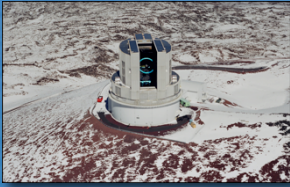


61.9 uHz

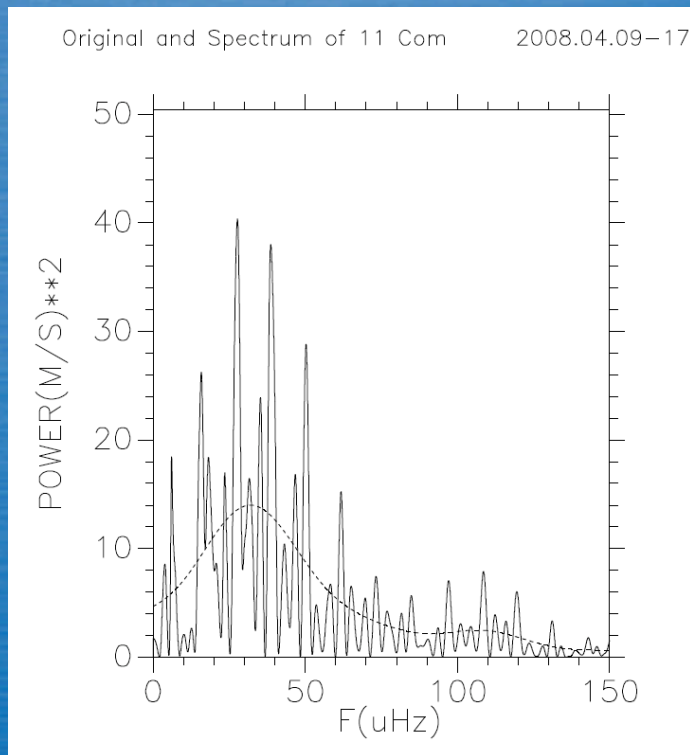
Echelle Spectrum of etau 2008.12.06-14



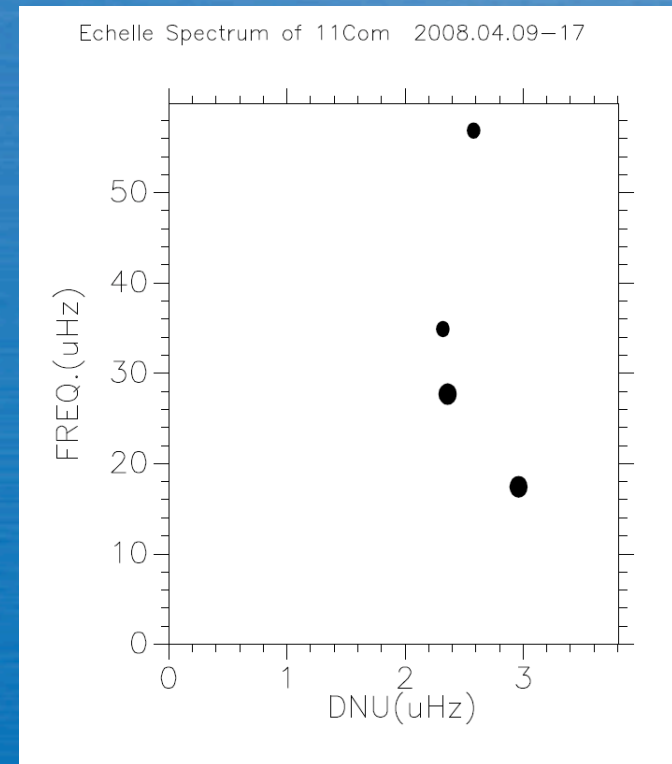
4.10 uHz



# 11 Com-a



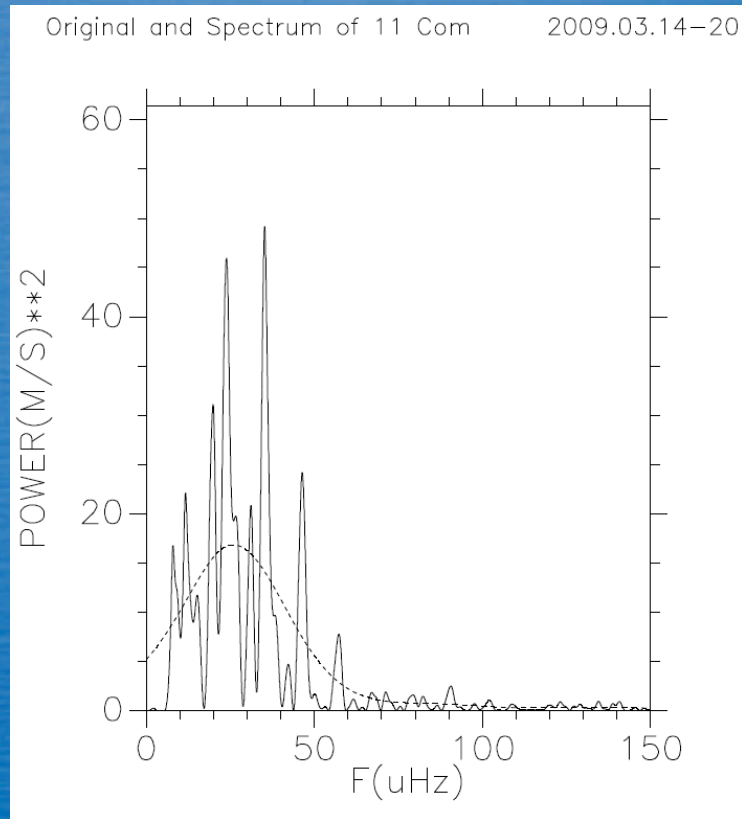
32.0 uHz



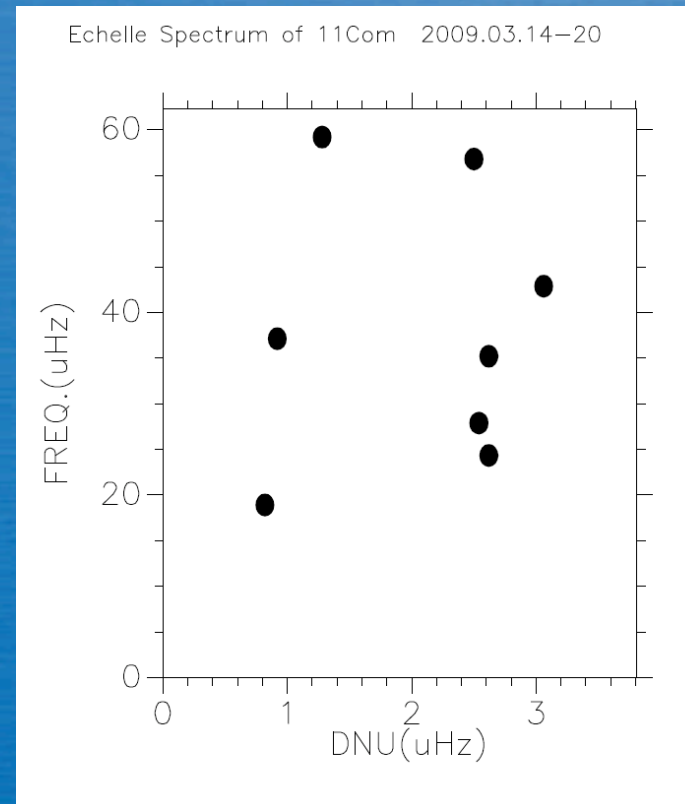
3.62 uHz



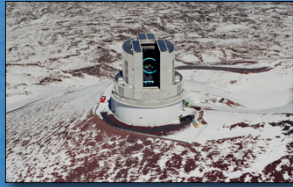
# 11 Com-b



25.9 uHz



3.62 uHz

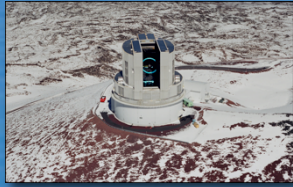


## 観測のまとめ

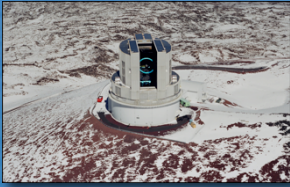
Star	$\nu_{max}$	$\Delta\nu$
$\zeta$ Hya	30.8	2.22
	34.4	2.66
$\eta$ Her	82.8	5.92
$\epsilon$ Tau	61.9	4.10
11 Com	32.0	3.62
	25.9	3.62



# 太陽型振動星のまとめ



Star	$T_e$	$\log g$	$\nu_{max}$ ( $\mu Hz$ )	$\Delta\nu$ ( $\mu Hz$ )	$\pi$ ( $mas$ )	$\theta$ ( $mas$ )	$R/R_\odot$
Dwarfs							
Sun	5777	4.44	3050	134.9			1.00
$\alpha$ CenA	5790	4.32	2360	105.5	754.85	8.511	1.21
$\alpha$ CenB	5260	4.51	4090	161.1	796.77	6.001	0.81
$\beta$ Vir	6128	4.09	1400	72.1	91.50	1.45	1.70
70 OphA	5314	4.51	4800	161.8	196.66		
HD49933	6522	4.00	1700	88.7	33.68		
Subgiants							
Procyon	6612	4.00	900	53.6	284.52	5.446	2.06
$\eta$ Boo	6120	3.79	750	39.9	87.77	2.2690	2.78
$\zeta$ HerA	5820	3.76	700		93.31	2.367	2.73
$\nu$ Ind	5381	3.43	320	25.1	34.84		
$\beta$ Hyi	5964	4.02	1000	57.2	134.07	2.22	1.78
$\mu$ Ara	5813	4.25	1960	90.0	64.48		
$\delta$ Eri	5100	3.80	700	43.8	110.62	2.39	2.32
$\kappa$ CrB	4877	3.21	180		32.79		
Giants							
$\zeta$ Hya	4844	2.30	31	2.22	19.49	3.24	17.9
	4844	2.30	34	2.66	19.49	3.24	17.9
$\eta$ Her	5045	2.79	83	5.92	30.02	2.57	9.2
$\epsilon$ Tau	4901	2.64	62	4.10	22.27	2.671	13.7
11 Com	4841	2.51	32	3.62	11.23		
	4841	2.51	26	3.62	11.23		
$\zeta$ Hya	5000	2.85	86	7.11	25.14	2.386	10.2
$\epsilon$ Oph	4931	2.69	58	5.3	30.62	2.94	10.3
$\eta$ Ser	4972	3.12	130		53.93	2.98	5.94
$\beta$ Gem	4904	2.84	87		96.52	7.96	8.86
$\alpha$ Ari	4504	2.20	20.3		49.55	6.89	14.9
$\beta$ Oph	4550	2.55	39	4.00	39.86	4.63	12.5
$\iota$ Dra	4526	2.64	45		32.23	3.73	12.4
$\alpha$ Boo	4320	1.50	3.5	0.83	88.83	21.373	25.9
$\gamma$ Dra	3960	1.30	2.9		21.15	9.86	50.1



## スケール則

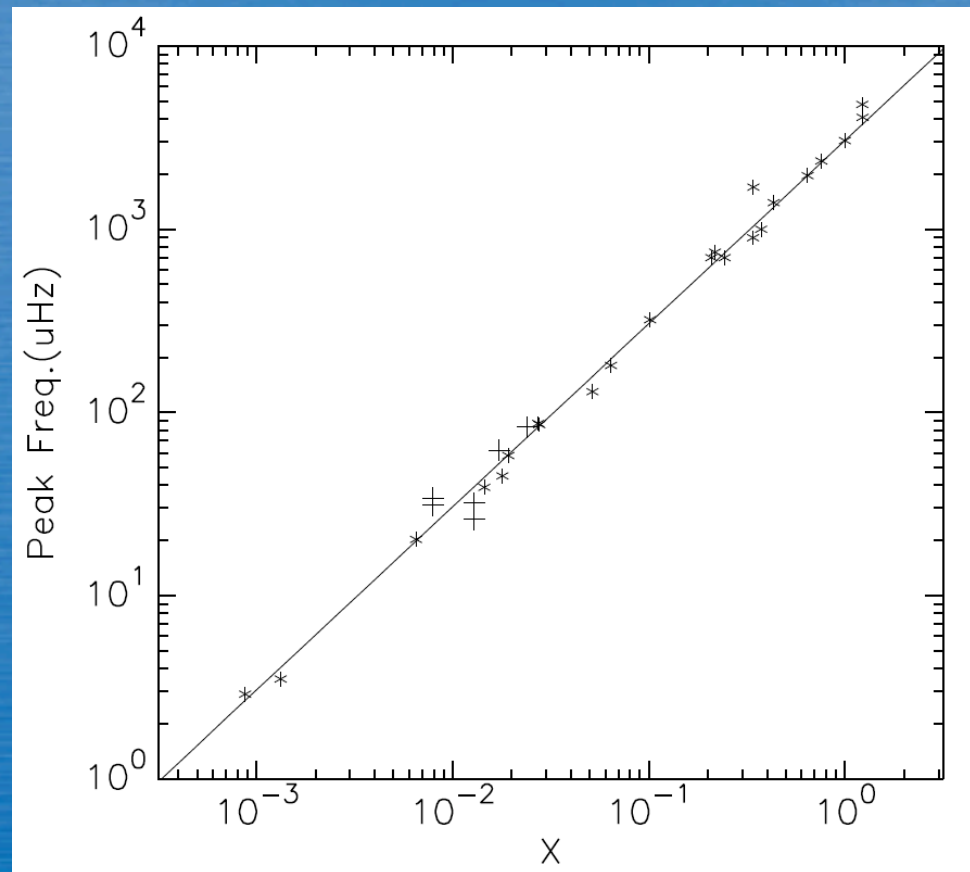
$$\nu_{max} = 3050 \left( \frac{g}{g_{\odot}} \right) \left( \frac{Te}{Te_{\odot}} \right)^{-\frac{1}{2}} \quad (\mu Hz) , \quad (1)$$

$$\Delta\nu = 134.9 \left( \frac{g}{g_{\odot}} \right)^{\frac{1}{2}} \left( \frac{R}{R_{\odot}} \right)^{-\frac{1}{2}} \quad (\mu Hz) , \quad (2)$$

where  $\log g_{\odot} = 4.44$ , and  $Te_{\odot} = 5777K$  .

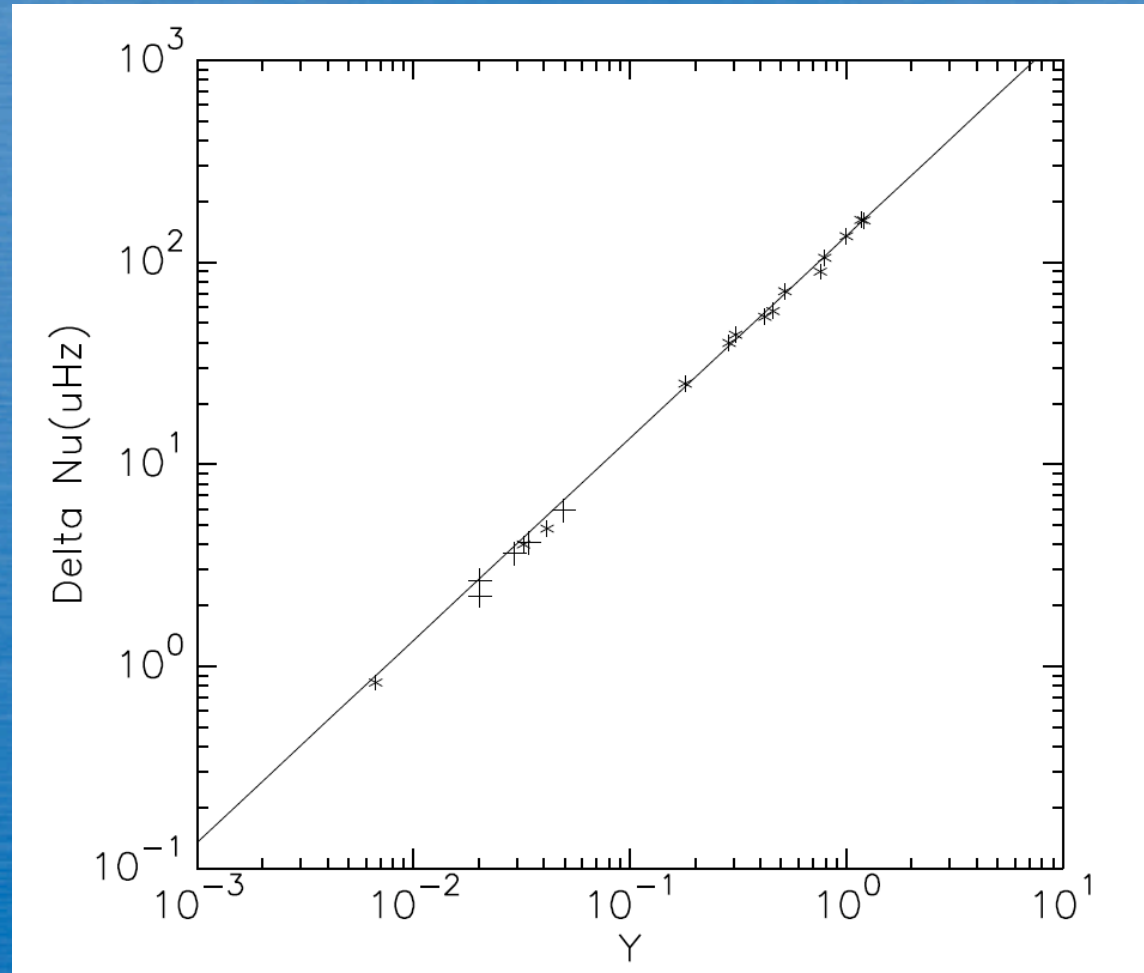


## $\nu_{\max}$ に対するスケール則





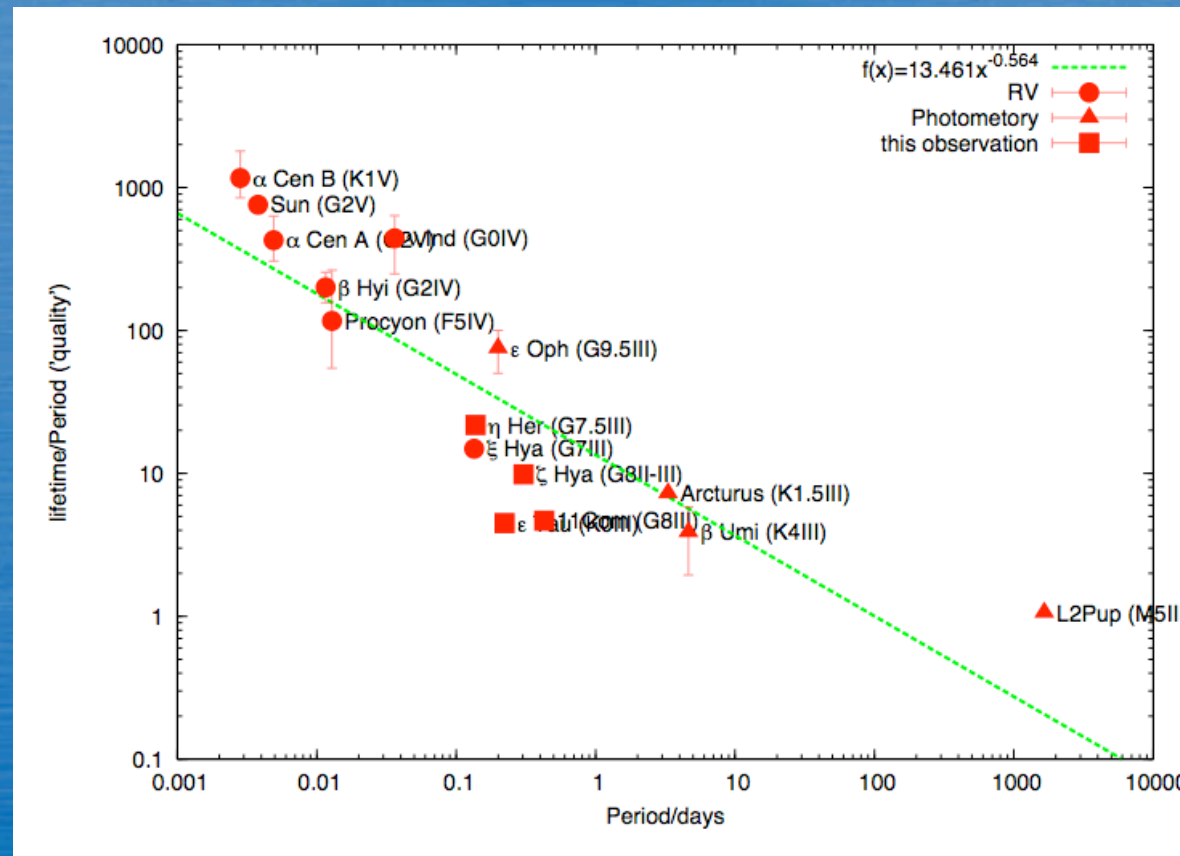
## $\Delta\nu$ に対するスケール則

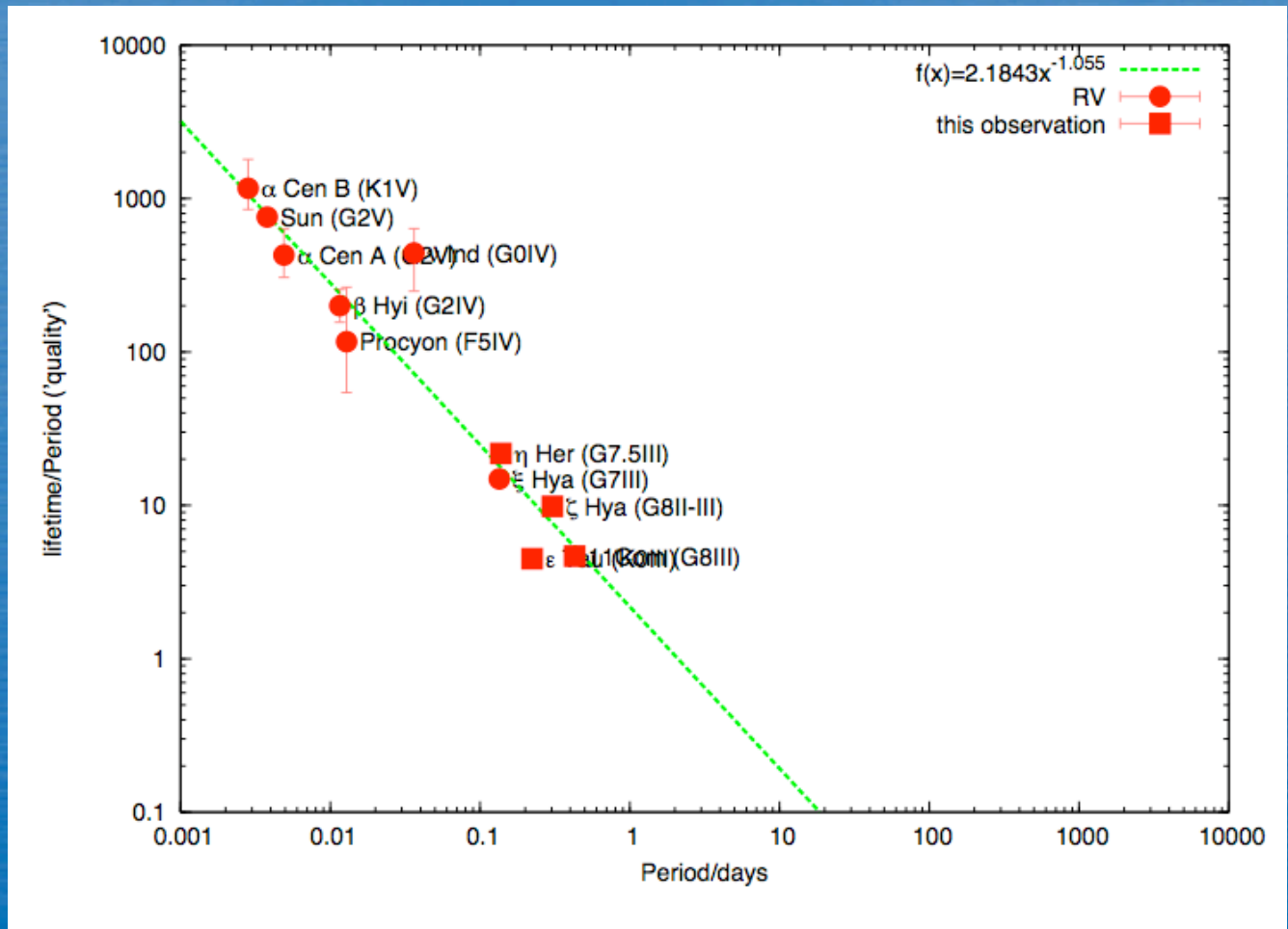
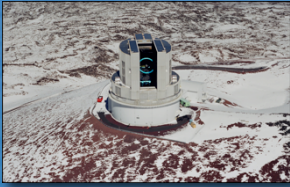


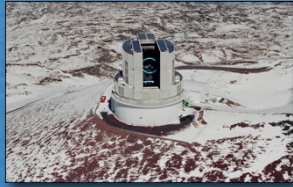




# Damping time







## 結論

- 1 2つの振動特性 ( $v_{\max}$ ,  $\Delta v$ ) はスケーリング則に従う
- 2 減衰係数と周期の関係は太陽型振動矮星の延長上にある
- 3 G型巨星の振動は 太陽型振動  
(ただし、常時励起されるモード数は矮星の場合ほど多くはない)
- 4 振動と惑星保有との関連は見られない

振動数のモデル計算と観測を比較する準備ができた