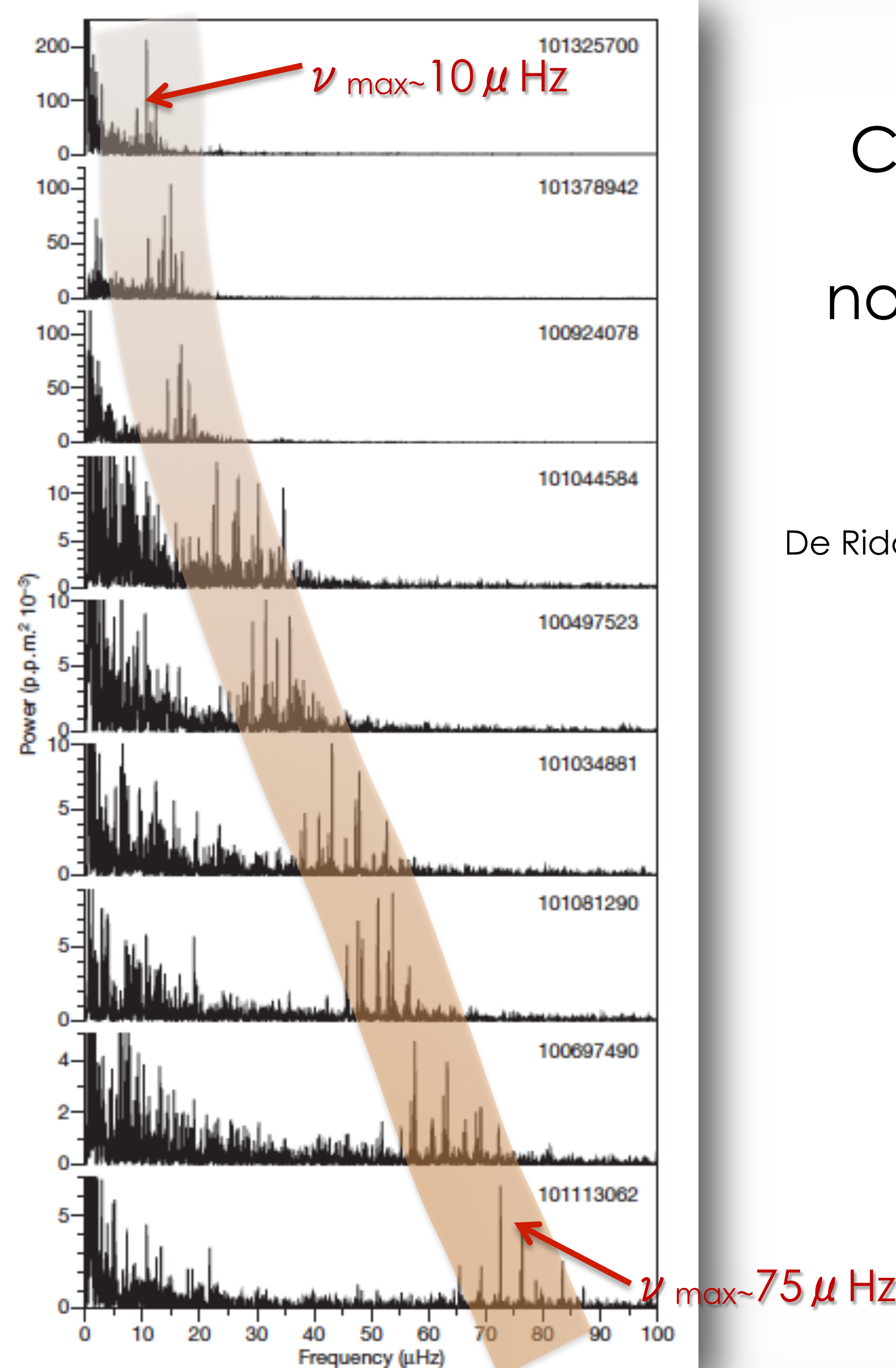
Red Giants in seismo and exo fields

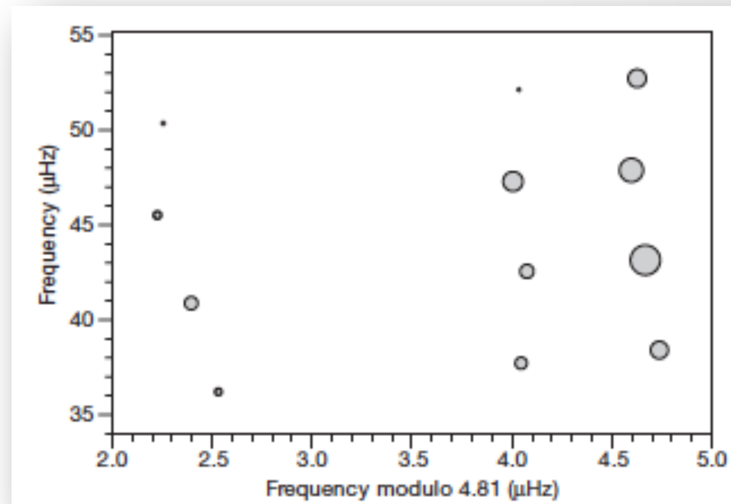
J. Montalban & CoRoT Red Giants team

Obs. Paris-Meudon, IAS, INAF-Brera, INAF-Roma, Univ. Birmingham, Univ. Vienna, KUL, IAP, Univ. Amsterdam & Univ. Liege



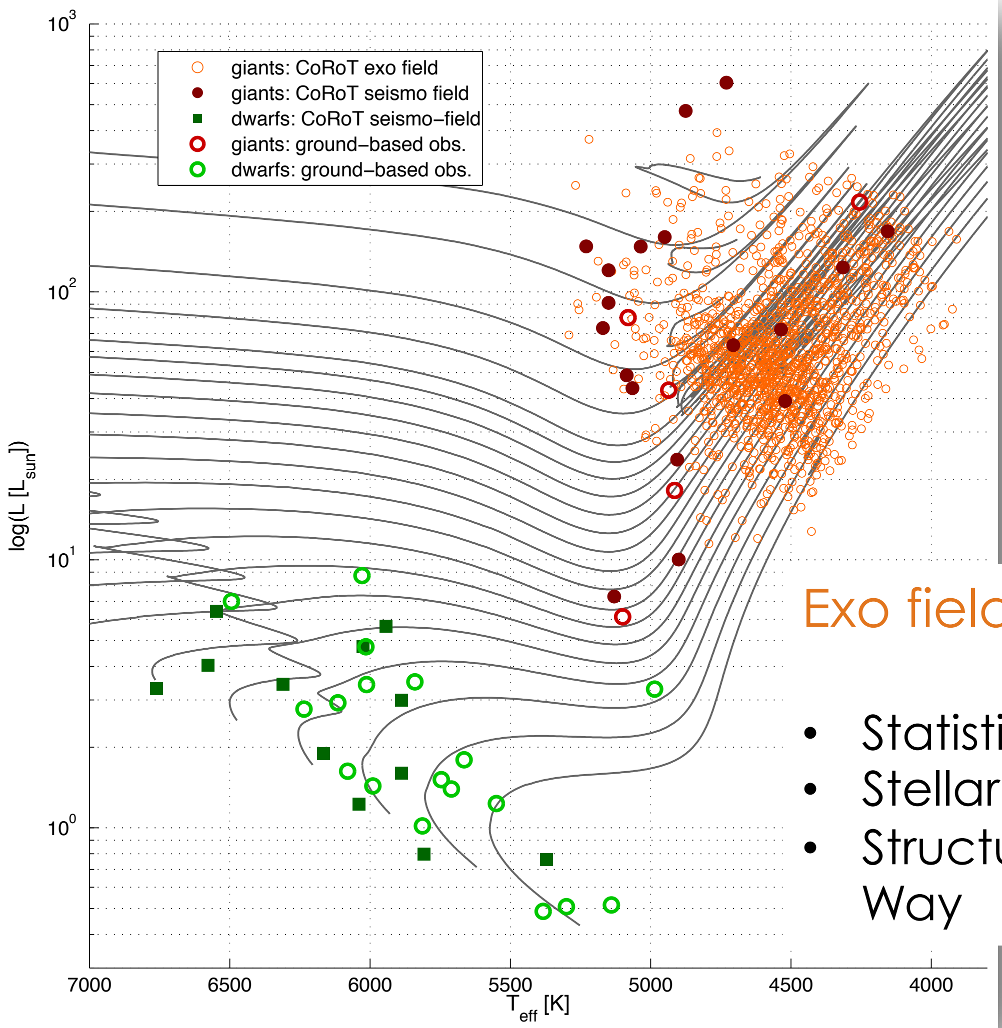
CoRoT detects and confirms the presence of non-radial solar-like oscillations In several hundred G-K Red Giants

De Ridder et al. Nature 2009



Echelle diagram with ridges corresponding to radial and non-radial modes

Red Giants in CoRoT



Seismo field

18 G-K Red Giants

- Stellar parameters
- Chemical abundances
- Check of scaling relations

Exo field: several thousands

- Statistical studies
- Stellar population studies
- Structure and evolution of the Milky Way

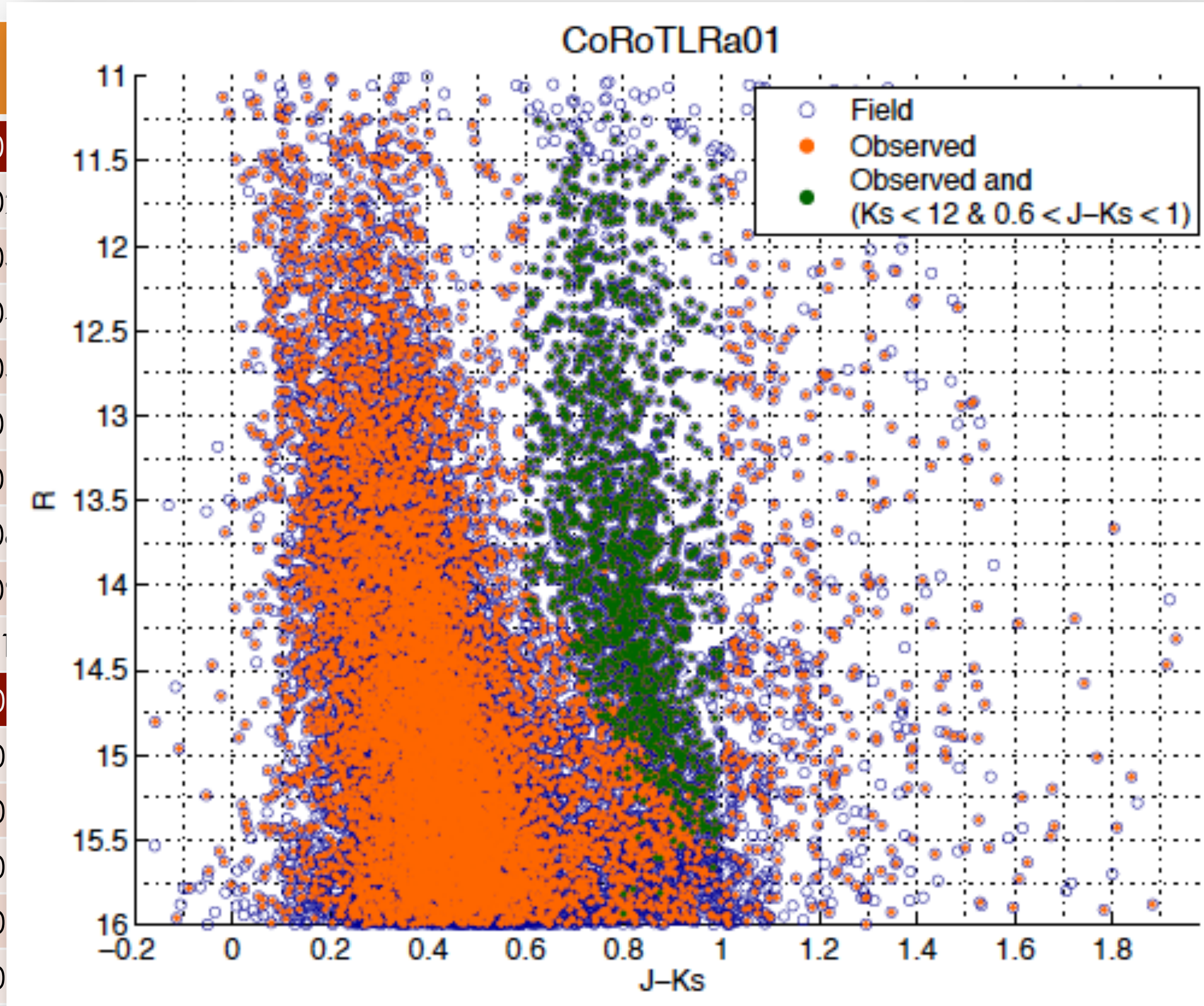
Credits A. Miglio

Red Giants in CoRoT

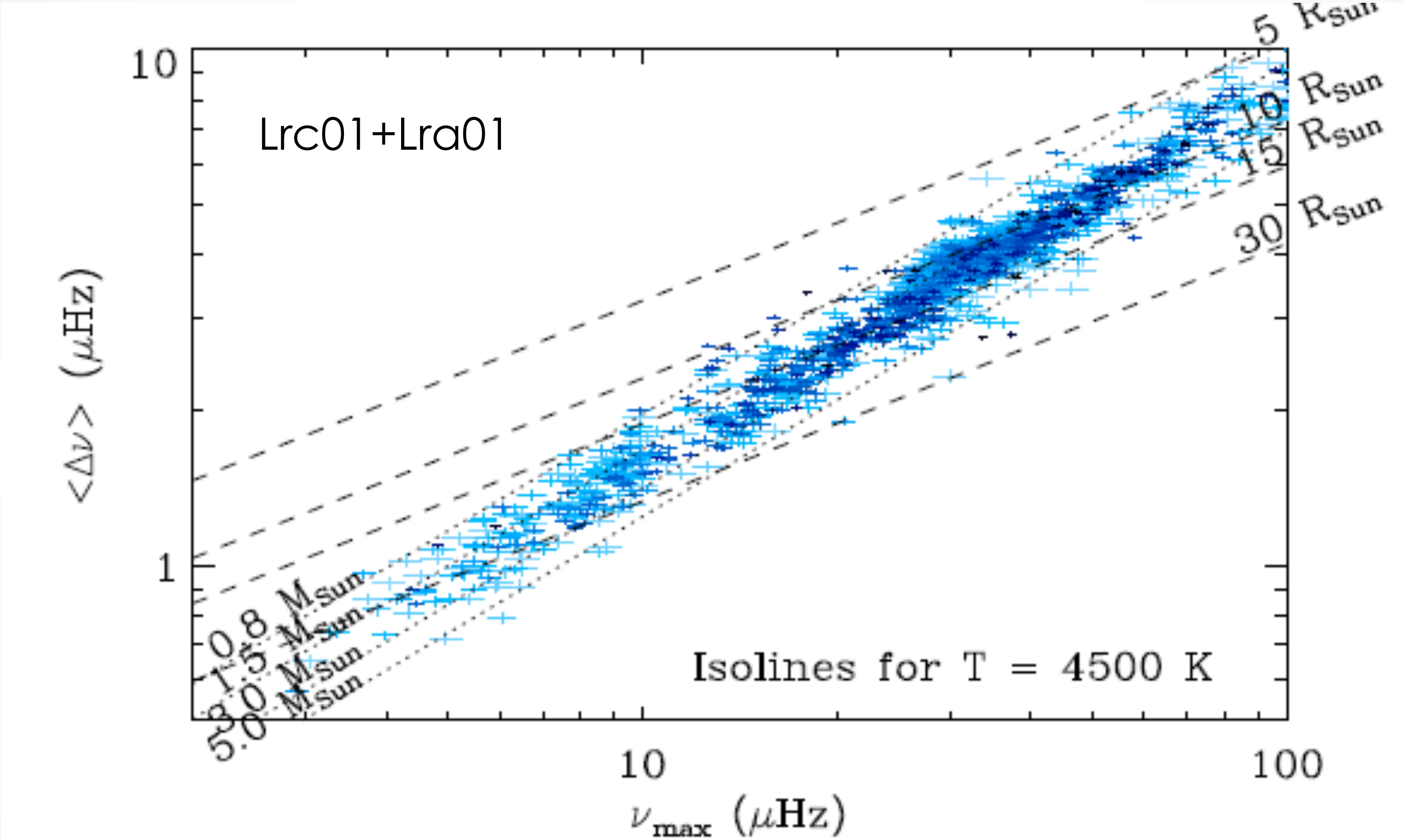
RUN	N RGs	RG with oscillations	
LRc01	3988	1400	Mosser et al. , Hekker et al, Kallinger et al.
LRc02	3234	200	Mosser&Baudin
LRc03	1955	60	Mosser&Baudin
LRc04	576		
LRc05	2148		
LRc06	2205		
LRc07	3722		
LRc08	1525		
LRc09	1941		
IRa01	1458		
LRa01	1698	400	Mosser et al. 2010 A&A
LRa02	1481	200	Mosser&Baudin
LRa03	755	100	Mosser&Baudin
LRa04	660		
LRa05	664		
LRa06	1099		

Red Giants in CoRoT

RUN	
LRc0	ger et al.
LRc0	
LRc0	
LRc0	
LRc0	
LRc0	
LRc0	
LRc0	
LRc0	
IRa01	
LRa0	
LRa0	
LRa0	
LRa0	
LRa0	
LRa0	



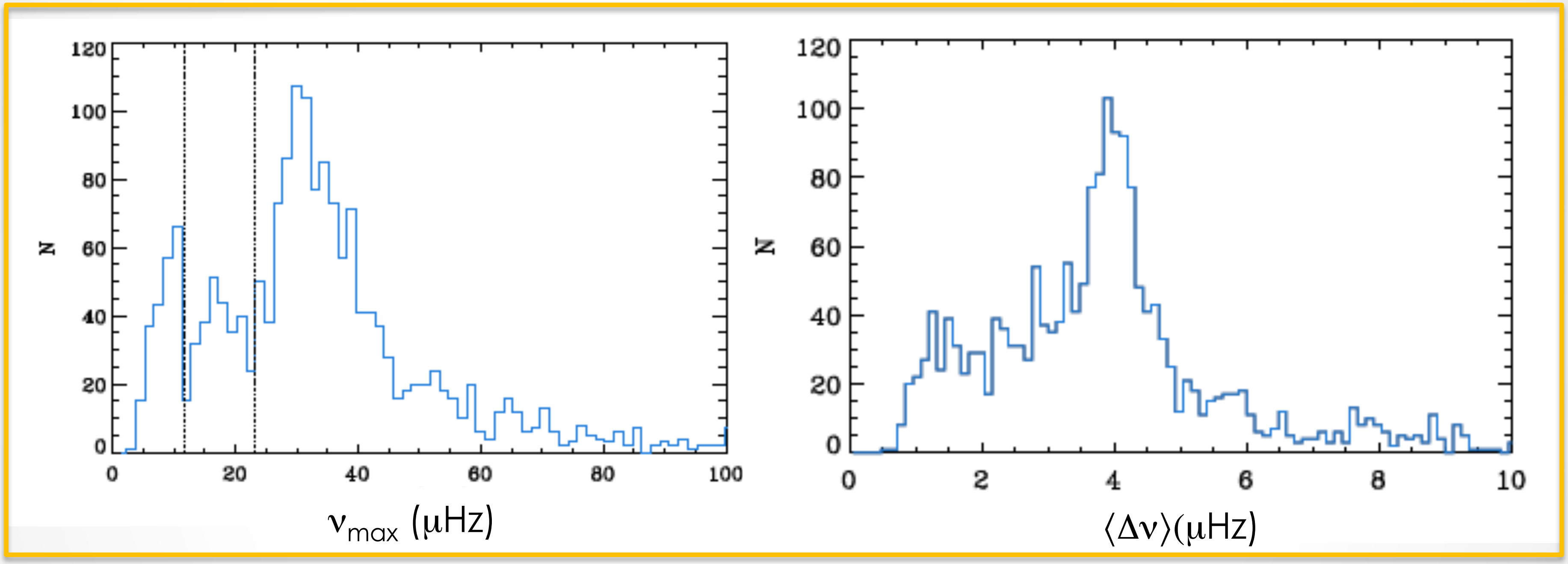
Seismic parameters in exo RGs



$$\langle \Delta\nu \rangle \simeq (0.280 \pm 0.02)\, \nu_{\max}^{0.75 \pm 0.01}$$

- Mosser et al. A&A 2010, see also Hekker et al. A&A 2009, Kallinger et al. A&A2010

Seismic parameters in exo RGs



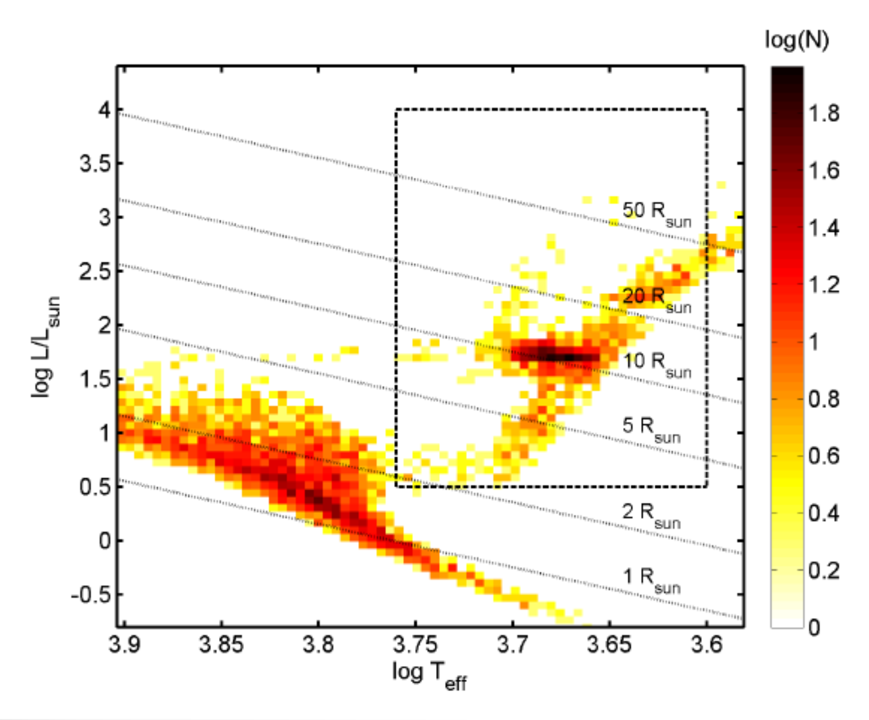
$\nu_{max} \sim [30\text{-}40]$ μHz

$\langle \Delta\nu \rangle \sim 4$ μHz

Mosser et al. A&A 2010, see also Hekker et al. A&A 2009, Kallinger et al. A&A2010

Characterization of exo RG population

- CoRoT LRc01 (l=37, b=-7) $11<m_V<15$



TRILEGAL

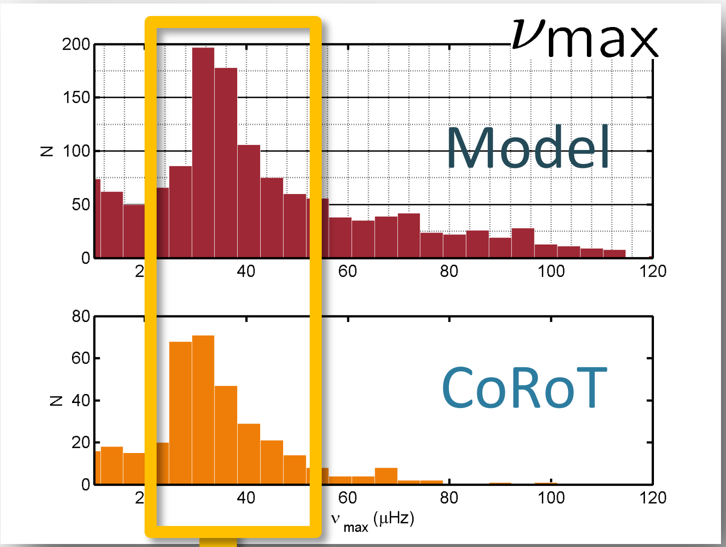
Pop. Synthesis software

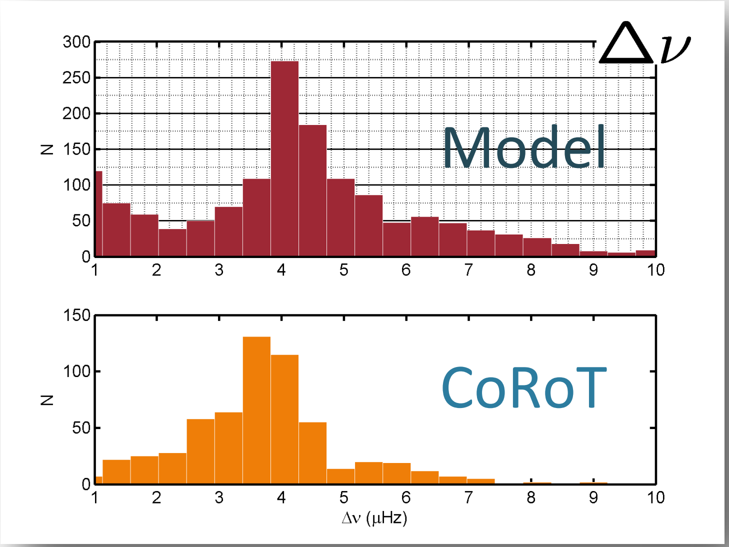
+

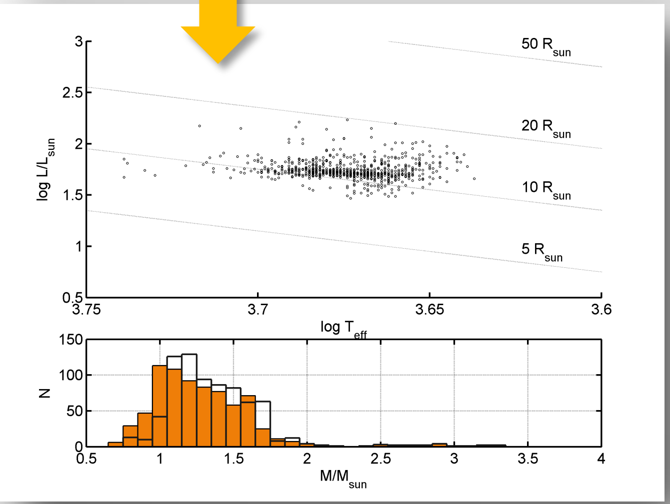
$$\Delta\nu \simeq \sqrt{\frac{M/M_\odot}{(R/R_\odot)^3}}\Delta\nu_\odot$$

$$\nu_{\max} \simeq \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{T_{\rm eff}/T_{\rm eff\odot}}}\nu_{\max\odot}$$

Population study of CoRoT RedG







Sample dominated by Red Clump stars!

ν_{max}~35μHz
Δν ~ 4 μHz

Miglio et al. 2009 A&A

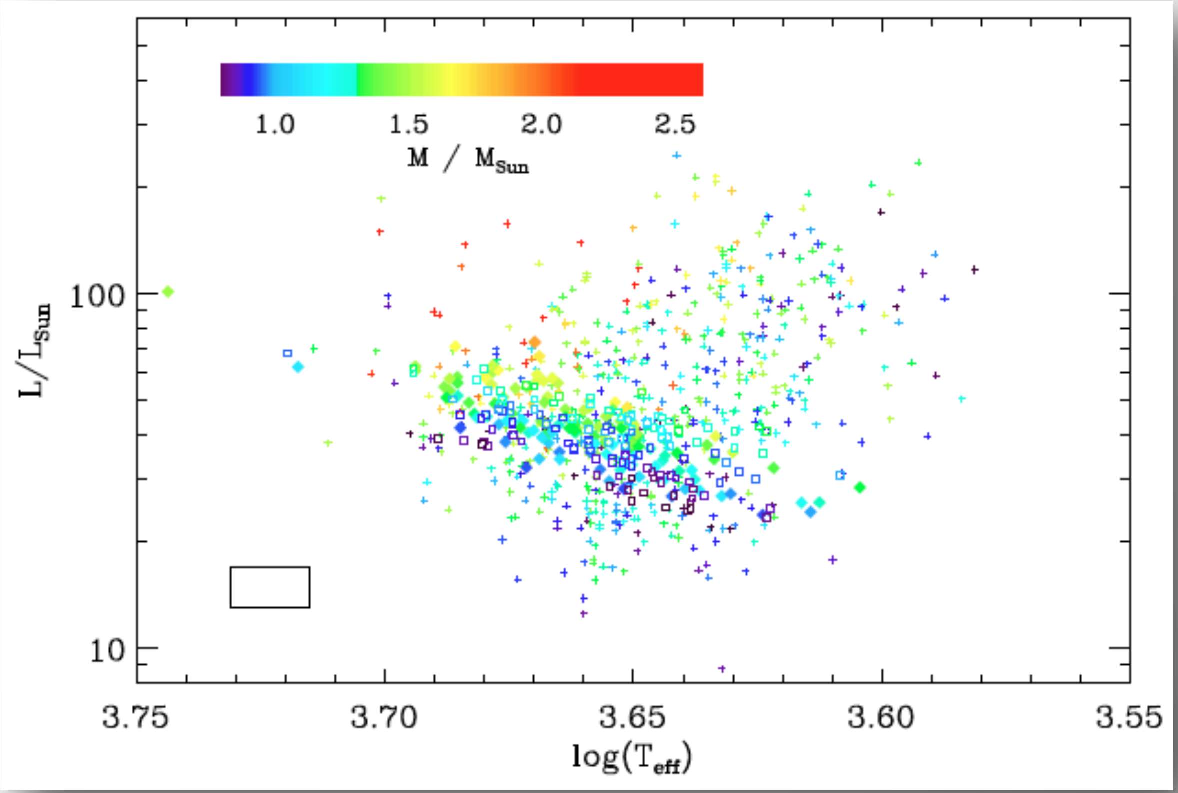
Characterization of exo RG population

- CoRoT LRc01 LRa01

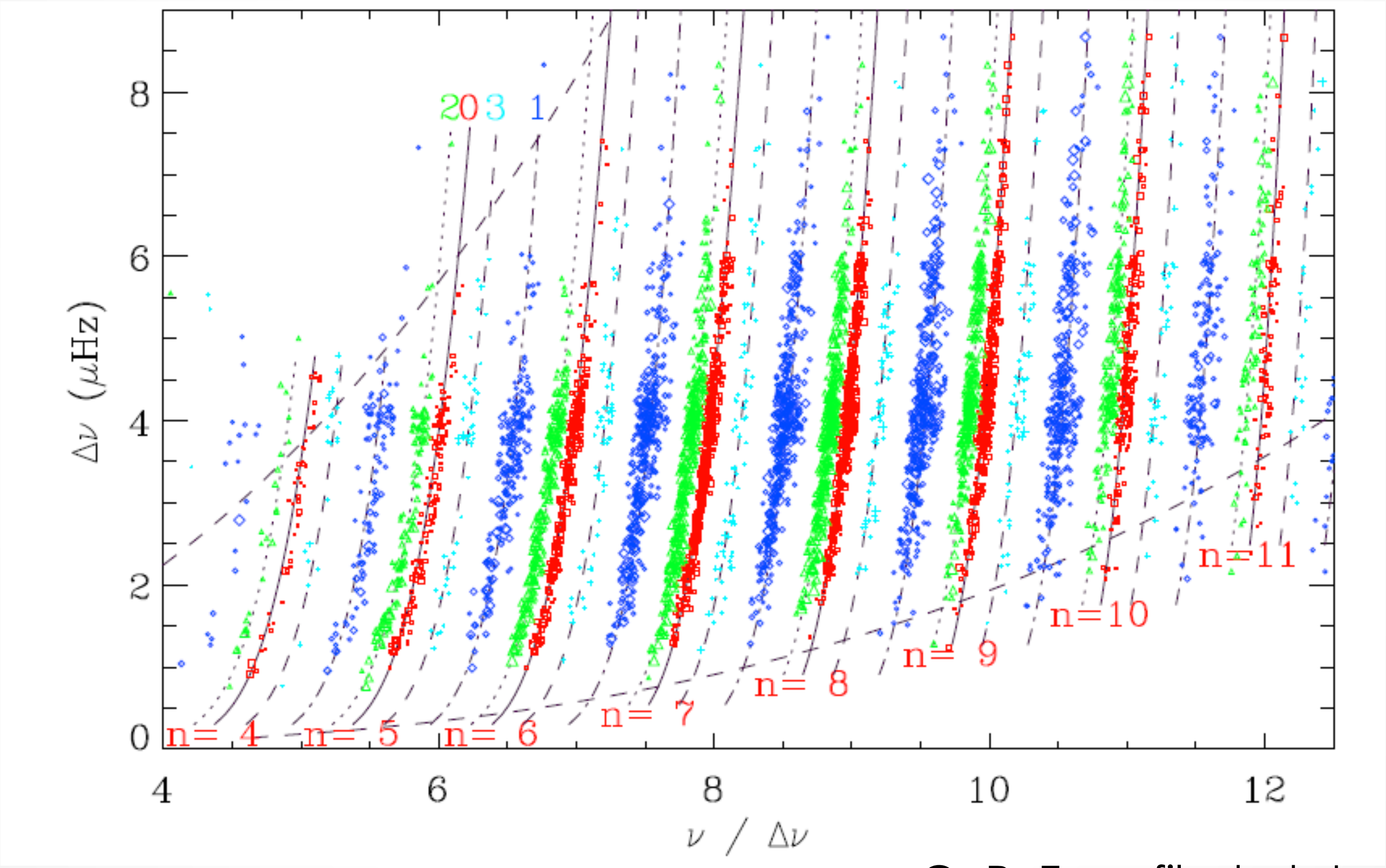
$$\nu_{\max} \simeq \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{T_{\rm eff}/T_{\rm teff\odot}}}\nu_{\max\odot}$$

$$\Delta\nu \simeq \sqrt{\frac{M/M_\odot}{(R/R_\odot)^3}}\Delta\nu_\odot$$

Mosser et al. 2010 A&A

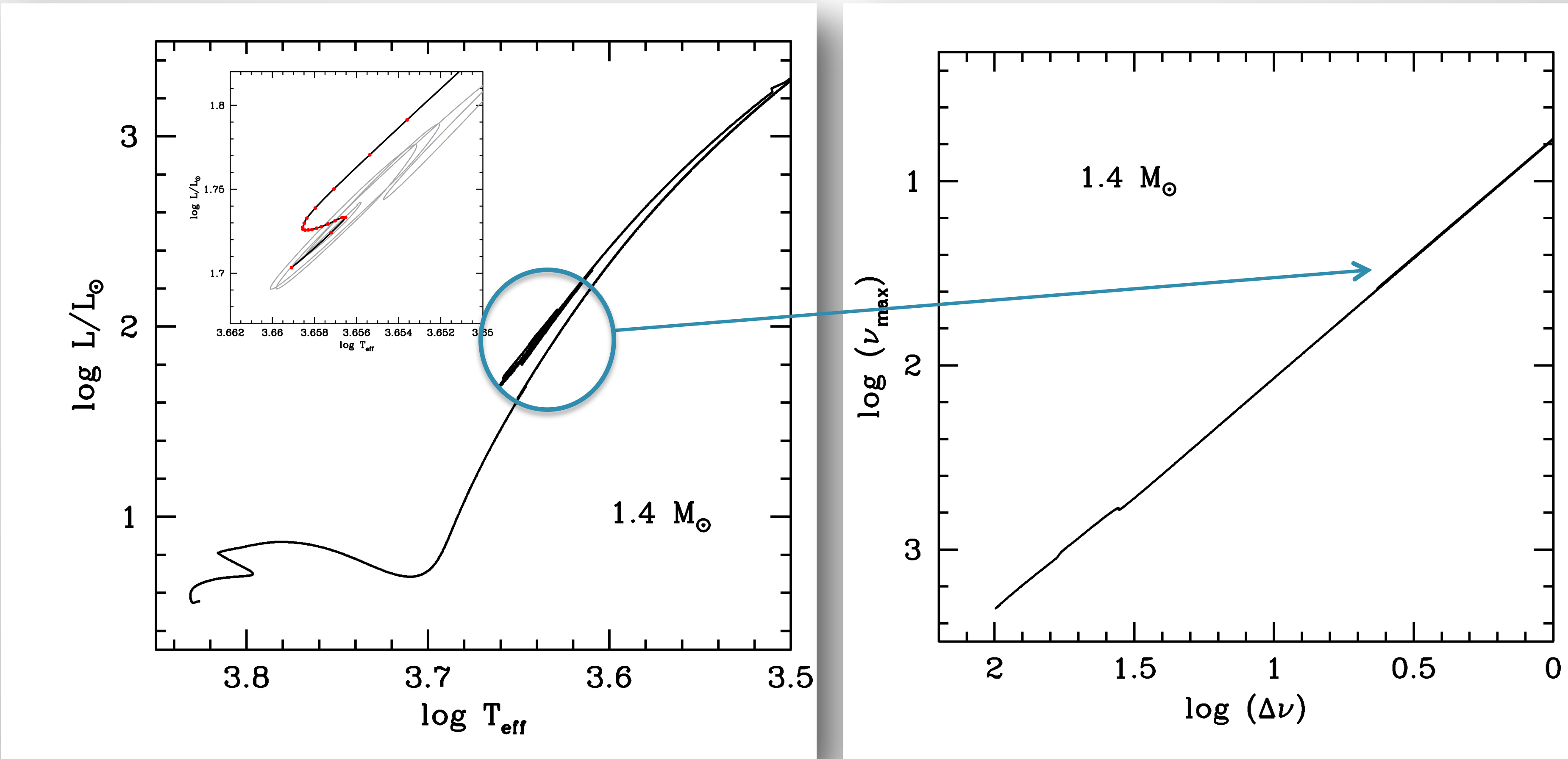


Seismic parameters in exo RGs

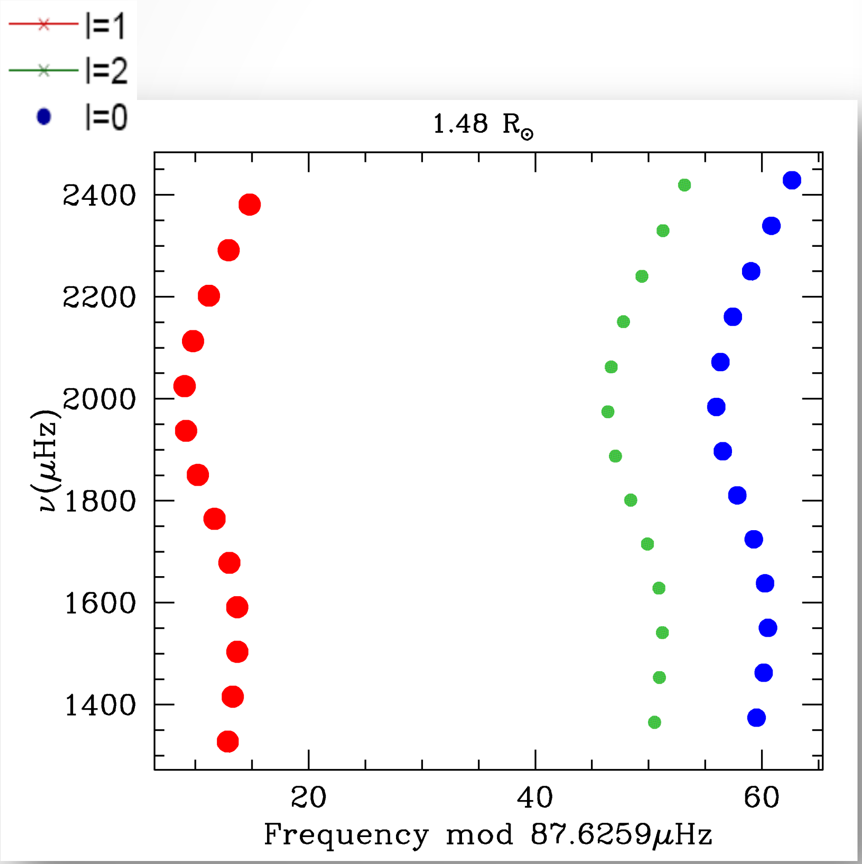


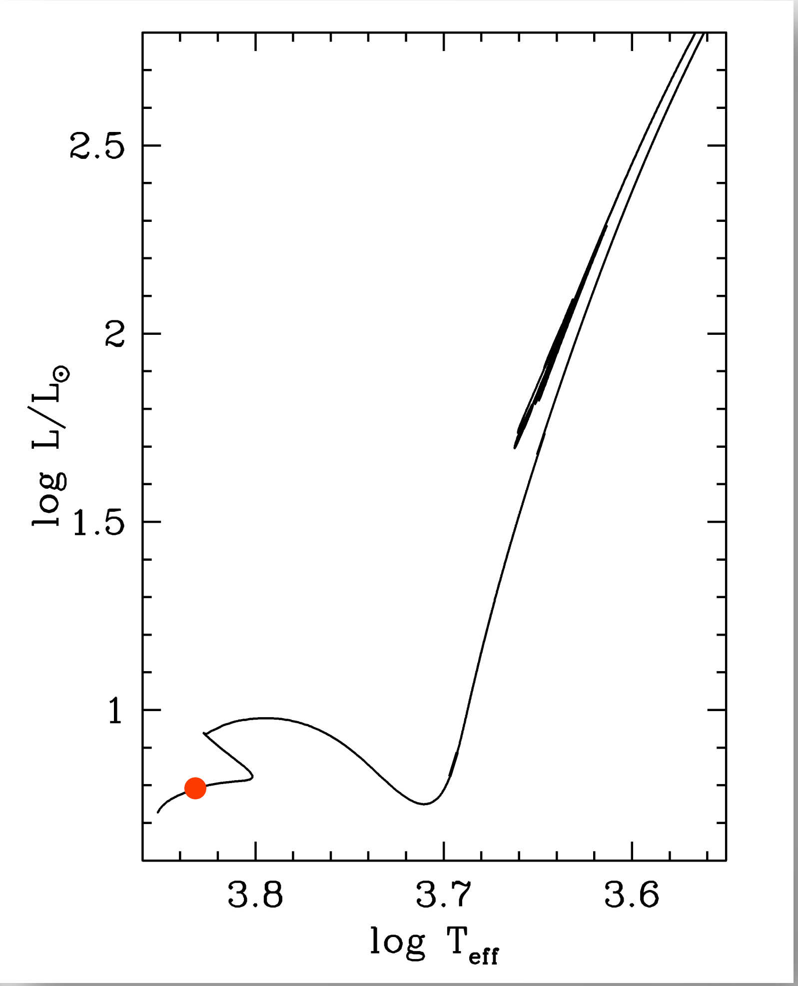
CoRoT exofiled data
Mosser et al. 2010, A&A

HR Diagram & $\Delta\nu$-ν_{max}

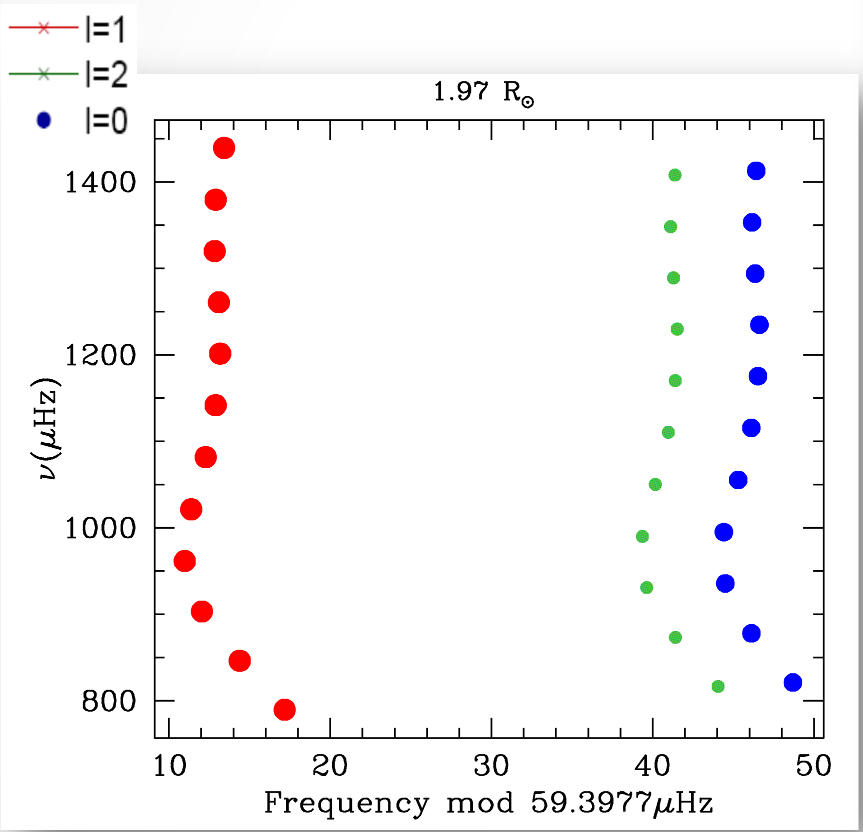


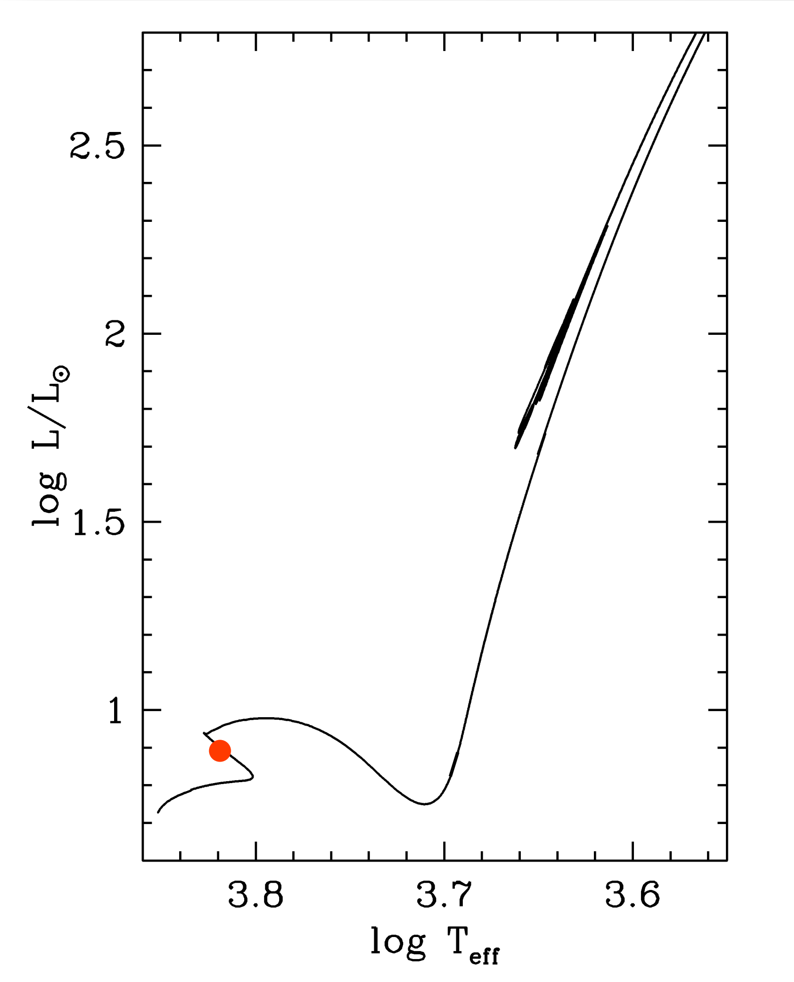
Evolution of a 1.5 Msun



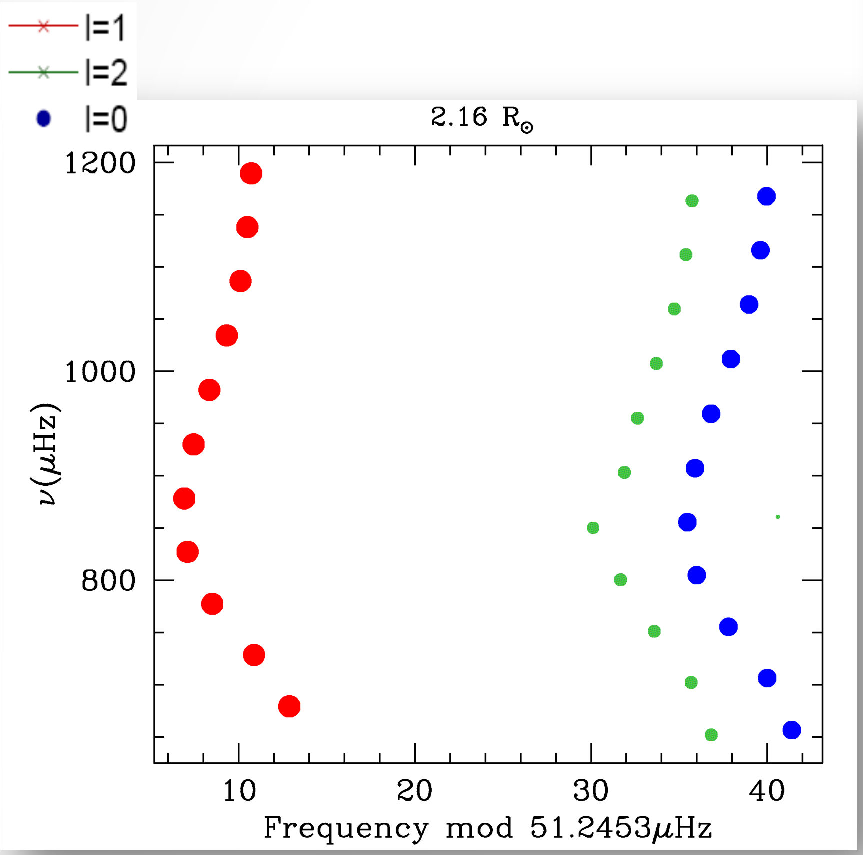


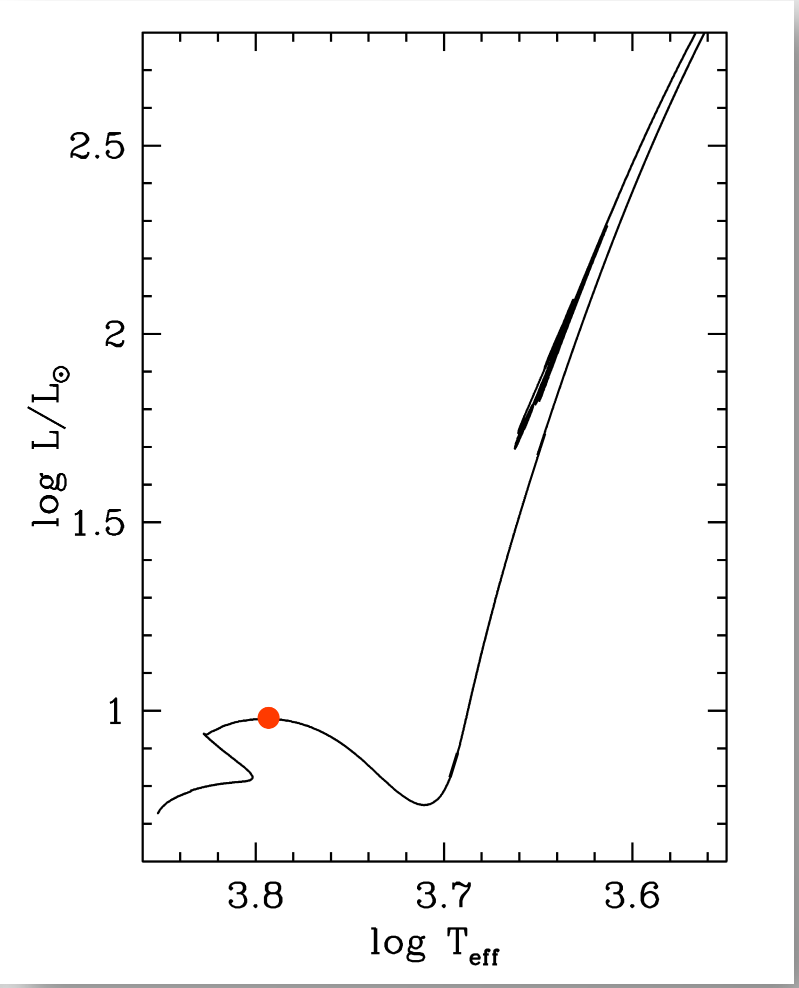
Evolution of a 1.5 Msun



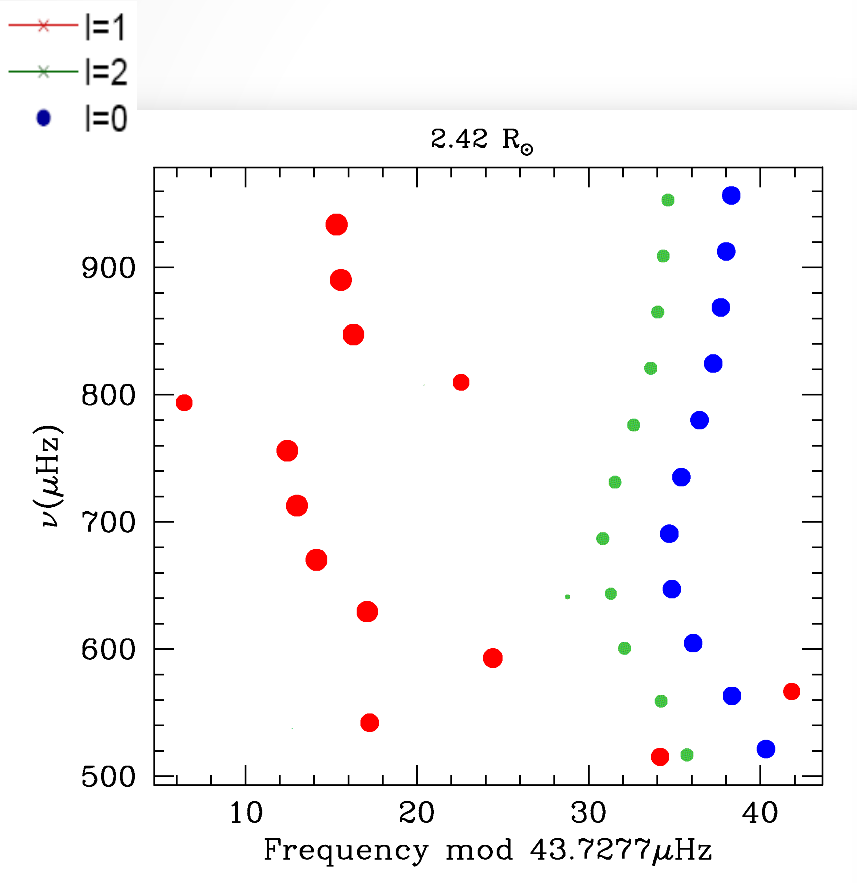


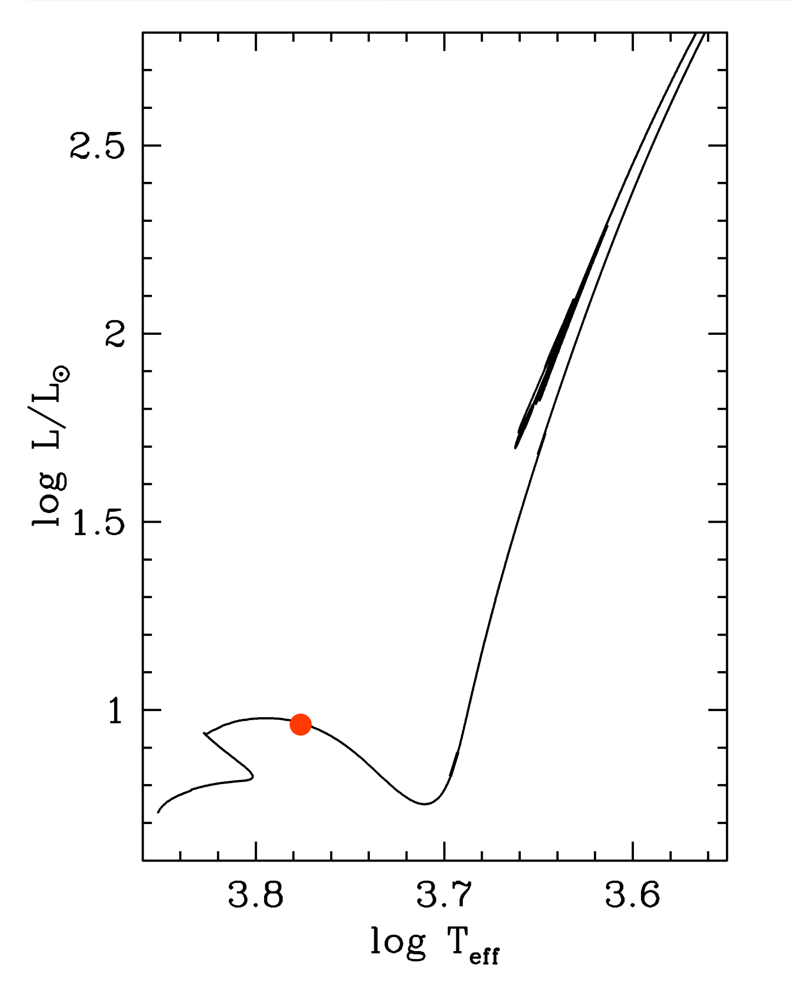
Evolution of a 1.5 Msun



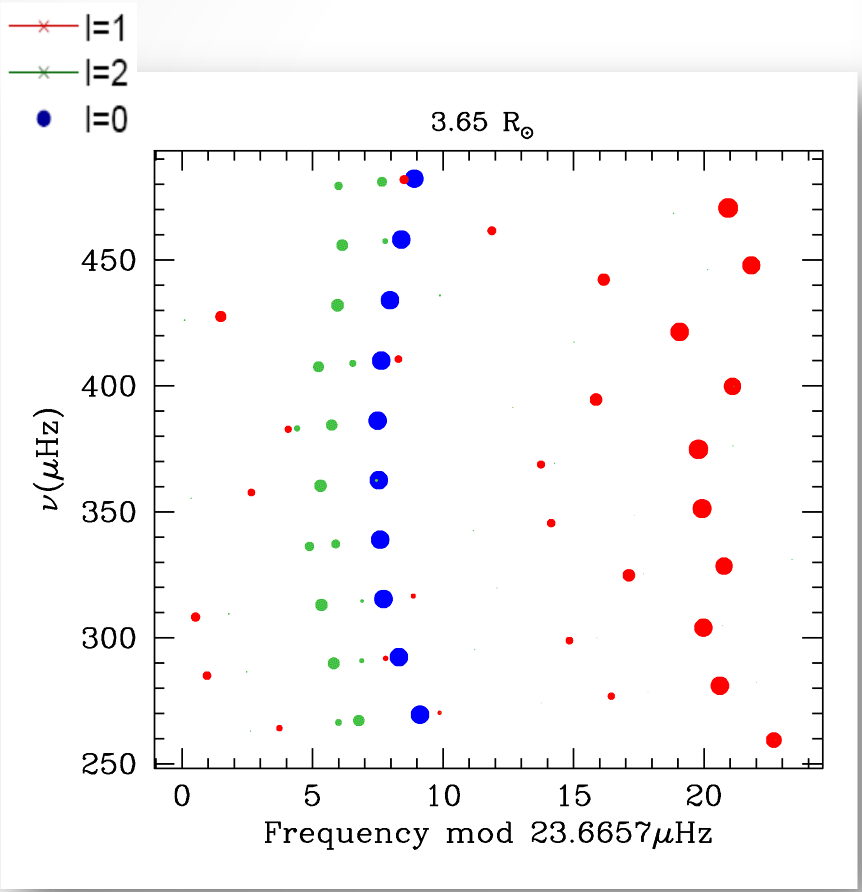


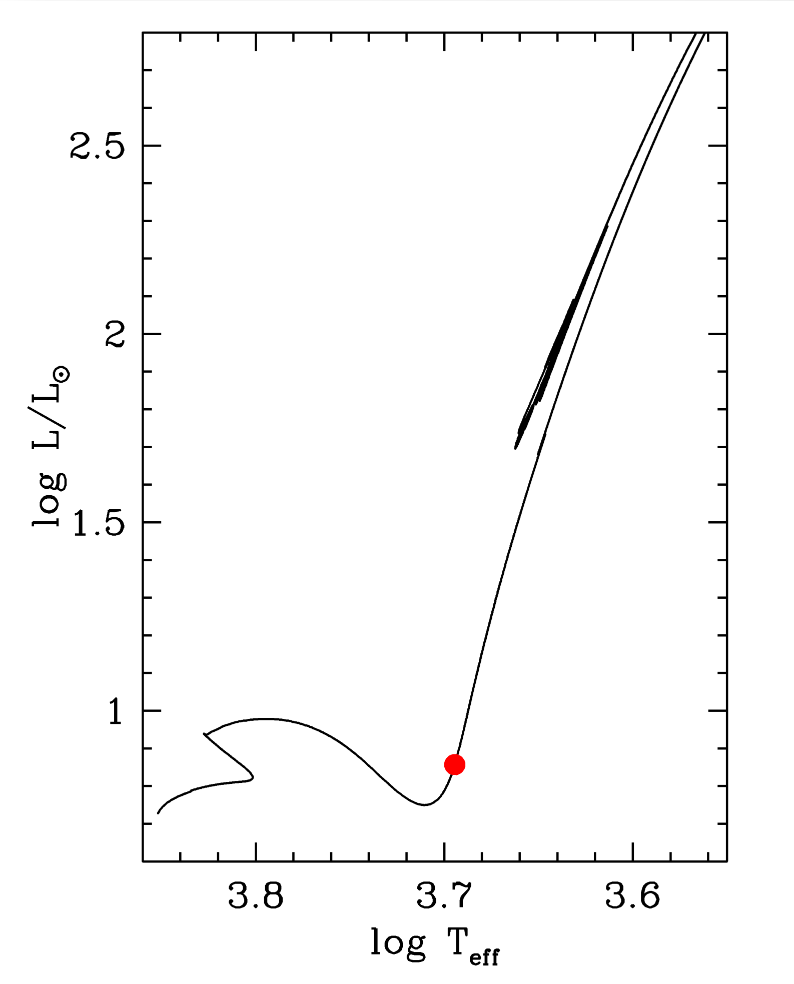
Evolution of a 1.5 Msun



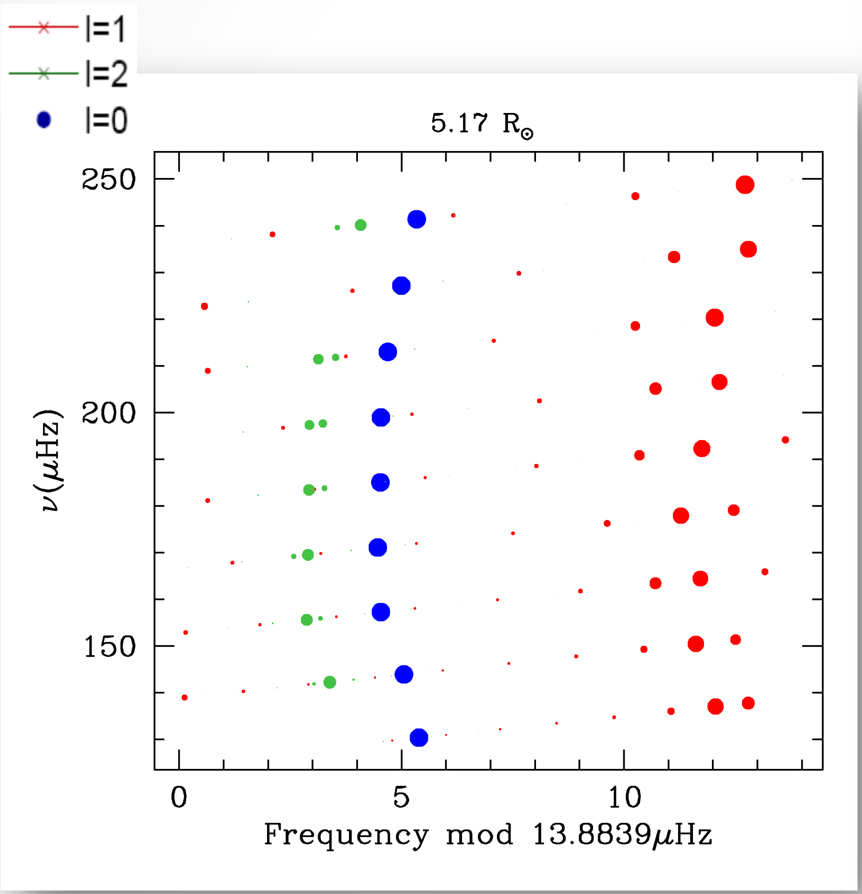


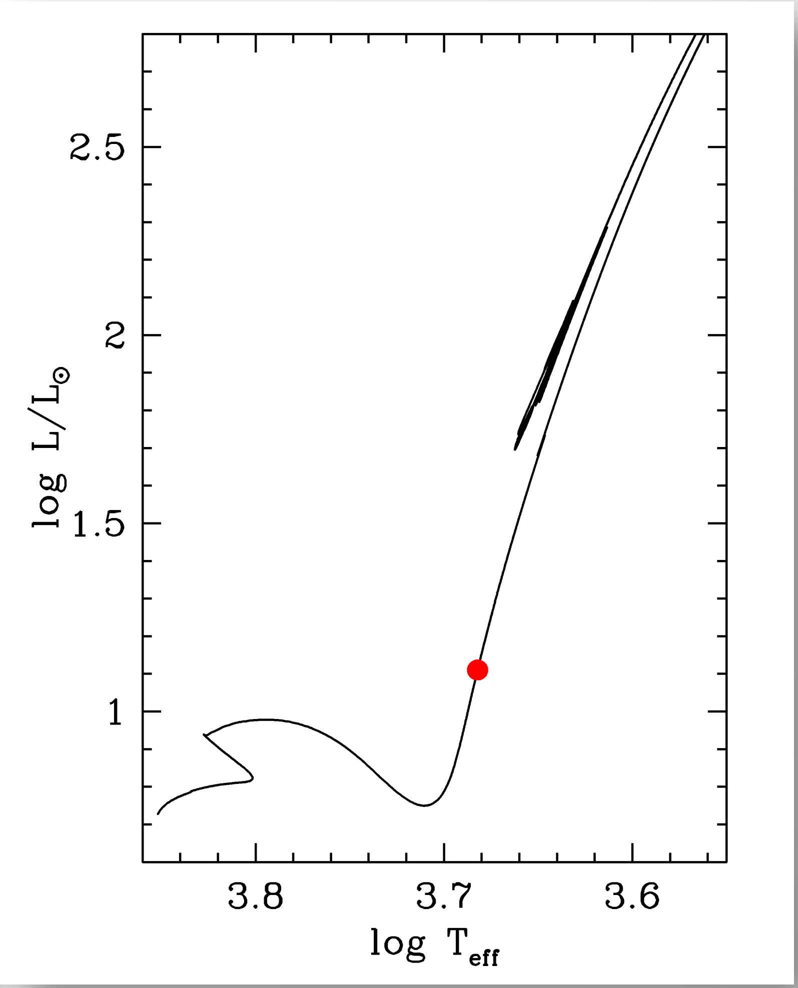
RedG evolution of a 1.5 Msun





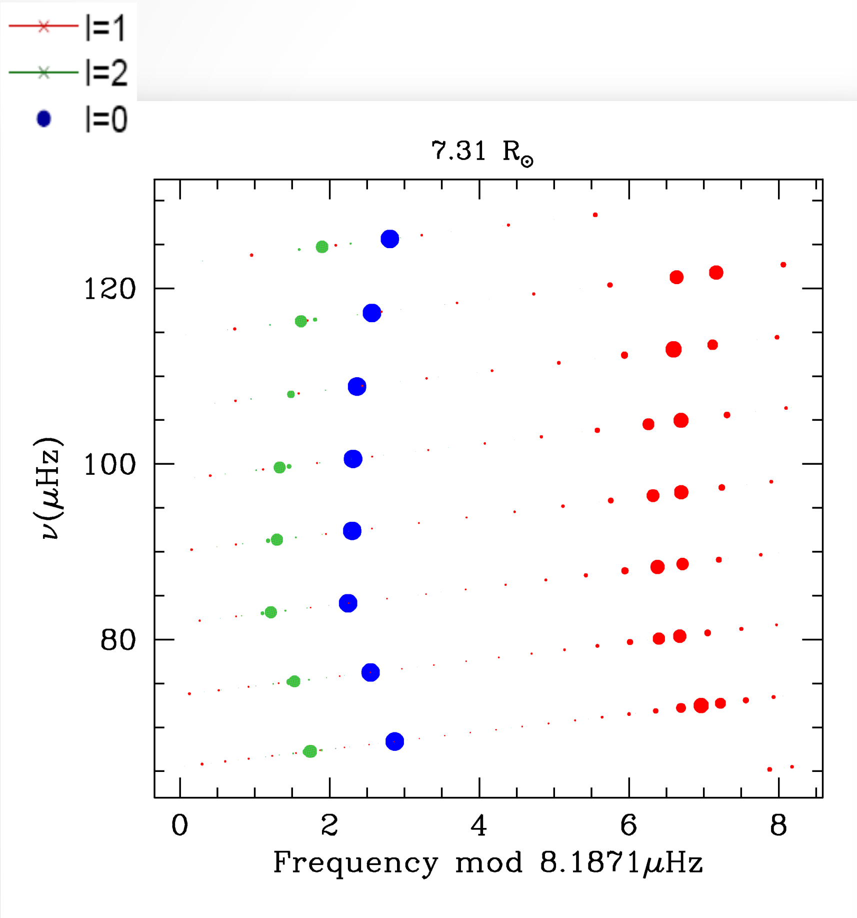
RedG evolution of a 1.5 Msun

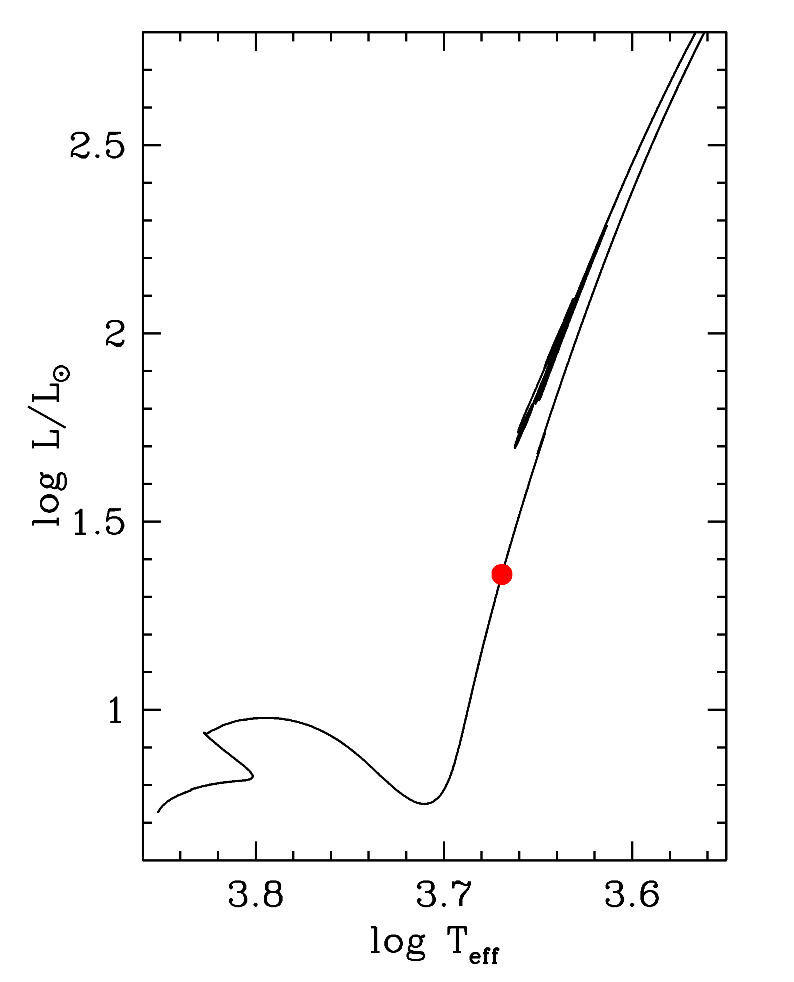




ΔP ~ 40-80s

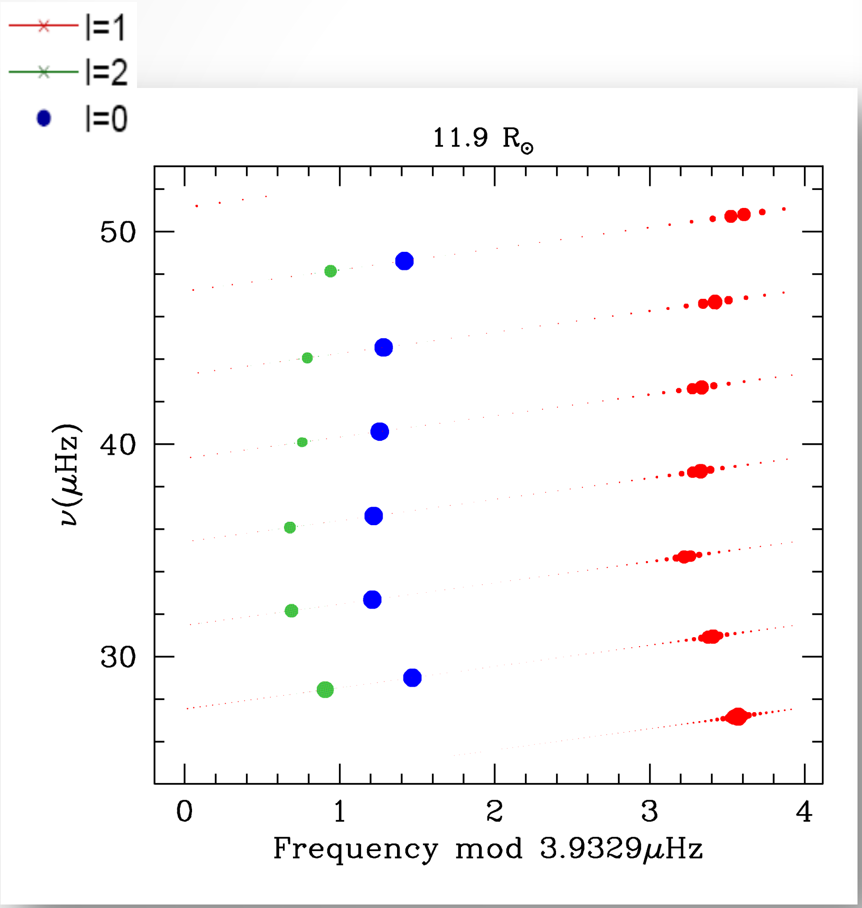
RedG evolution of a 1.5 Msun

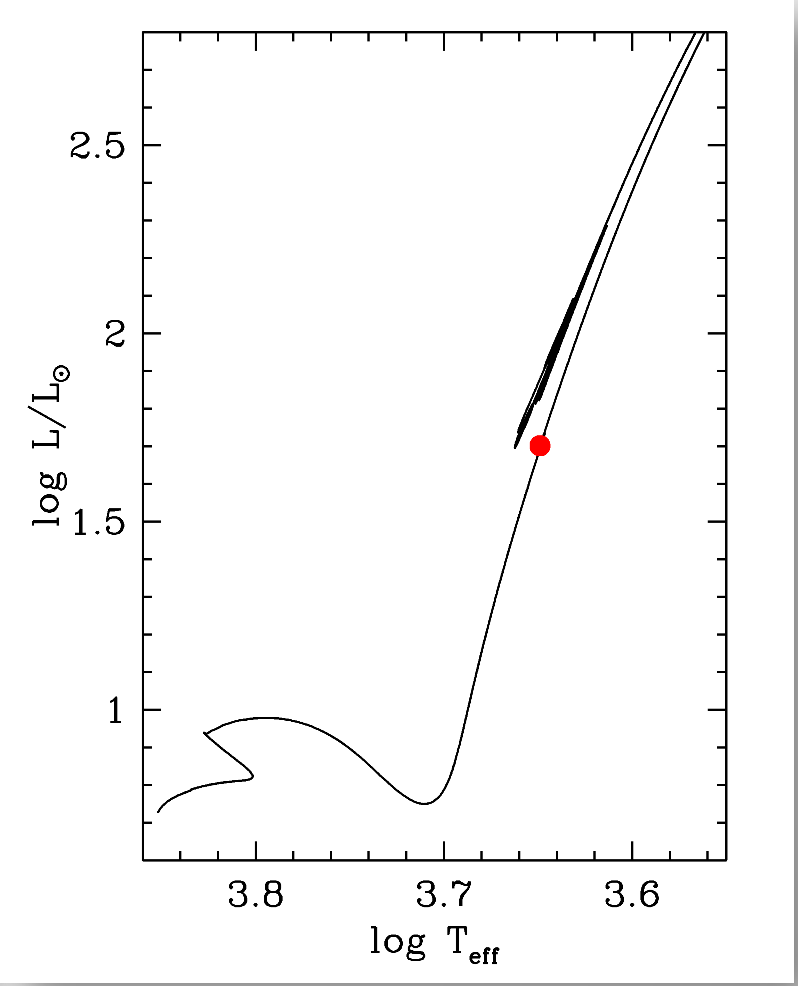




$\Delta P \sim$ 40-75s

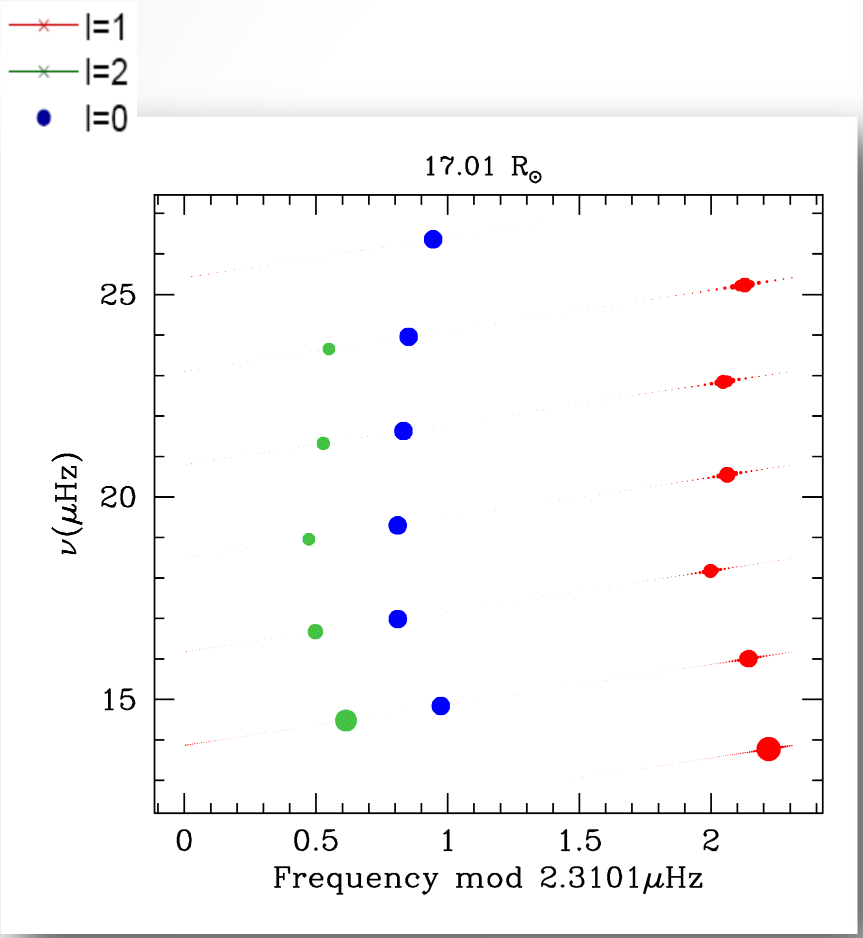
RedG evolution of a 1.5 Msun

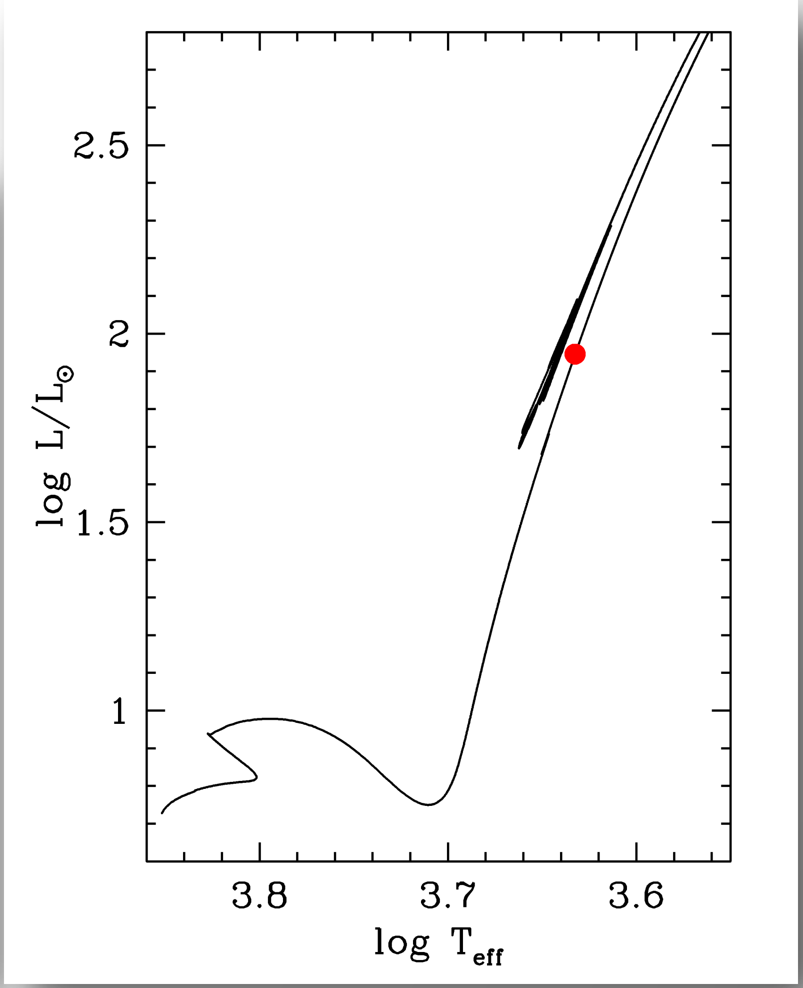




$\Delta P \sim 20\text{-}60s$

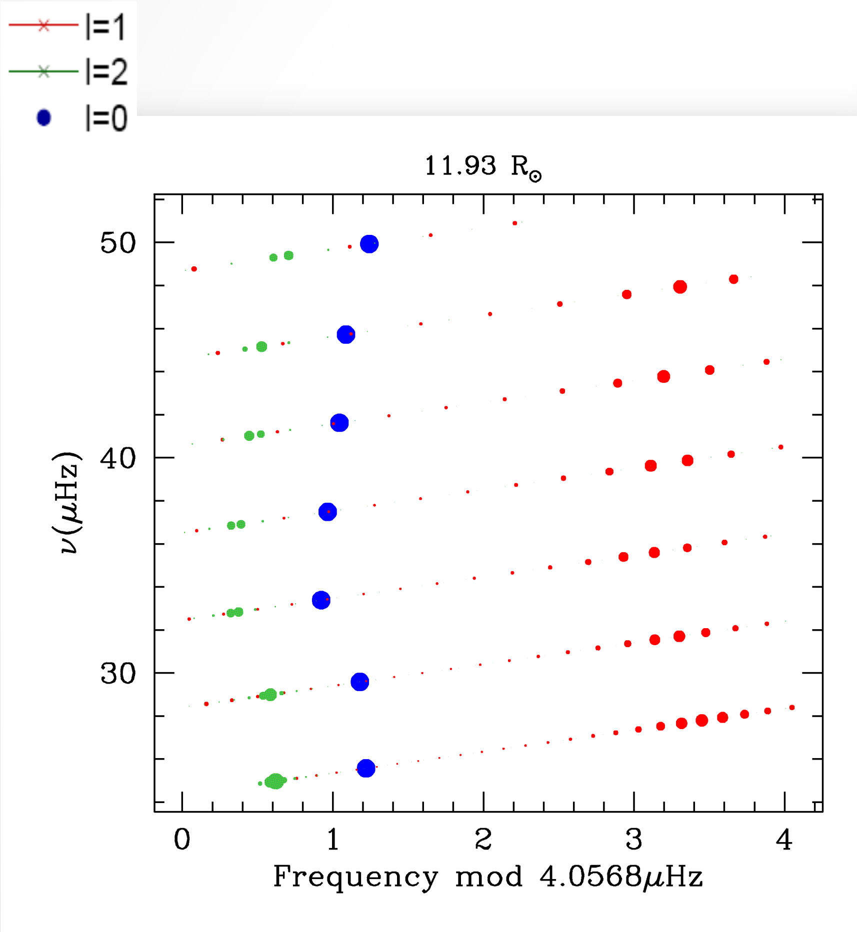
RedG evolution of a 1.5 Msun

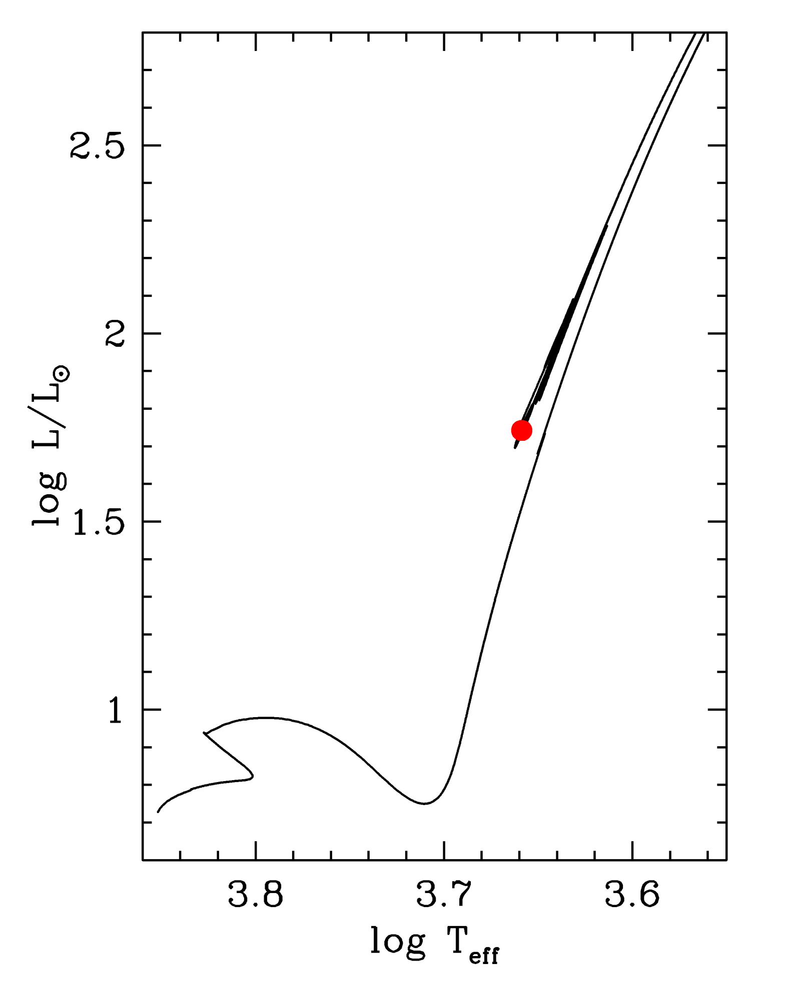




$\Delta P \sim$ 20-55s

RedG evolution of a 1.5 Msun

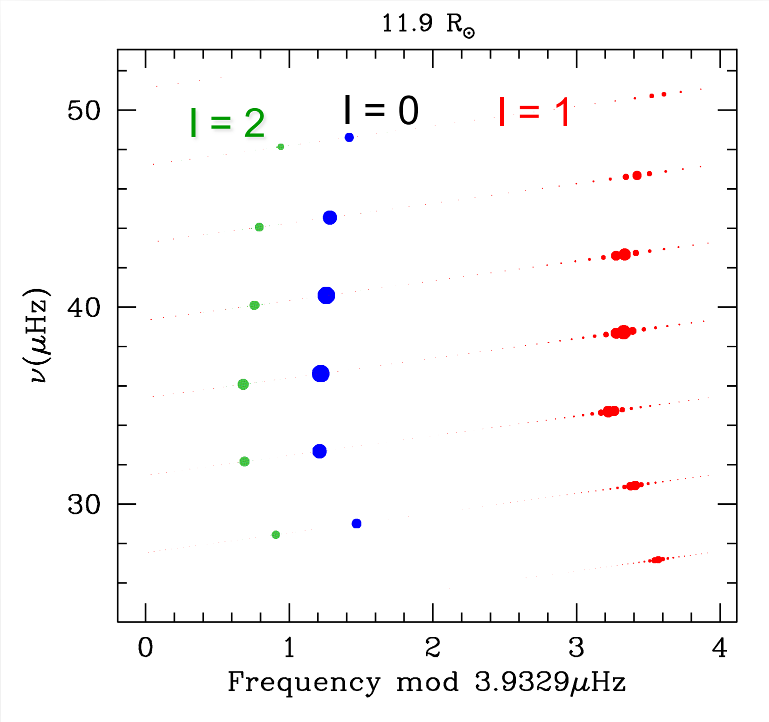




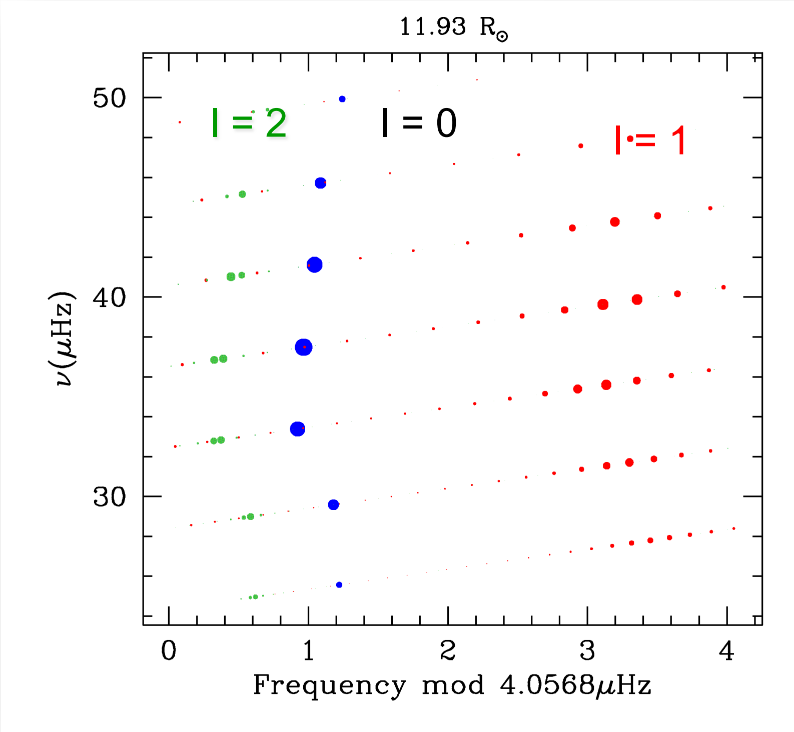
ΔP ~ 180-240s

Echelle Diagram : RC vs RGB

M=1.5 Msun

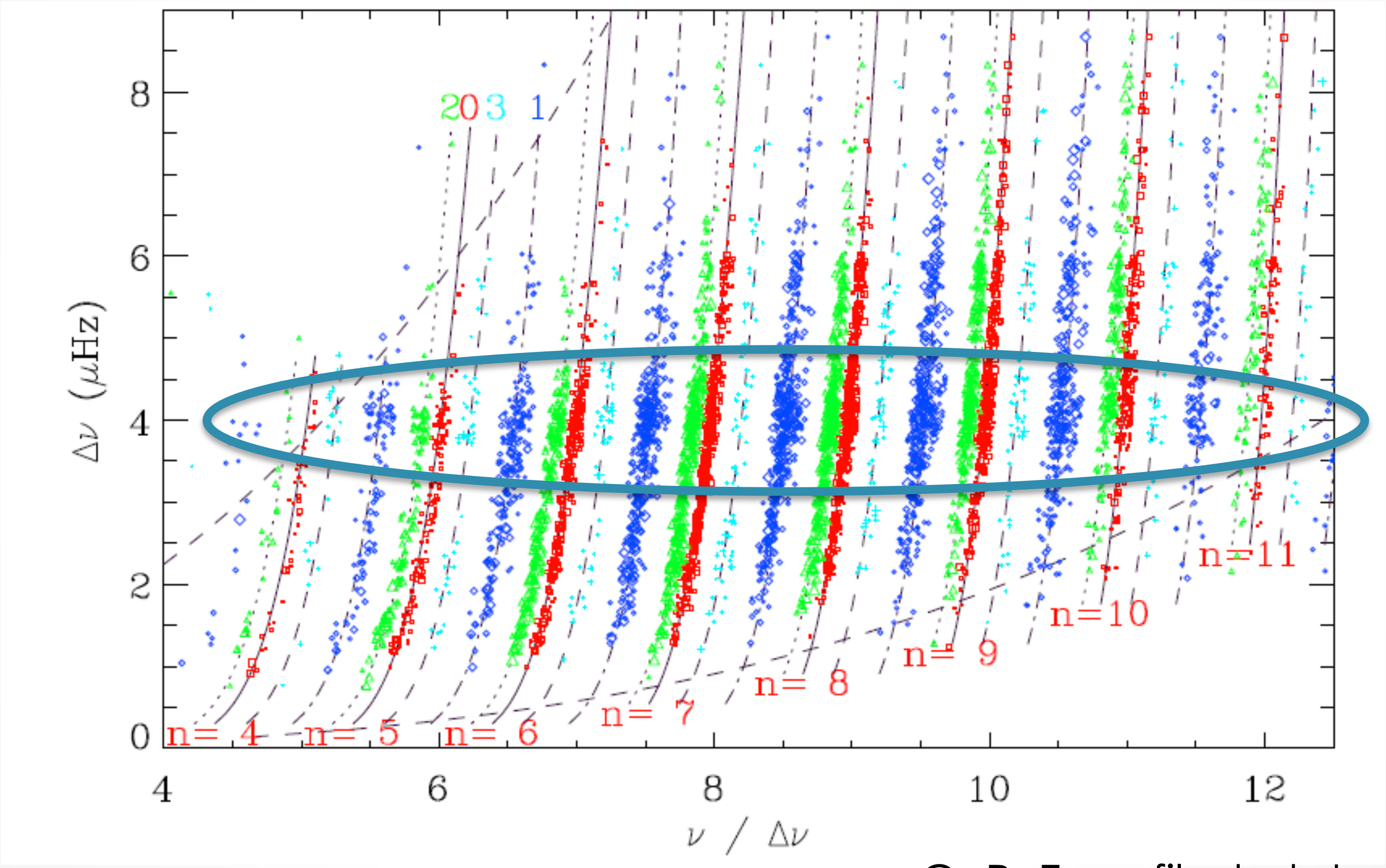


RGB



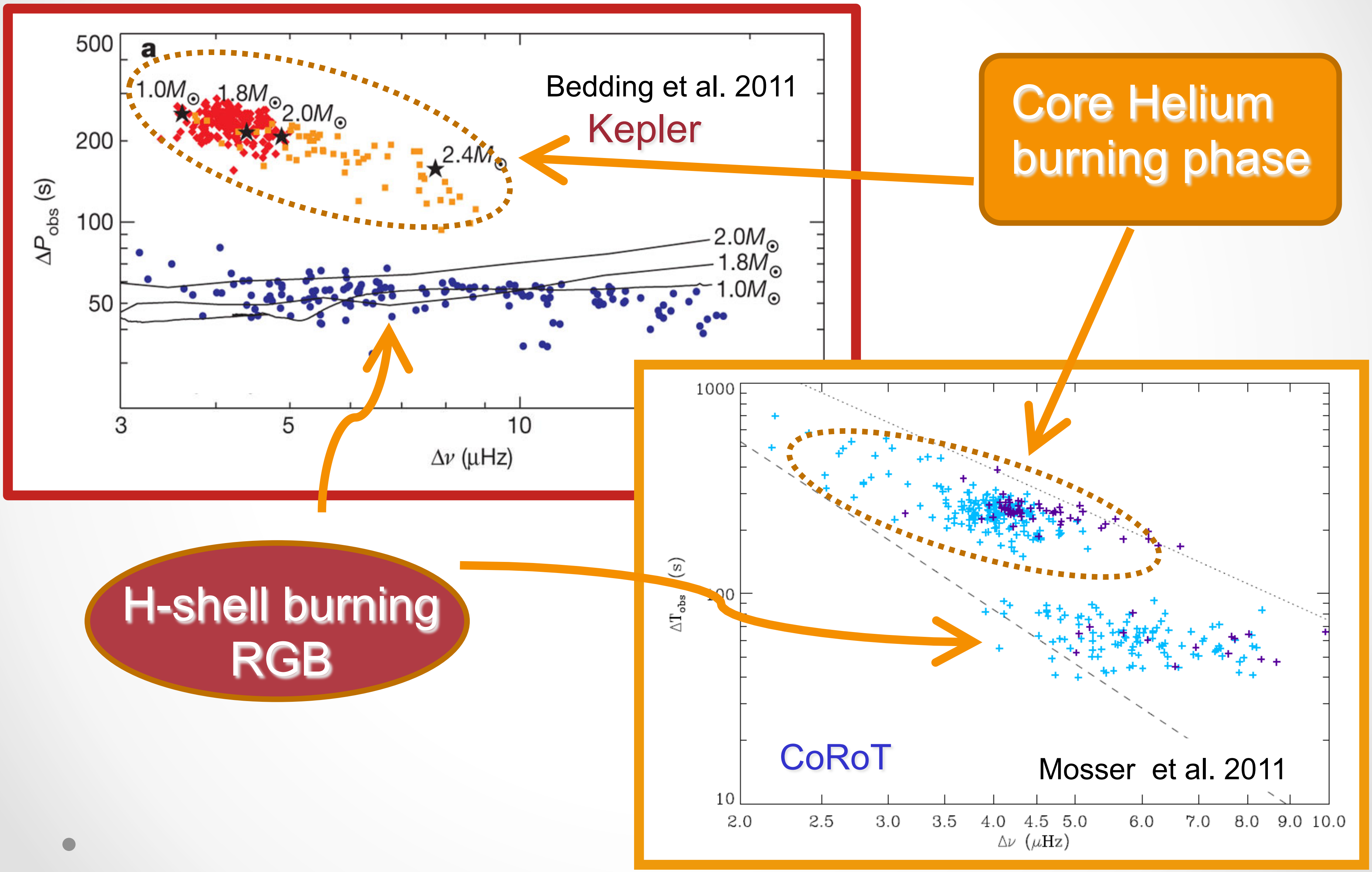
RC

Seismic parameters in exo RGs



CoRoT exofiled data
Mosser et al. 2010, A&A

Period spacing in red giants



Ensemble seismology of G-K giants

average seismic parameters:

$$\Delta\nu \simeq \sqrt{\frac{M/M_\odot}{(R/R_\odot)^3}}\Delta\nu_\odot$$

$$\nu_{\rm max} \simeq \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{T_{\rm eff}/T_{\rm teff\odot}}}\nu_{\rm max\odot}$$

+ $T_{\rm eff}$

STELLAR RADIUS → DISTANCE

STELLAR MASS → AGE (model dependent)

SURFACE GRAVITY → SPECTROSCOPY

Ensemble seismology of G-K giants

- Radius + T_{eff} → L
- apparent mag + BC → ℓ

→ $d^2 \propto L/\ell$

$$\log d = 1 + 2.5 \log T_{\rm eff} + \log \nu_{\rm max} - 2 \log \Delta\nu + 0.2 (m_{\rm bol} - M_{\rm bol\odot})$$

- ν_{max} and $\Delta\nu$ with 2.4% and 0.6% (Mosser et al. 2010)
- T_{eff} from 2MASS J and Ks photometry in EXODAT (σ ~0.02 mag) + colour-T_{eff} calibration (Alonso et al. 1999) ➔ $\sigma(T_{eff})$~ 190K
- Ks BC (Girardi et al. 2005)
- Galactic extinction (Drimmel et al. 2003) (σ(Av) ~0.3)

→ DISTANCE
10-15% uncertainty

Miglio et al. 2013 EDJ-Proc

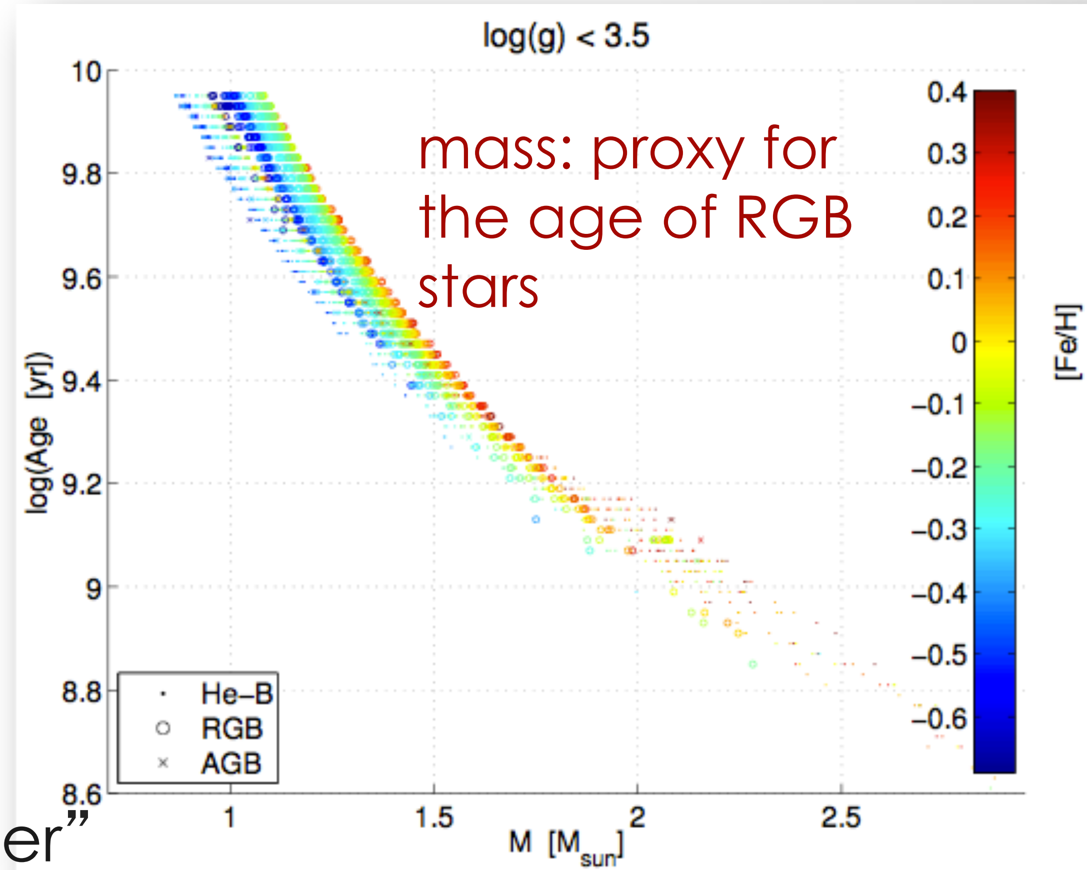
Ensemble seismology of G-K giants

- Mass ➡ age

Age-mass relation
GIANTS

+ ΔP ⬇

uncertainty ~ 40%



M+[Fe/H]: “chronometer” for evolved stars

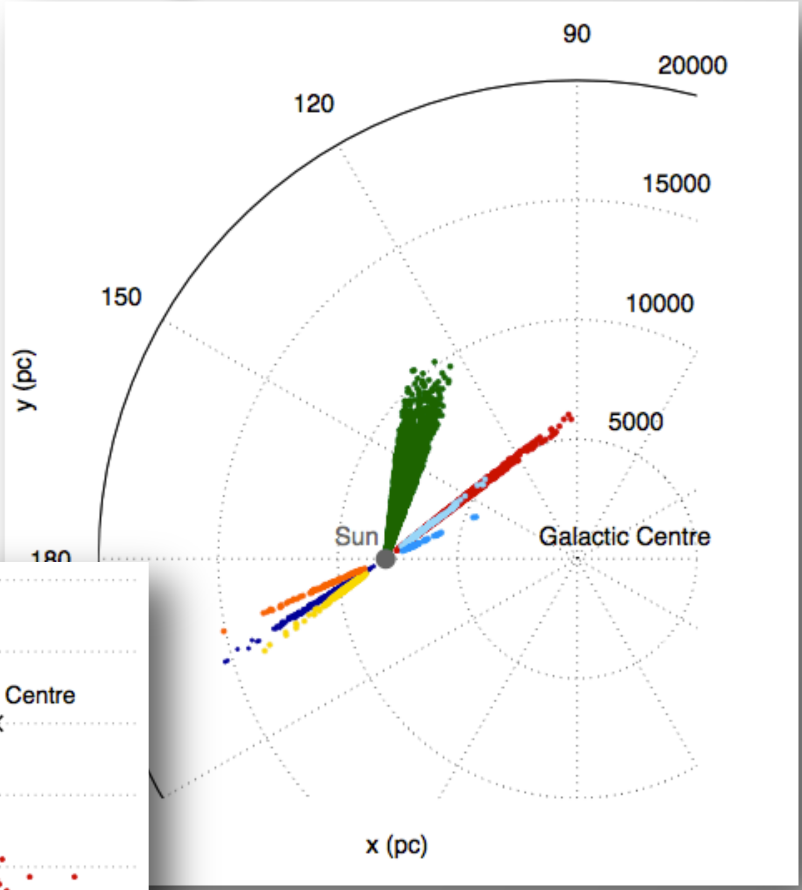
Uncertainty 15%

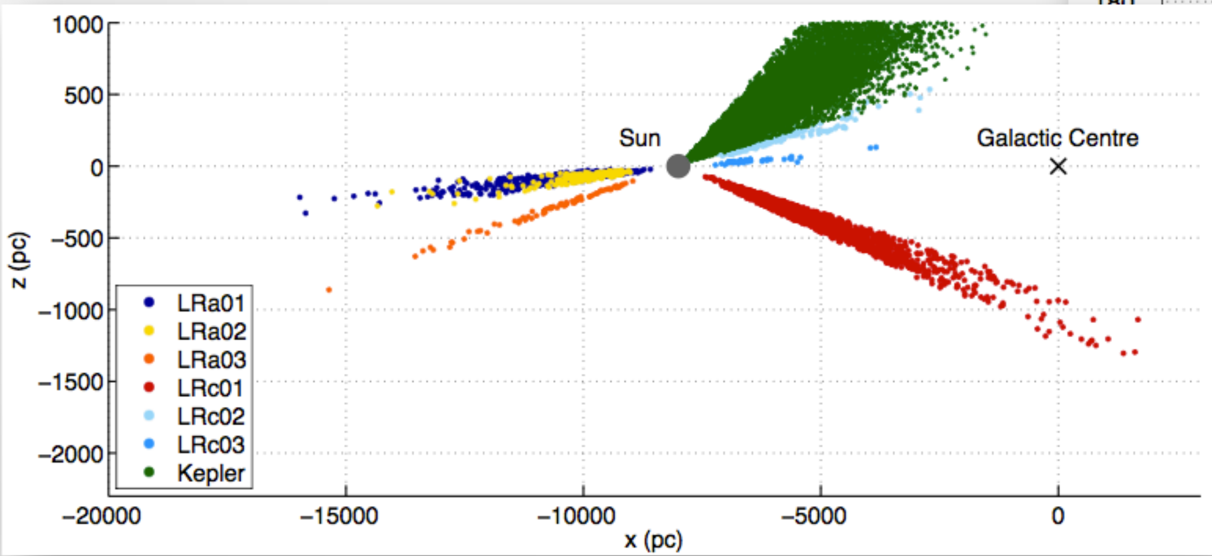
3D map of G-K giants

CoRoT LRs: ~ 2000 stars
Mosser et al. 2010

Kepler data: ~ 10000 stars
Hekker et al. 2011, Stello et al.

CoRoT provide M, R, ages and distances for Red Giants up to 10 Kpc from the Sun (Hipparcos 100 pc)





3D map of G-K giants

CoRoT LRs: ~ 2000 stars
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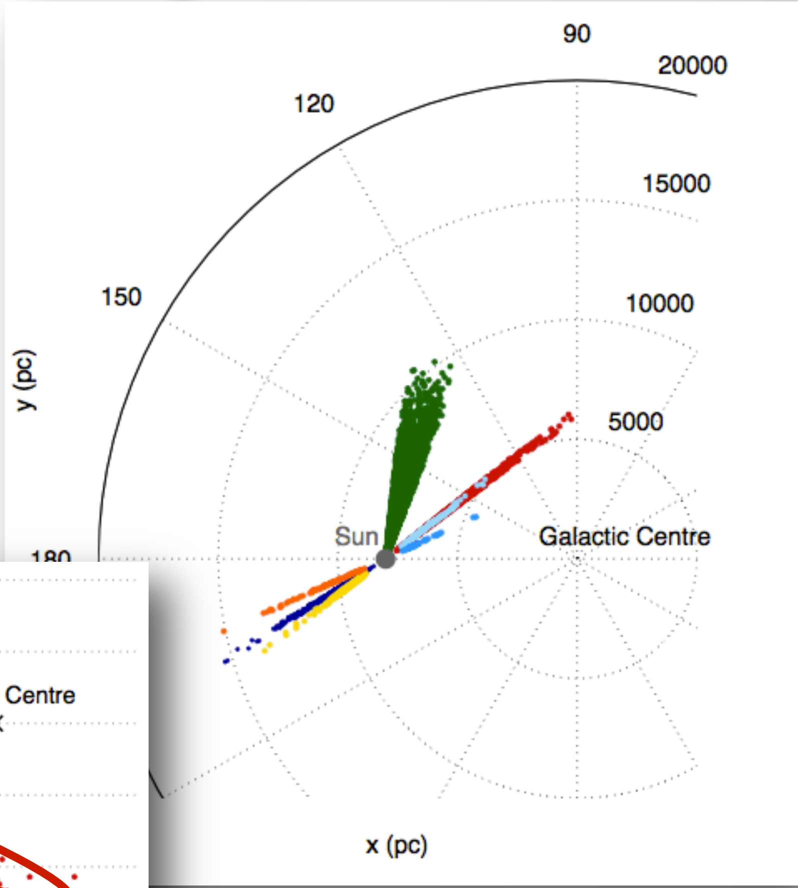
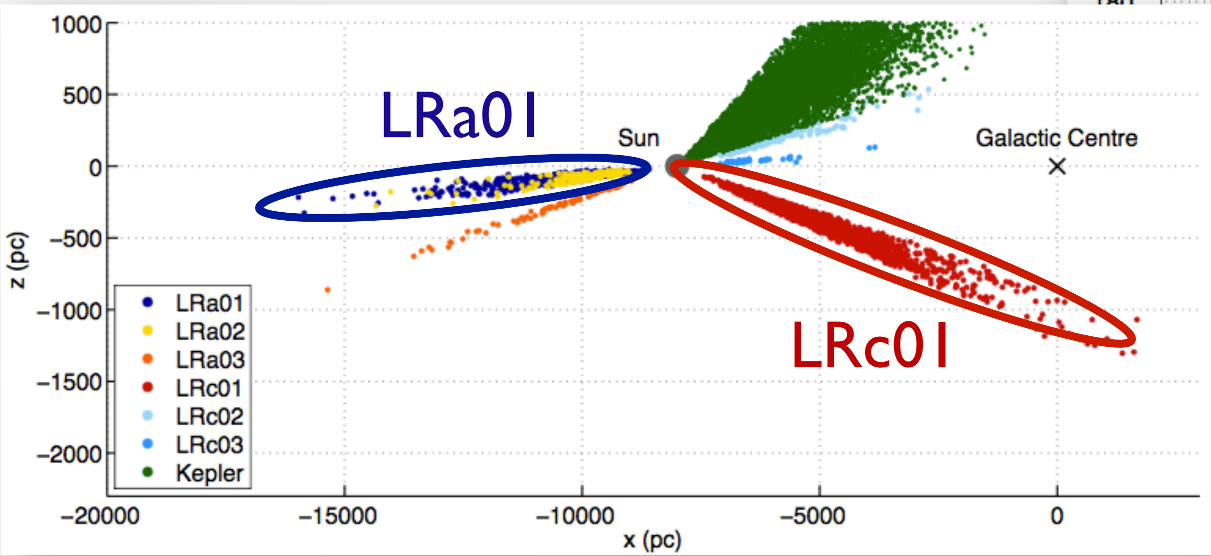
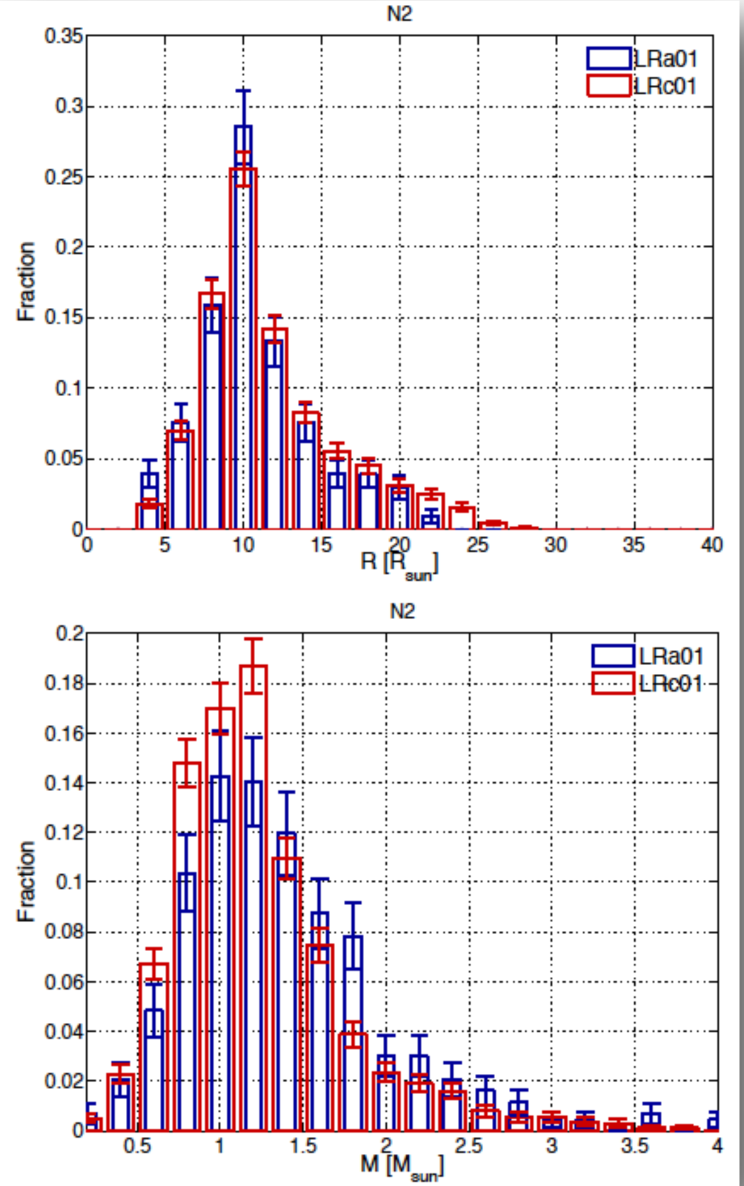
CoRoT LRa01+LRc01 => 2000 RGs with average seismic parameters





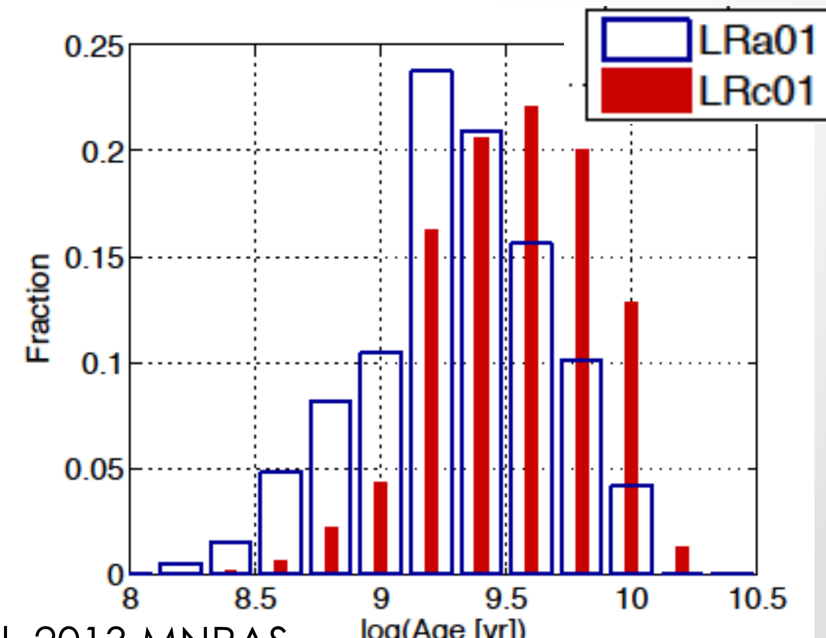
Early results: differential population studies



Different distribution of M in the center and anticenter directions

zLRa01 < zLRc01

Different ages LRc01 sample older thanLRa01



Miglio et al. 2013 MNRAS

RG seismo & structure and evolution of the Milky Way

To understand the mechanisms involved in the formation and evolution of the Galaxy, information on: KINEMATICS, CHEMISTRY, LOCATION and AGE of the stars in different regions of the Milky Way are needed.

seismology of giants in CoRoT and *Kepler* fields

\+

chemo-dynamical constraints from spectroscopic analyses

→

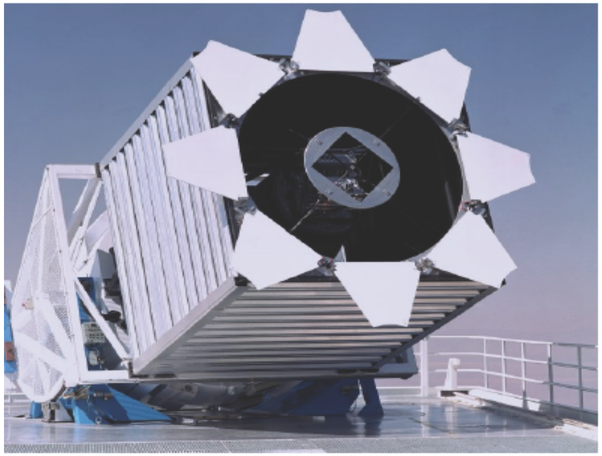
Age-metallicity
Age-RV
gold standard for current and future surveys of the Milky Way

"Red Giants as Probes of the Structure and Evolution of the Milky Way" , ApSS , Rome 2010

Structure and evolution of the Milky Way : colab. & surveys

❑ APOGEE

- H-band survey of Galactic populations (H < 12.5)
- 100,000 stars (80% red giants)
- R~22500, S/N=100
- Chemical abundances (0.1dex)
  15 elements – including : C, N, O, Na, Mg, Ca, Mn, Fe, Co, Ni
- Velocity error= 0.5 km/s
- Targeted from 2MASS



SDSS 2.5-meter telescope
at the Apache Point Observatory, NM
Image Credit: Sloan Digital Sky Survey

Already observed ~ 420 CoRoT RGs

CoRoT => logg to APOGEE
APOGEE => [Fe/H]

Under Discussion

Structure and evolution of the Milky Way : collab. & surveys

- HERMES-GALAH : Galactic archaeology with HERMES

HERMES multi-object high-resolution spectrometer on the Anglo Australian Telescope to measure abundances for up to 30 elements in about a million stars.

Already observing LRa01/c01 targets during commission time

- GAIA-ESO survey:

Gaia-ESO Public Spectroscopic Survey, a 300-night survey of all Galactic Stellar Populations, using FLAMES (both GIRAFFE and UVES) on the VLT's Unit Telescope 2 (UT2).

So far, only 15 targets for calibration of their pipeline

Structure and evolution of the Milky Way : colab. & surveys

- ESO proposal :Galactic archaeology: mapping and dating stellar populations by combining CoRoT photometry of red giants

  with spectroscopy => 1500 RedG in LRc01 with FLAMES
  180 RedG in LRc01 with UVES

  ?

- **Stromgren photometry** available for IRa01, LRc01, LRa01,
  LRc02,LRc03, LRc04, SRc01, LRa03,SRa01,
  SRa02, LRa02,LRc05, LRc06
  Hbeta for LRc01, LRc02,LRc03
  (I. Ribas, L. Ballaguer, C. Maceroni)
  Under analysis

Red Giants in CoRoT

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LRc01	3988	1400	Mosser et al. 2010 A&A
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LRa05	664		
LRa06	1099		

Next

- Analysis and re-analysis of all exofields using the same criteria of target selection and tools

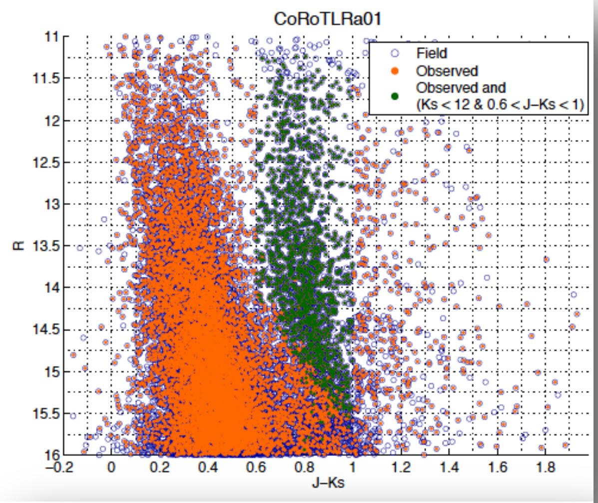
- Better selection:

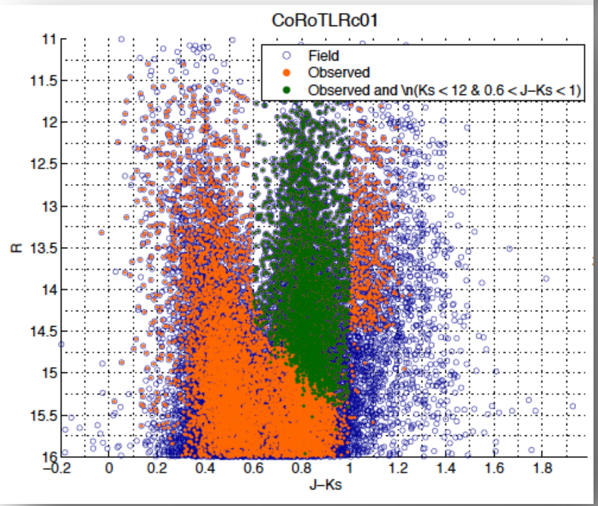
  J-Ks > 0.5/0.6 & R< 15 or R <16

- Test on LRc07 =>

  Eliminate binaries from sample

  Provide LC clean enough to run available pipelines on large number   of targets => col. detection team



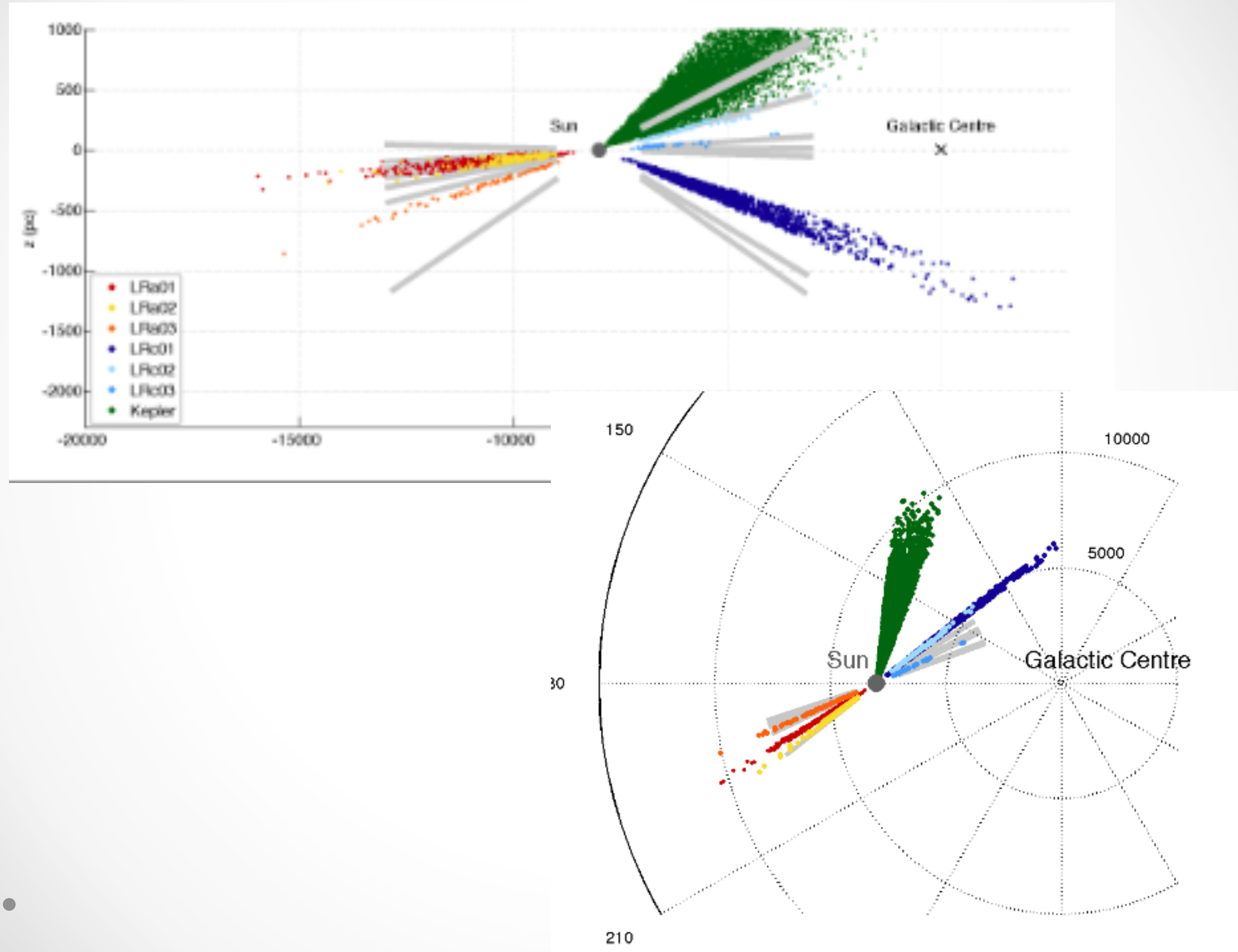


CoRoT extension program

Simulations utilisant le modèle de Galaxie Triegal donnant des estimations du nombre total de géantes rouges, de la population du disque mince, du disque épais du halo et du bulge,.

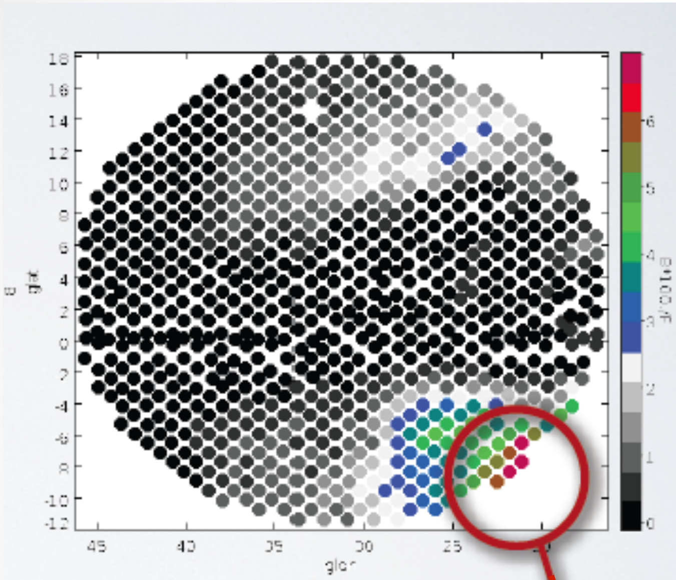
block	NT	Thin D	Thick D	H	B
1859	1431	1400 (98.9%)	14 (1%)	2 (0.14%)	0
1861	1258	1242 (98.7%)	15 (1.2%)	1 (0.08%)	0
1863	1258	997 (97.75%)	22 (2.15%)	1 (0.1%)	0
1864	2807	2788 (99.3%)	17 (0.6%)	2 (0.07%)	0
1865	272	250 (92%)	20 (7.35%)	2 (0.74%)	0
1866	1404	1179 (83.97%)	137 (9.76%)	39 (2.8%)	49 (3.5%)
1867	1226	945 (77%)	131 (10.7%)	48 (3.9%)	102 (8.32%)
1868	789	621 (78.7%)	99 (12.55%)	34 (4.3%)	35 (4.4%)
1869	590	585 (99.15%)	3 (0.5%)	1 (0.17%)	1 (0.17%)
1871	1184	1164 (98.3%)	14 (1.18%)	3 (0.25%)	3 (0.25%)
1872	1231	1197 (97.24%)	24 (1.95%)	6 (0.5%)	4 (0.3%)
1873	3338	3315 (99.3%)	21 (0.63%)	2 (0.06%)	0
1874	974	824 (84.6%)	74 (7.6%)	29 (3%)	47 (4.5%)

+ BULGE



1000
500
0
-500
-1000
-1500
-2000
z (pc)
-20000
-15000
-10000
Sun
Galactic Centre
LRa01
LRa02
LRa03
LRc01
LRc02
LRc03
Kepler
150
10000
5000
Sun
Galactic Centre
210

The Bulge



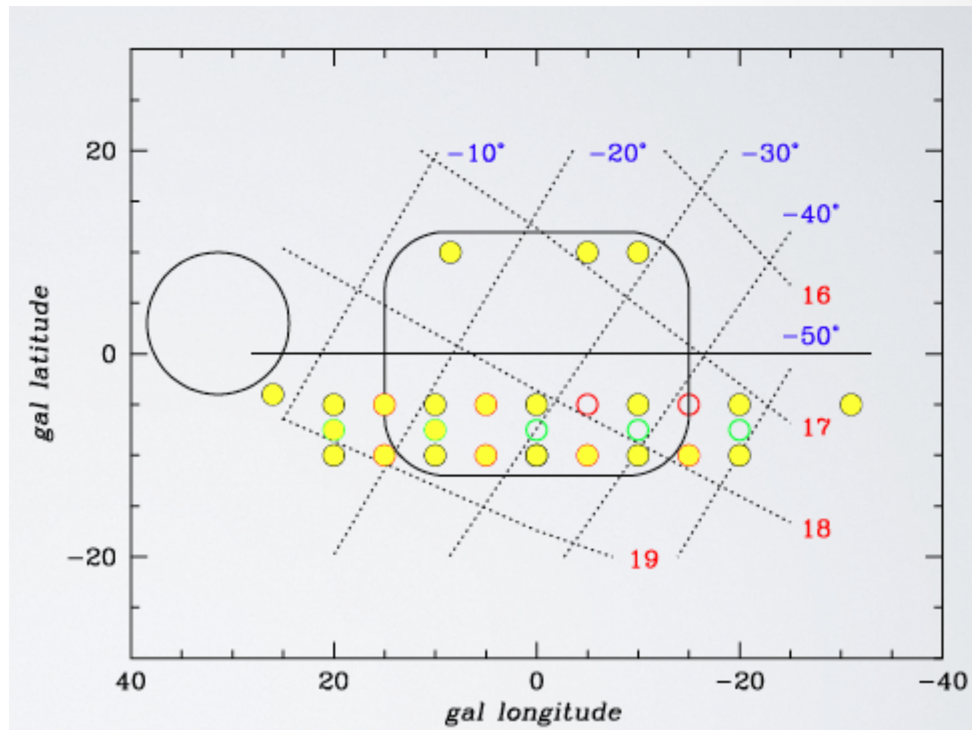
5 < νmax < 100 μ Hz

(l,b)=(~22,~-8)

Percentage of Bulge giants
respect the total number of stars .

Barbieri, Miglio, Girardi, in prep.

(l,b)=(~22,-8)
in a 4deg^2 field
there are ~24k stars,
of which ~19k giants.
R <15 (K. Freeman)



Spectroscopic survey by K. Freeman

Target	Run	time(d)	$\Delta\nu$	ν_{max}	ν´s	spec	
HD49566	SRa01	27	X	X		X	Hekker+2011 (AstroPH)
HD50890	IRa01	55	X	X	X	X	Baudin+2012A&A
HD169370	LRc03	90	X	X		X	Hekker+2011 (AstroPH)
HD169751	LRc03	90	X	X		X	Hekker+2011 (AstroPH)
HD170008	LRc03	90	X	X	X	X	Baudin (prep)
HD171427	LRc02	150	X	X	X	X	No oscillations
HD175679	SRc01	27	X	X		X	
HD181907	LRc01	150	X	X	X	X	Carrier+2010A&A, ApSS, Miglio+2010 A&A
HD45398	SRa04	55	X	X		X	
HD49429	SRa01	27	X	X		X	
HD170031	LRc07/08	169	X	X	X	X ❍	NGC6633 !!!!
HD170053	LRc07/08	169	X	X	X	X	NGC6633
HD170174	LRc07/08	169	X	X	X	X	NGC6633
HD170231	LRc07/08	169	X	X	X	X	NGC6633
HD169689	LRc04/10	169	X	X		X ❍	
HD49161	SRa01	27					
HD48976	SRa01	27					
HD174323	SRc02	24					
HD178484	LRc09	86	X	X		X ❍	

CoRoT potential

- Nearby giants with accurate Π
- Binary systems
- Stellar clusters

→ Independent estimate of stellar parameters & Test of scaling relations

- Nearby giants : ground follow up (RV)

Results from RG in seismo field

- **HD 50890** : Massive red giant (3-5$M_\odot$) NO evident dipole mode (Baudin et al 2012 A&A)

- **HD 181907**: low mass Red G (1.2 $M_\odot$) R=12.2 $R_\odot$ in agreement with its parallax . (Carrier et al 2010, A&A)

  First detection of HeII signal in a red giant (Miglio et al. 2010, A&A)

Periodic components in ν

Signature of an acoustic glitch in the star!!

$$\delta\nu = A(\nu)\cos\left(4\pi\tau_0\nu + \phi\right)$$

$$\tau_0 = \int_{r_0}^{R} \frac{\mathrm{d}r}{c}$$

$$t_0 = T - \tau_0 = \left(2\left\langle\Delta\nu\right\rangle\right)^{-1} - \tau_0$$

acoustic depth

acoustic radius

Period ⟷ acoustic depth (*)

e.g. Gough 1990

Results from RG in seismo field

- **HD 50890** : Massive red giant (3-5$M_\odot$) NO evident dipole mode (Baudin et al 2012 A&A)

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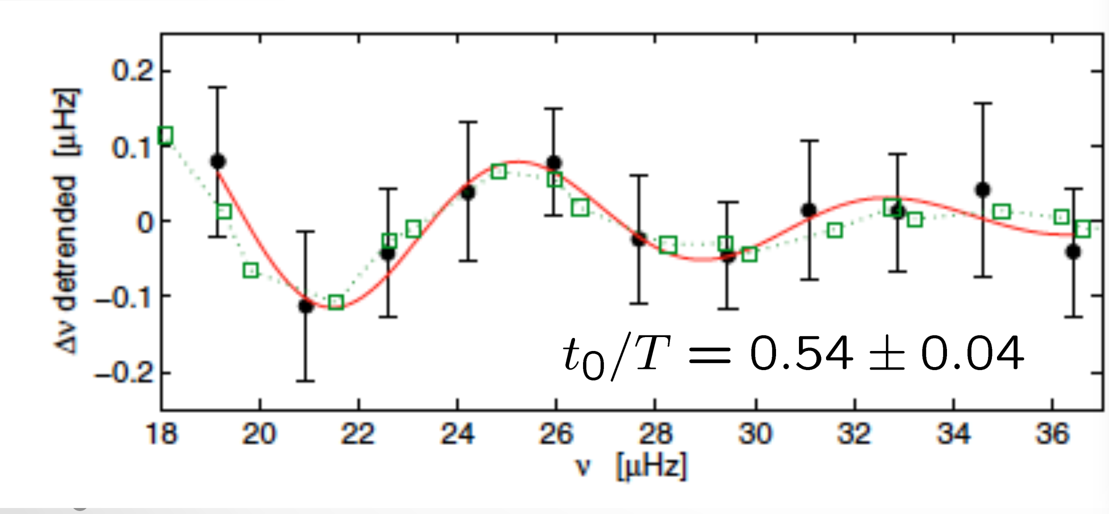
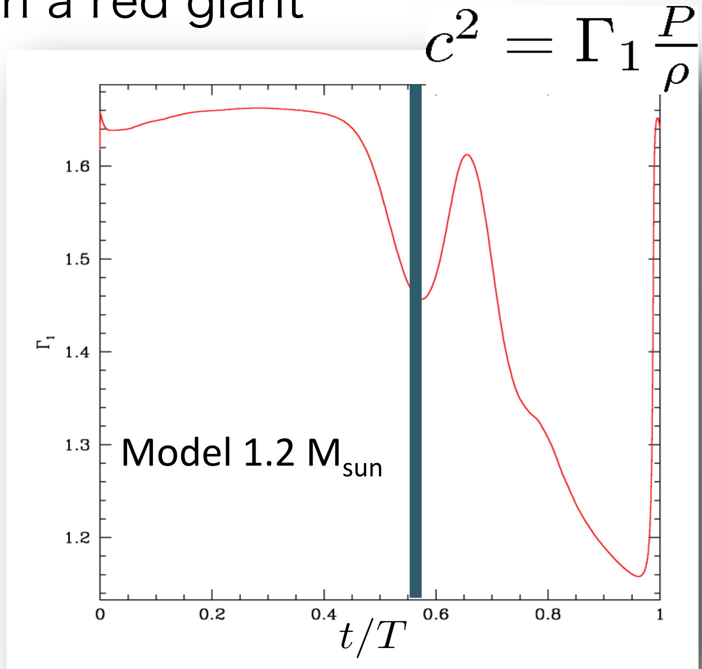




Results from RG in seismo field

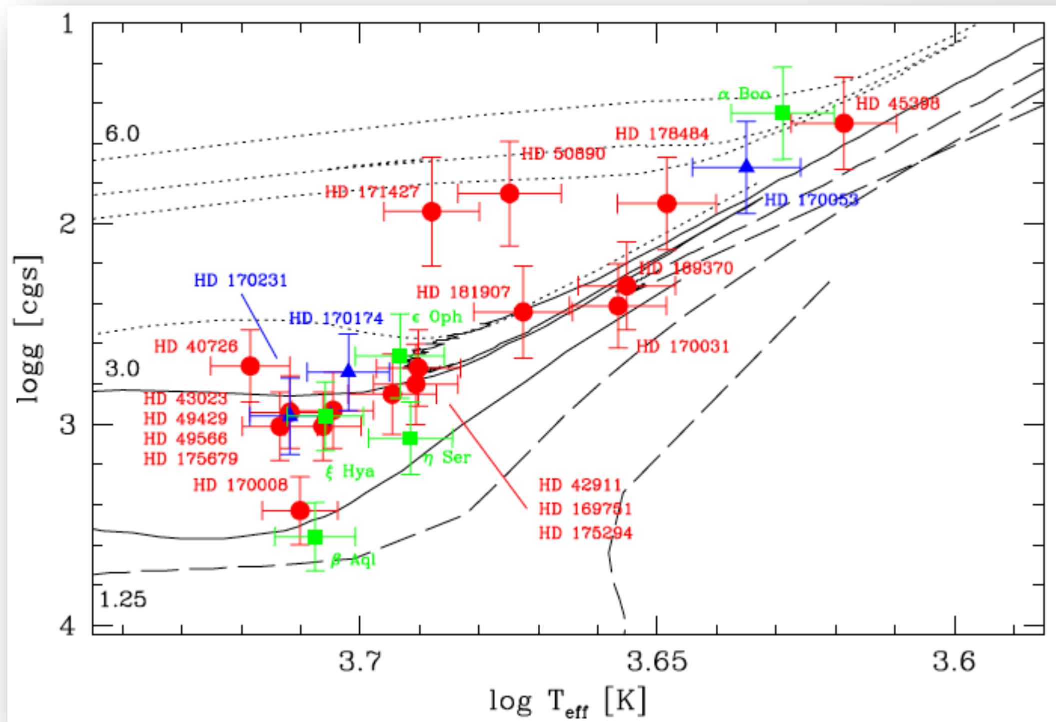
Spectroscopic follow up of RGs with HARPS & FEROS

Teff , log g, [Fe/H]
& individual elements

Check of seismic gravities

Seismic constraints =>
M and evolutionary stage

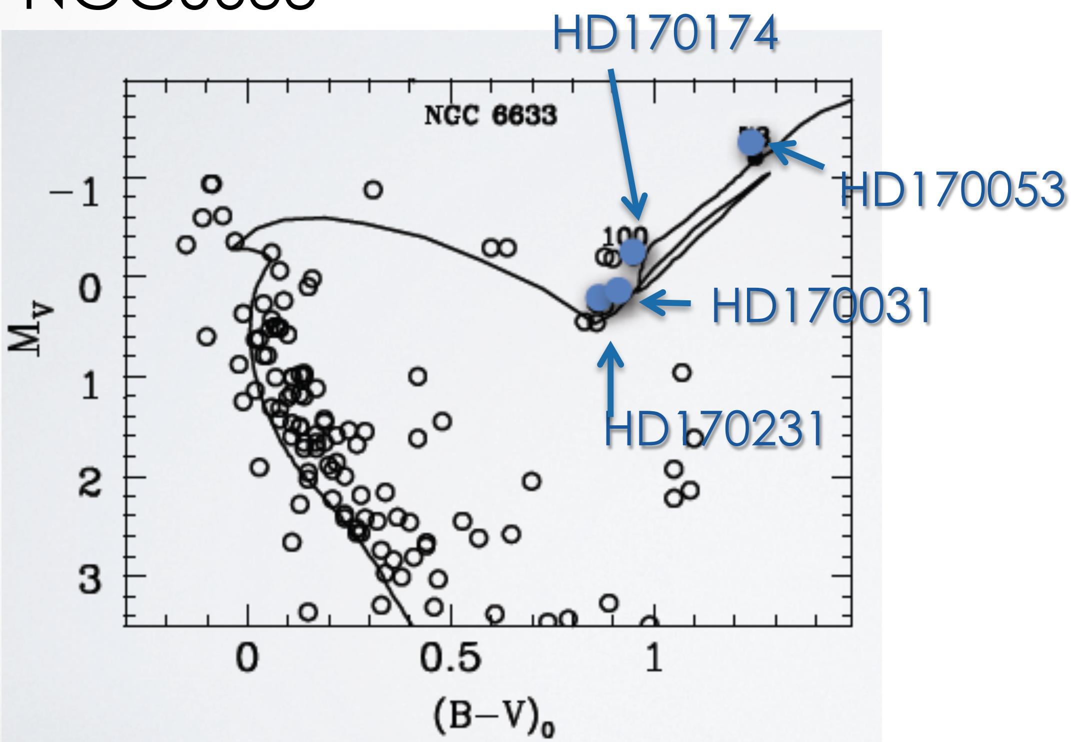
Better interpretation of abundance results.
In particular that of elements indicating mixing



Morel et al. 2013, in prep

Red Giants in a cluster

NGC6633



Smiljanic et al. 2009

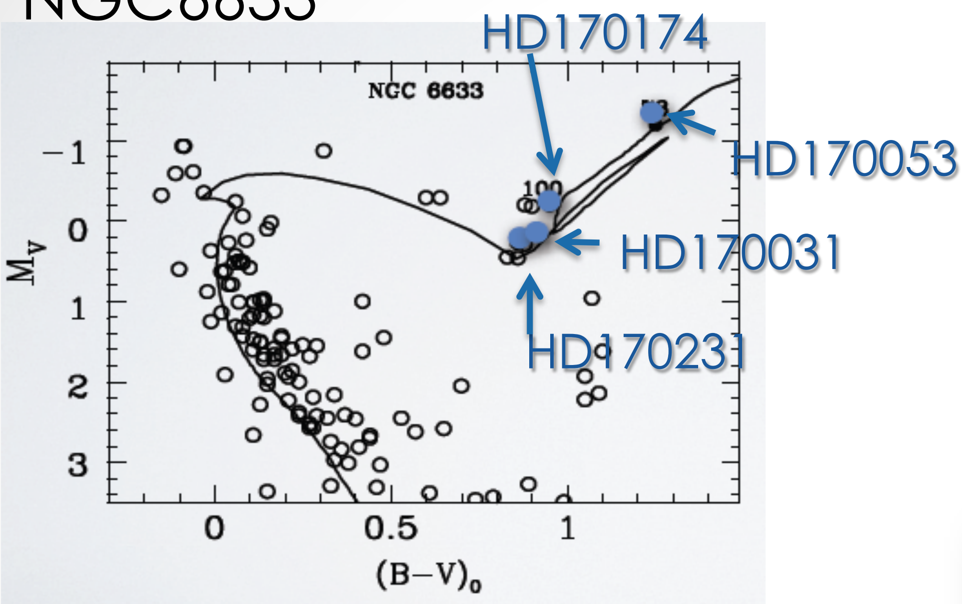
Observed during LRc07&LRc08

$M_{clump} \sim 2.8 M_{\odot}$

$d_{\odot}$=375pc (van Leeuwen 09)

[Fe/H]=-0.04 -- -0.096
(Jeffreis et al. 02
Paunzen et al. 10)

NGC6633



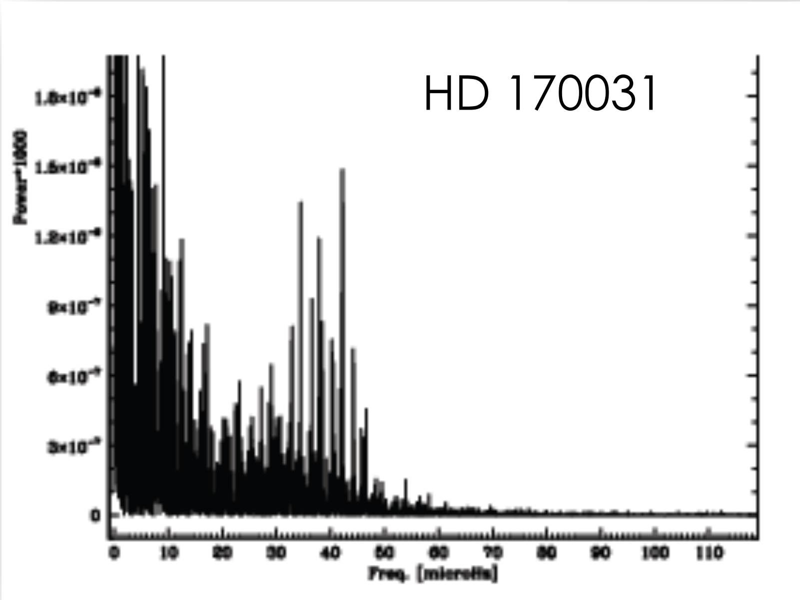
Individual freqs:

HD 170174
HD 170231
HD 170053
HD 170031

15-30 modes

RV, M and Ba abundance

HD 170031 No member



- ✓ Atmospheric parameters derived (Morel et al. 2013 in prep)
- ✓ Global seismic parameters: ν_{max} & $\Delta\nu$ from 3 diff. groups

First estimate of R & M

Credit E. Poretti

Radial Velocity campaign

Simultaneous radial velocity campaign

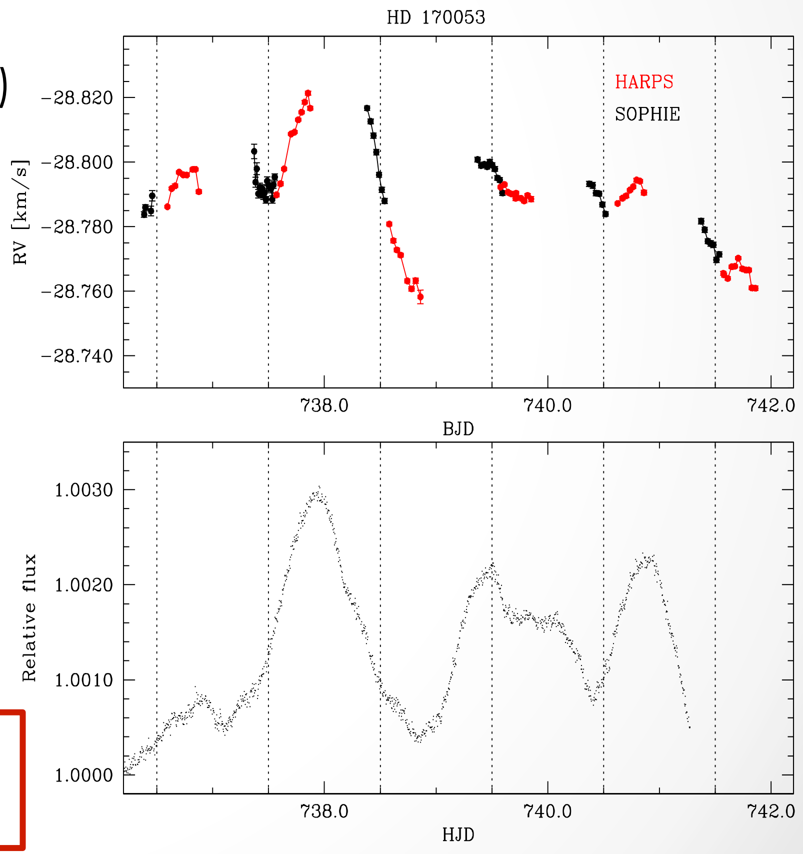
HARPS (PI. E. Poretti) + SOPHIE (PI P. Mathias)

Amplitude ratio in RV and I

Excitation and damping mechanisms
Convection

➔ Kevin's talk

RV campaign for 3 RGs in NGC6633
+ HD178484 + HD45398 + 1 dwarf



Conclusions

ESO-ESA Working groups Report #4 on Galactic populations, Chemistry and Dynamics (Turon et al. 2008) did the following recommendation to ESA :

"Asteroseismology: this is a major tool to complement Gaia with respect to age determinations. ESA should encourage the community to prepare for a next-generation mission, which would sample the different populations of the Galaxy much more widely than CNES-ESA's Corot (50 targets, mainly main-sequence stars with a metallicity close to solar) and NASA's Kepler (mainly main-sequence stars, some giants and pulsating stars)".

BUT

CoRoT and Kepler missions have already observed several thousands of red giants in different directions (16) of the Milky Way, and therefore they are able (once chemical composition added) to provide a precious complement to GAIA measurements for the study of the structure, formation and evolution of the Galaxy.