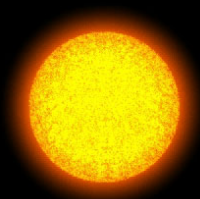
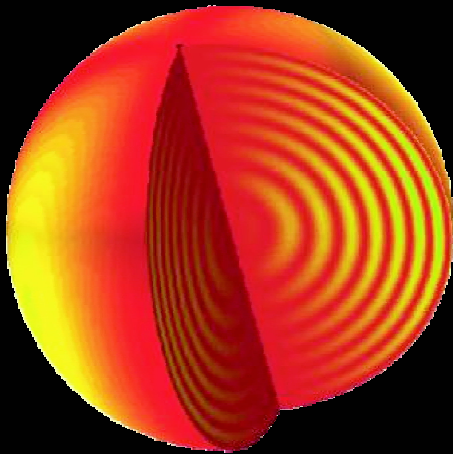


Oscillation properties in solar-like stars

Günter Houdek



Outlet

- ☀ Equations of solar structure and pulsation
- ☀ Pulsation amplitudes and phases in the solar atmosphere
- ☀ Activity cycle and oscillation properties

Equations of solar structure and stability

Equations of stellar (envelope) structure and stability

$$\frac{\partial p}{\partial m} = -\frac{1}{4\pi r^2} \left(\frac{Gm}{r^2} + \frac{\partial^2 r}{\partial t^2} \right)$$

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho}$$

$$c_p \frac{\partial T}{\partial t} - \frac{\tilde{\delta}}{\rho} \frac{\partial p_g}{\partial t} = -4\pi \frac{\partial}{\partial m} \left[r^2 (F_r + F_c) \right]$$

turbulent heat flux: $F_c = \rho c_p \overline{w\vartheta}$

turbulent velocity field: $\mathbf{u} = (u, v, w)$

Equilibrium model: set $\frac{\partial}{\partial t} = 0$

e.g.: $4\pi r^2 (F_r + F_c) = L$

Radial pulsation equations

perturbed energy equation:

$$\frac{\partial}{\partial m} \left(\frac{\delta L}{L} \right) = -i\omega \frac{c_p T}{L} \left(\frac{\delta T}{T} - \nabla_{\text{ad}} \frac{\delta p}{p} \right)$$

with:

$$\delta L = \delta L_r + \delta L_c$$

perturbed momentum equation:

$$\frac{\partial}{\partial m} \left(\frac{\delta p}{p} \right) = f \left(\frac{\delta r}{r}, \frac{\delta T}{T}, \frac{\delta p}{p} \right)$$

perturbed mass-conservation eqn:

$$\frac{\partial}{\partial m} \left(\frac{\delta r}{r} \right) = -\frac{1}{4\pi r^3 \rho} \left(3 \frac{\delta r}{r} + \frac{\delta \rho}{\rho} \right)$$

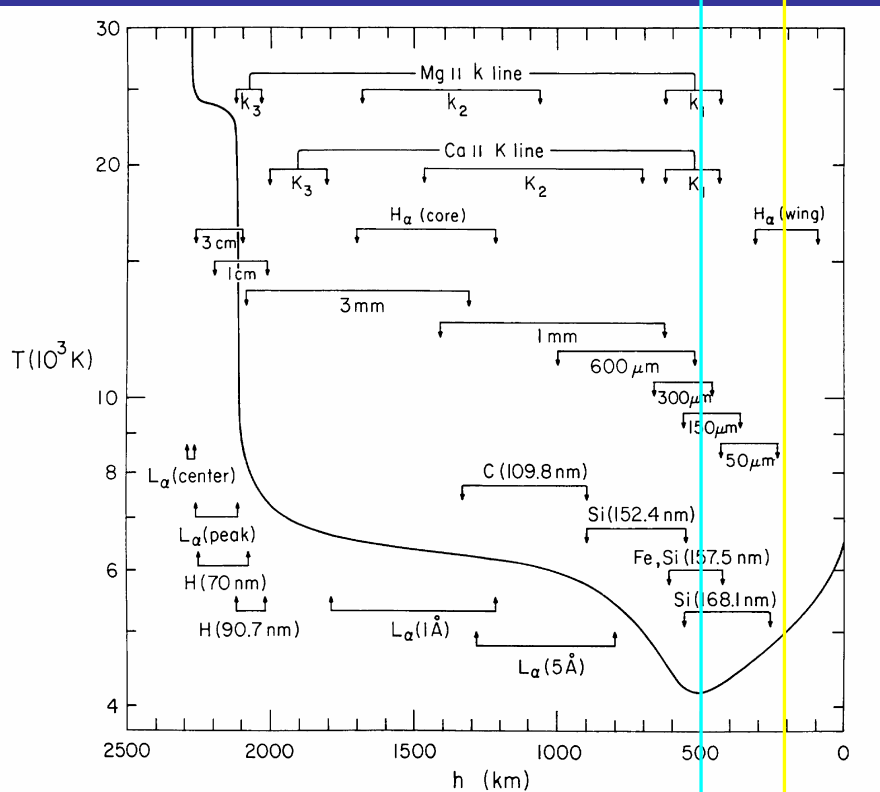
Amplitude ratio:

$$\frac{\Delta L_s}{\Delta V} := \frac{\delta L/L}{\omega_r r \delta r/r}$$

Pulsation amplitudes in the solar atmosphere

Pulsation amplitudes in the solar atmosphere

Spectral line formation in the Solar atmosphere



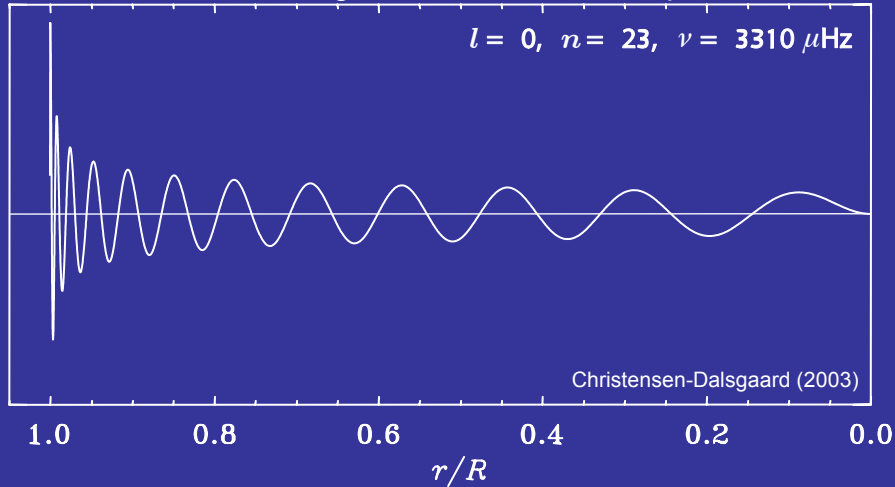
Vernazza, Avrett, Loeser (1981)

GOLF | BiSON

Instrument	line	λ (\AA)	τ_{5000}	height (km)
BBSO	Ca	6439	0.05	~129
BiSON	K	7699	0.013	~200
MDI	Ni I	6708	9×10^{-3}	~300
GOLF	Na D1/D2	5690	5×10^{-4}	~500

Pulsation amplitudes in the solar atmosphere

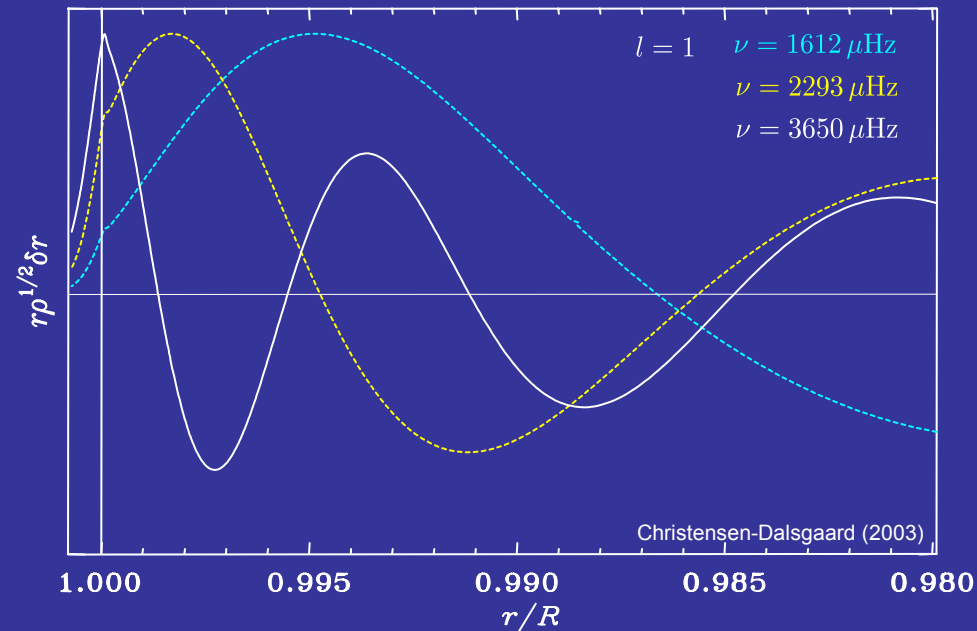
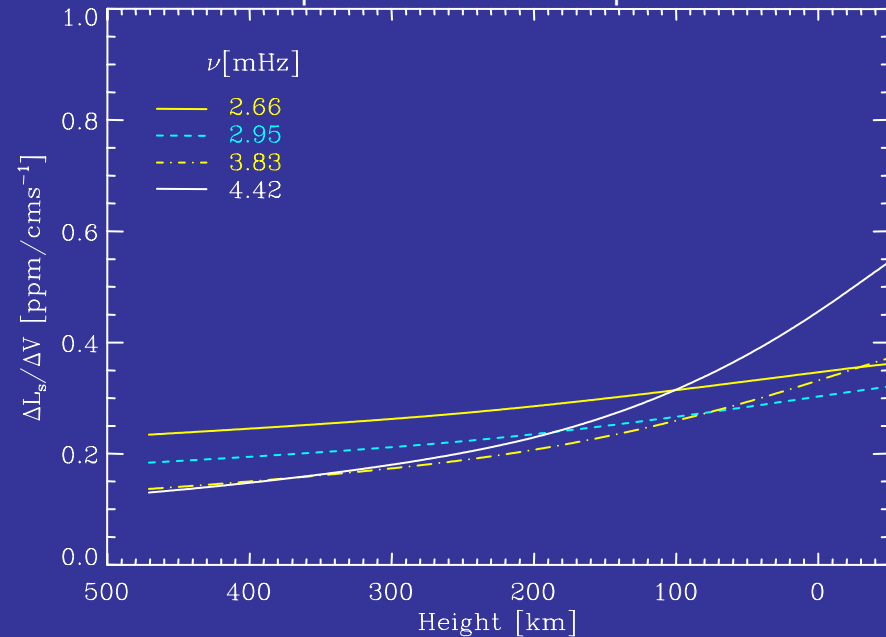
Scaled radial eigenfunction for a radial p mode



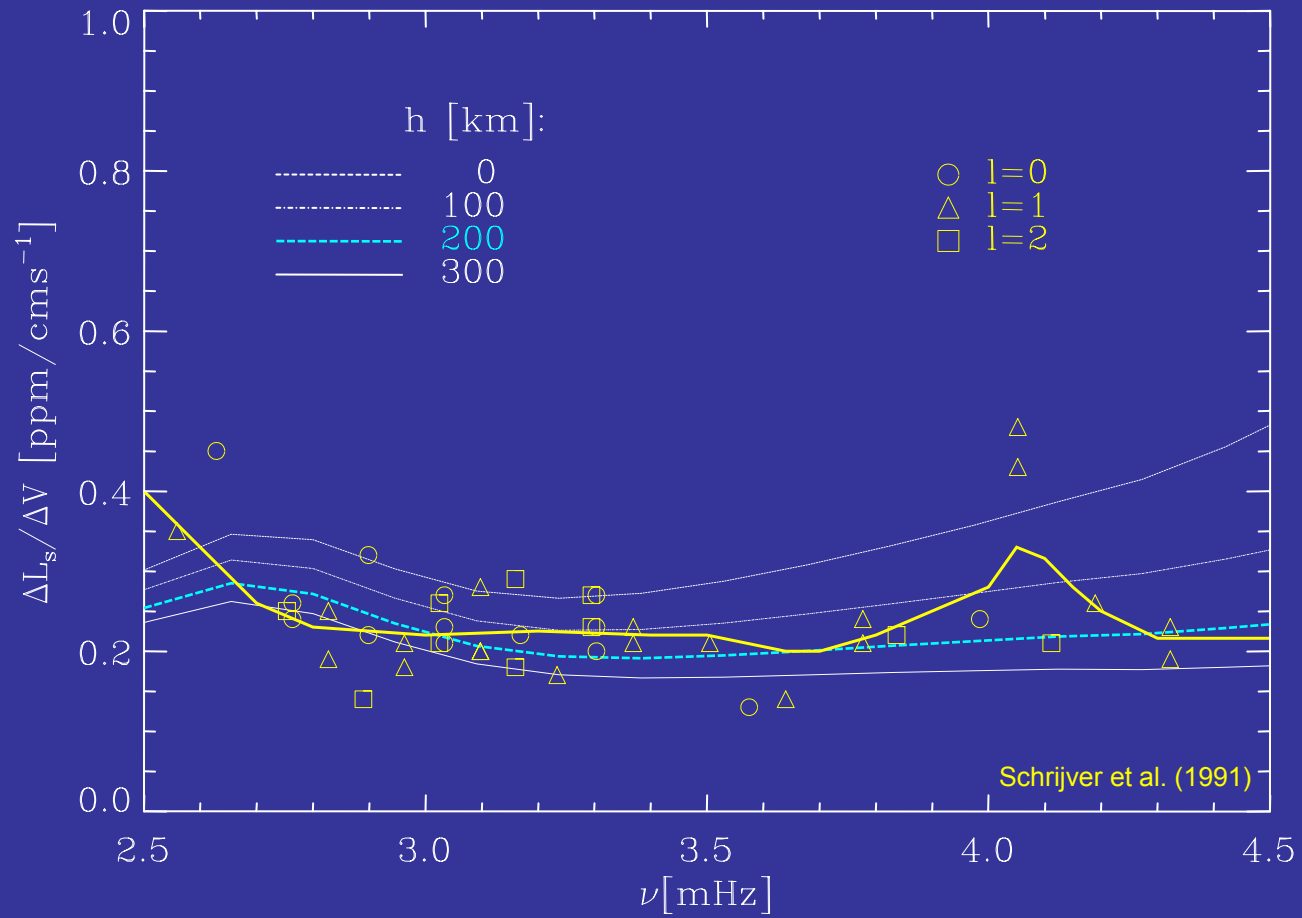
$$r\rho^{1/2}\delta r \propto \text{mode energy density (radial cpt.)}$$

$$\text{amplitude ratio: } \frac{\Delta L_s}{\Delta V} := \frac{\delta L/L}{\omega_r r \delta r/r}$$

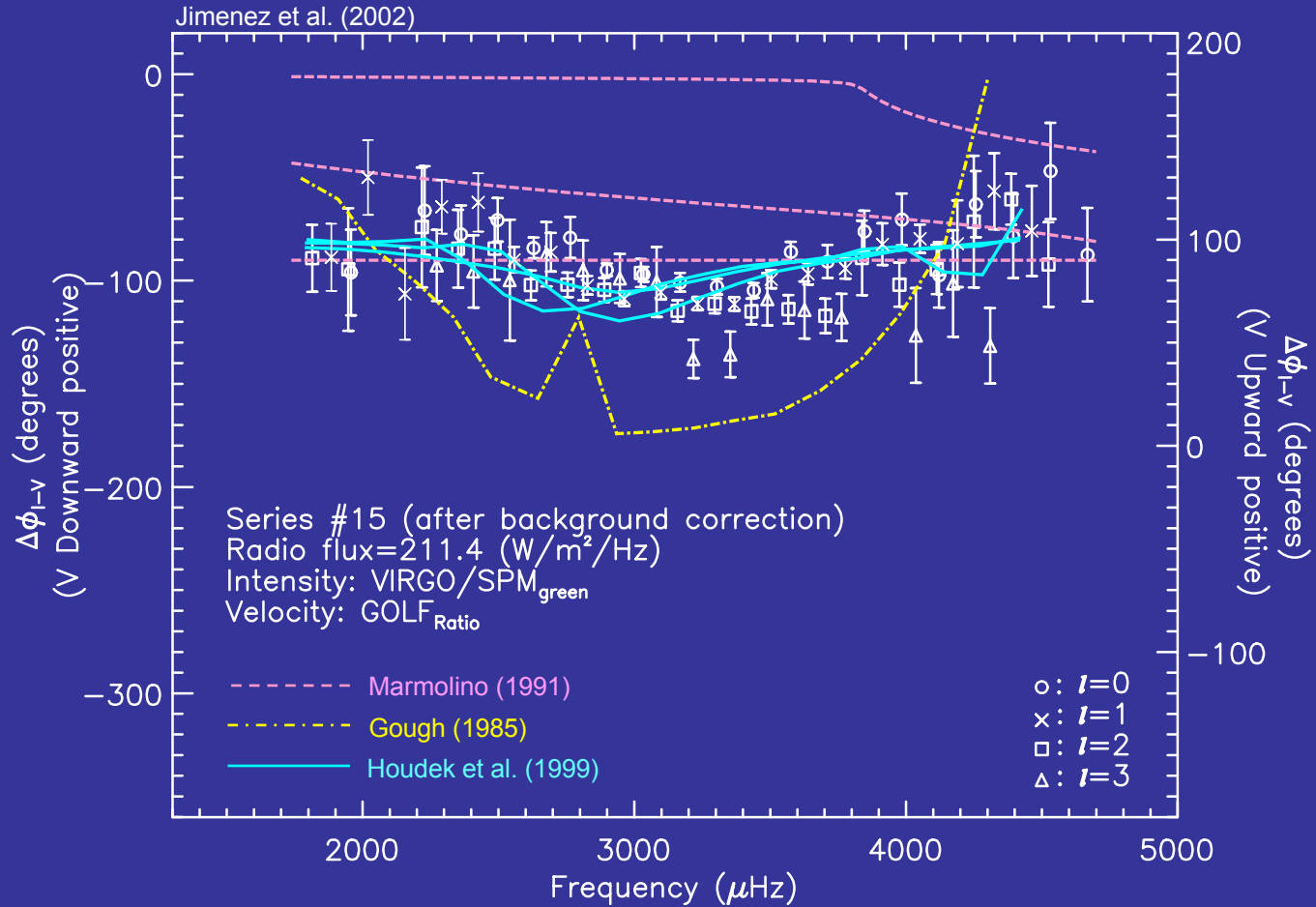
Amplitude ratios of radial p modes



Pulsation amplitudes in the solar atmosphere



Pulsation amplitudes in the solar atmosphere



Pulsation amplitudes in the solar atmosphere

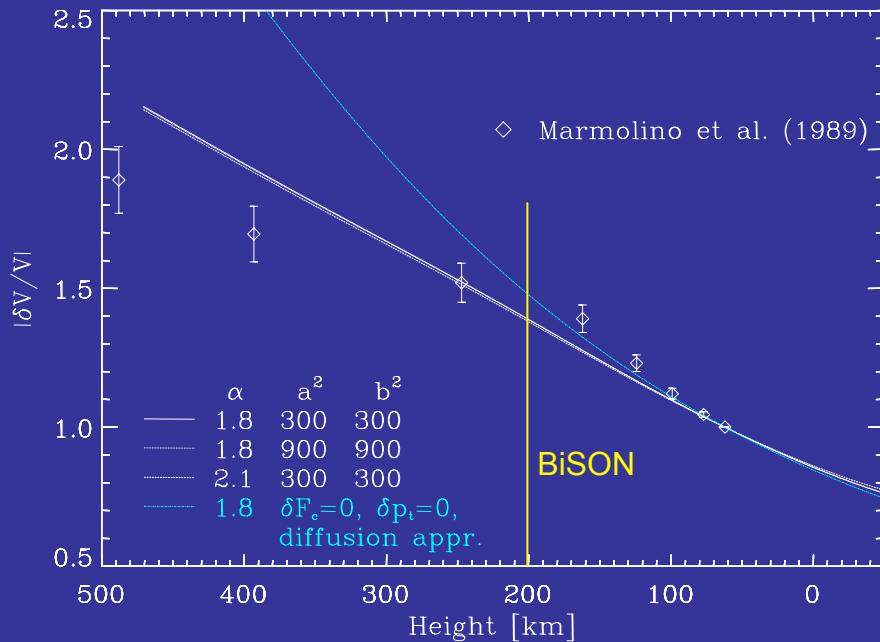
$$V^2 = \frac{P}{2\eta I}$$

P acoustic noise generation rate (from an excitation model)

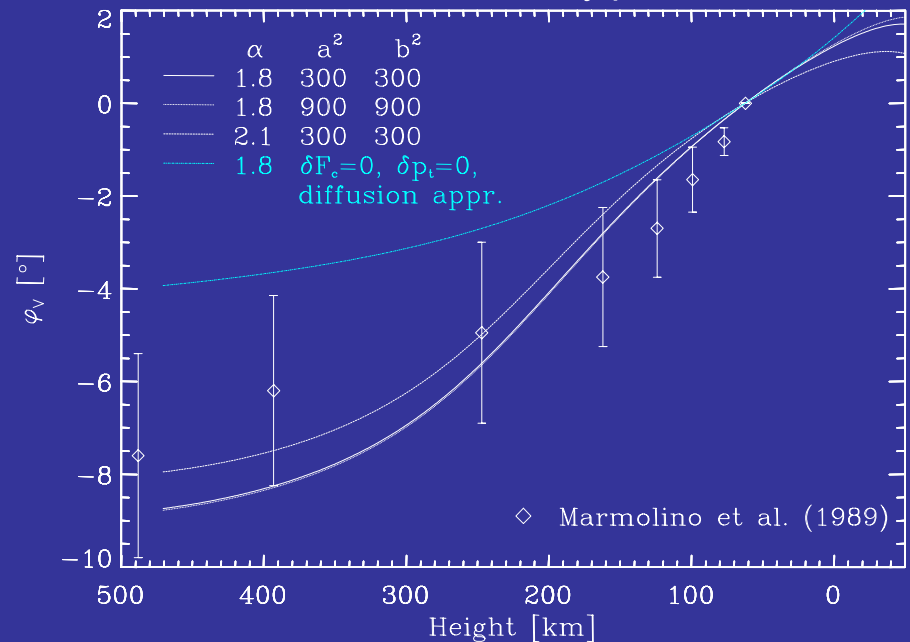
η damping rate (nonadiabatic pulsation model)

$$I = \frac{1}{\xi^2(R_s)} \int_{m_b}^M |\xi(m, \omega_r)|^2 dm \quad \xi := \delta r$$

Frequency-averaged relative velocity amplitude



Relative velocity phase



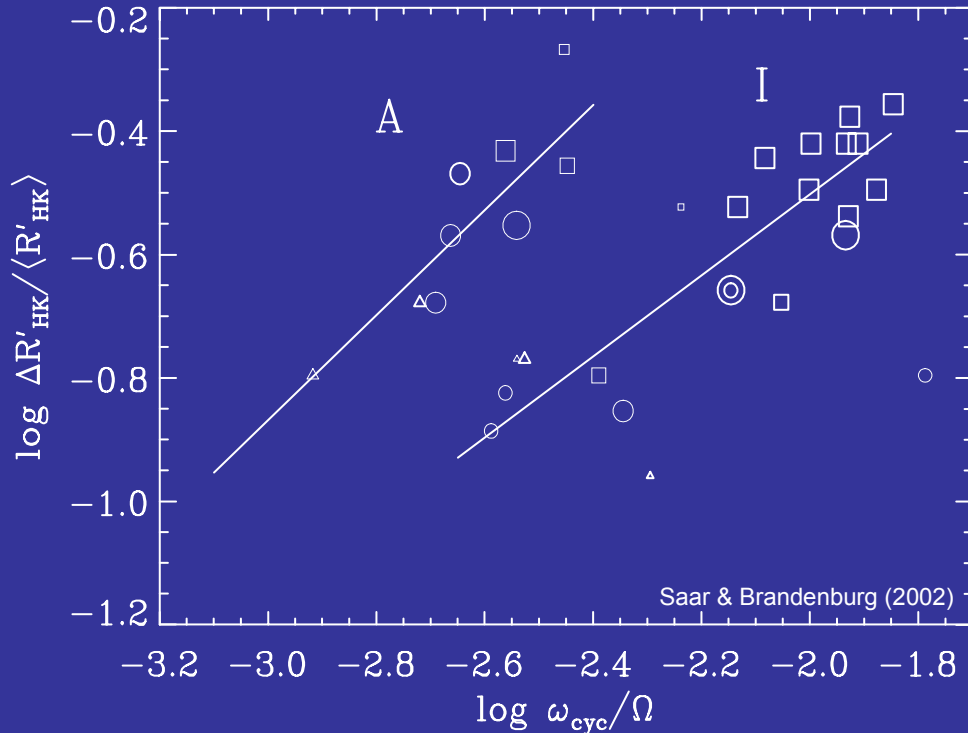
Activity cycle and acoustic oscillation properties
(with thanks to Bill Chaplin)

Activity cycle and acoustic oscillation properties

Magnetic cycle periods obtained from observations of Ca II emissions (e.g. Baliunas et al. 1995)

R'_{HK} CaII HK flux

$A_{\text{cyc}} = \Delta R'_{\text{HK}} / \langle R'_{\text{HK}} \rangle$ fractional peak – to – peak cycle amplitude



ω_{cyc} magnetic cycle frequency

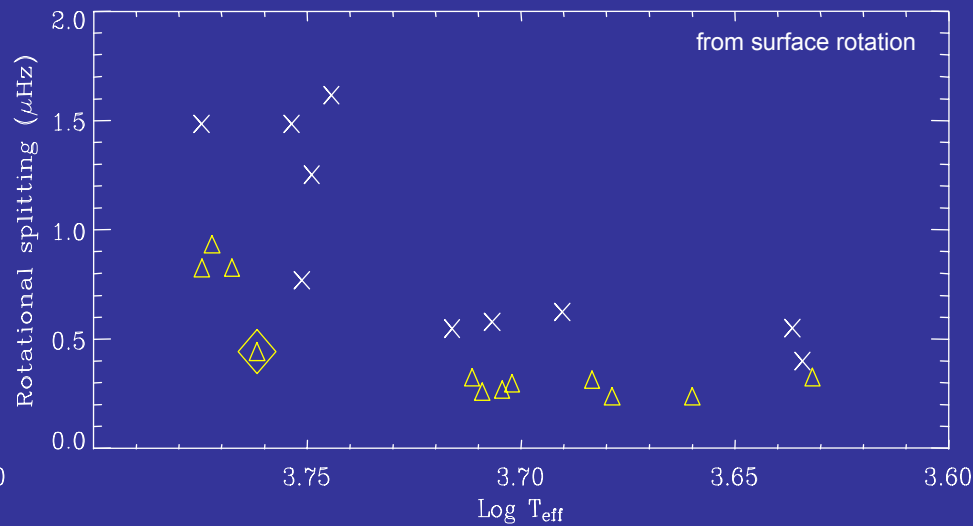
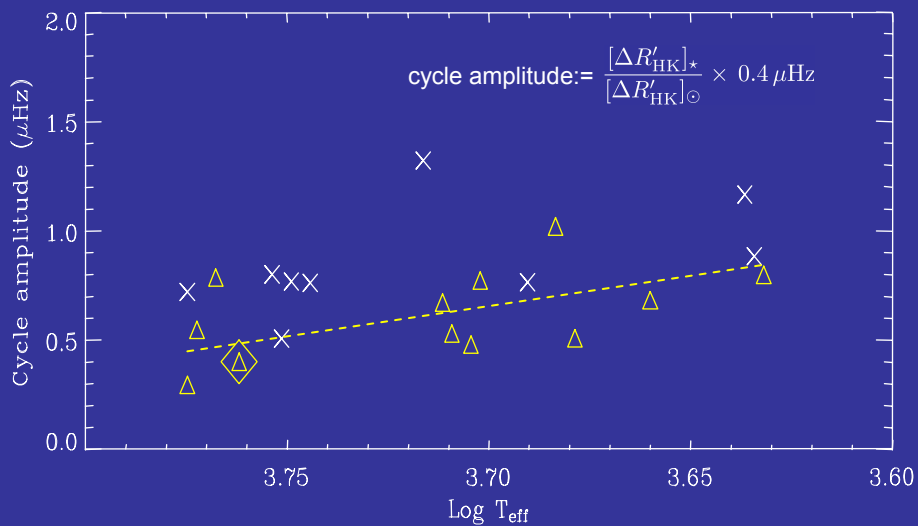
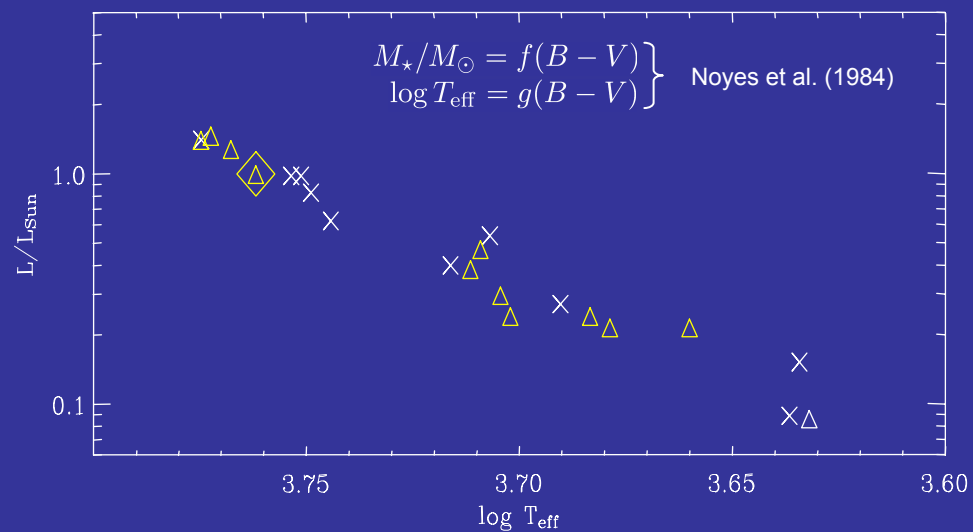
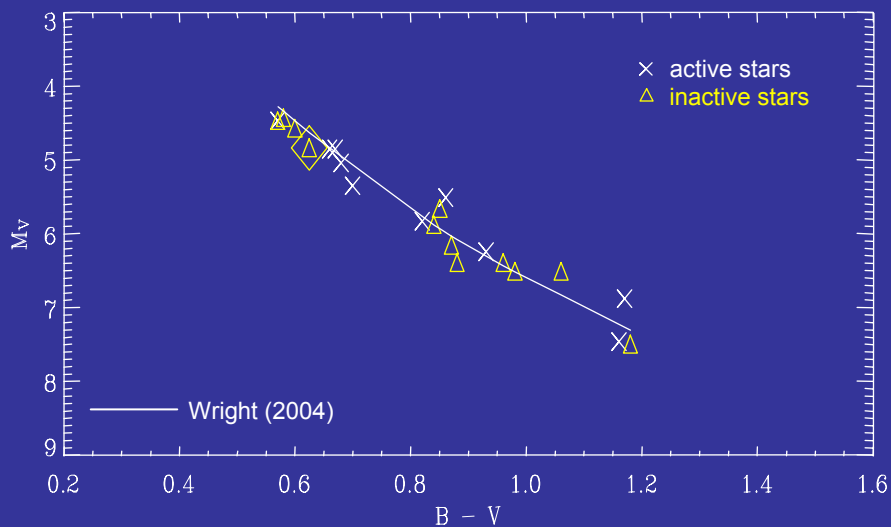
Ω surface rotational frequency

Main-sequence stars with $M_{\star} \leq M_{\odot}$

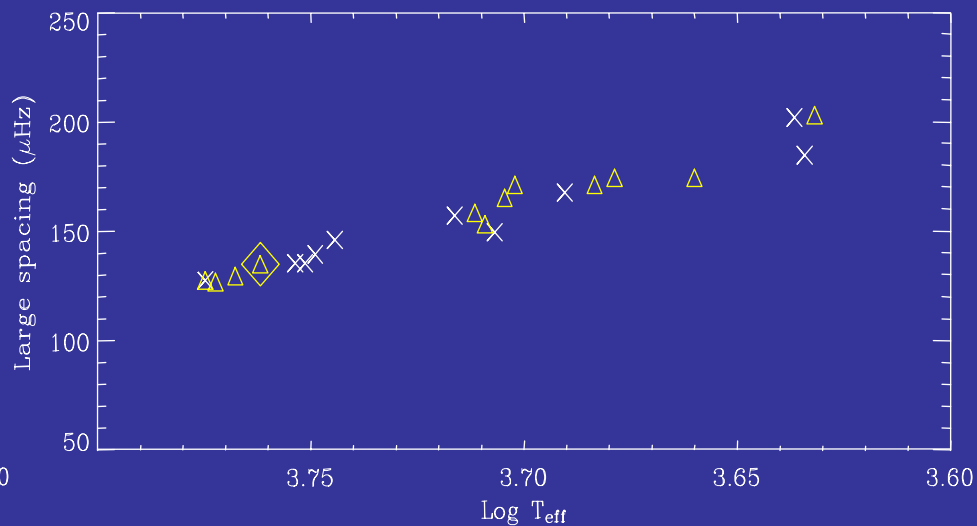
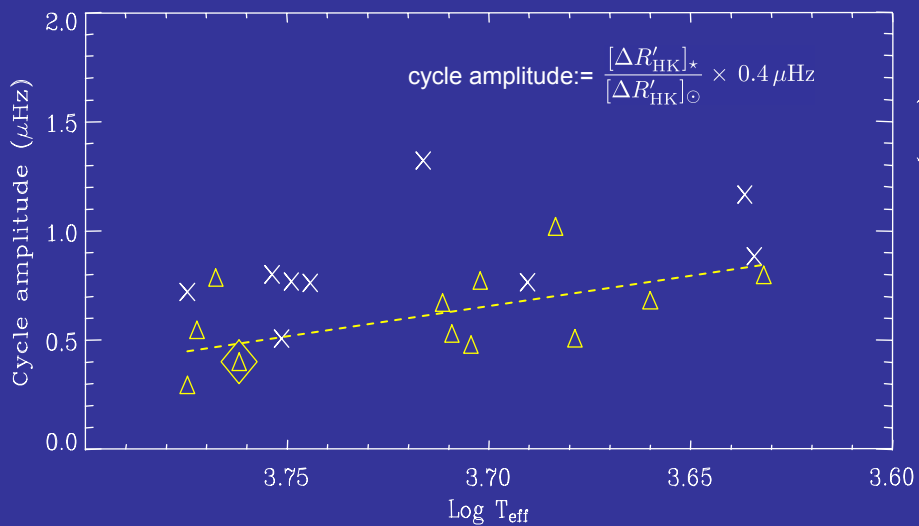
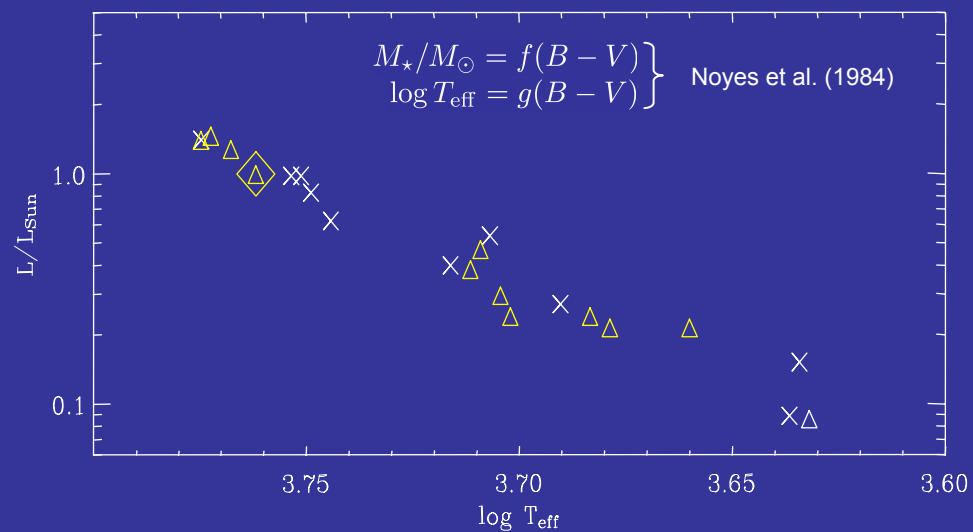
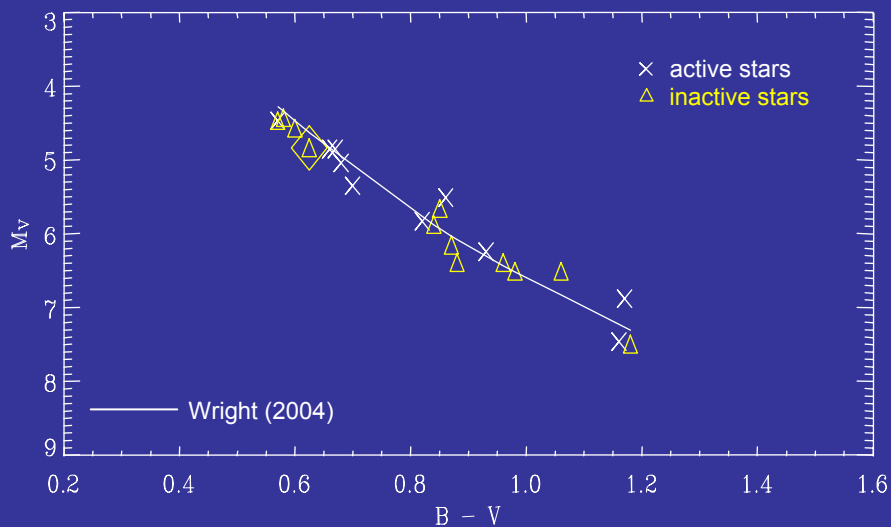
A active stars $\log R'_{\text{HK}} > -4.75$

I inactive stars $\log R'_{\text{HK}} \leq -4.75$

Activity cycle and acoustic oscillation properties



Activity cycle and acoustic oscillation properties



Activity cycle and acoustic oscillation properties

