Bayesian Ages from Asteroseismology

Aldo Serenelli
Institute of Space Sciences (CSIC-IEEC)
Bellaterra, Spain

Bayesian Inference

Model $\vec{M}$ characterized by certain information; ie. prior probability $p(\vec{M})$

Set of observations (evidence) $\vec{O}$

Characterize the posterior probability of $\vec{M}$, ie. its probability given $\vec{O}$

$$p(\vec{M}|\vec{O}) = \frac{p(\vec{O}|\vec{M})p(\vec{M})}{p(\vec{O})}$$

prior → $p(\vec{M})$

likelihood → $p(\vec{O}|\vec{M}) = \mathcal{L}(\vec{M}|\vec{O})$

marg. likeli. → $p(\vec{O}) = \int p(\vec{O}|\vec{M})p(\vec{M})\, d\vec{M}$

Any model quantity(ies) PDF then obtained from

$$p(x_i) = \int \delta(x_{\vec{M}} - x_i)\, p(\vec{M}|\vec{O})\, d\vec{M}$$

Bayesian Inference

Minimalist parameter space appropriate when using individual frequencies

$\vec{M} \equiv (\mathcal{M}_{\rm ini}, \tau, Z \text{ or } [\mathrm{Fe/H}]) \longrightarrow D_Y = \Delta Y / \Delta Z$

Bayesian Inference

Minimalist parameter space appropriate when using individual frequencies

$$\vec{M} \equiv (\mathcal{M}_{\rm ini}, \tau, Z \text{ or } [\mathrm{Fe/H}]) \longrightarrow (\mathcal{M}_{\rm ini}, \tau, Z, Y)$$

Bayesian Inference

Minimalist parameter space appropriate when using individual frequencies

$$\vec{M} \equiv (\mathcal{M}_{\rm ini}, \tau, Z \text{ or } [\mathrm{Fe/H}]) \longrightarrow (\mathcal{M}_{\rm ini}, \tau, Z, Y)$$

When using global seismic parameters from scaling relations

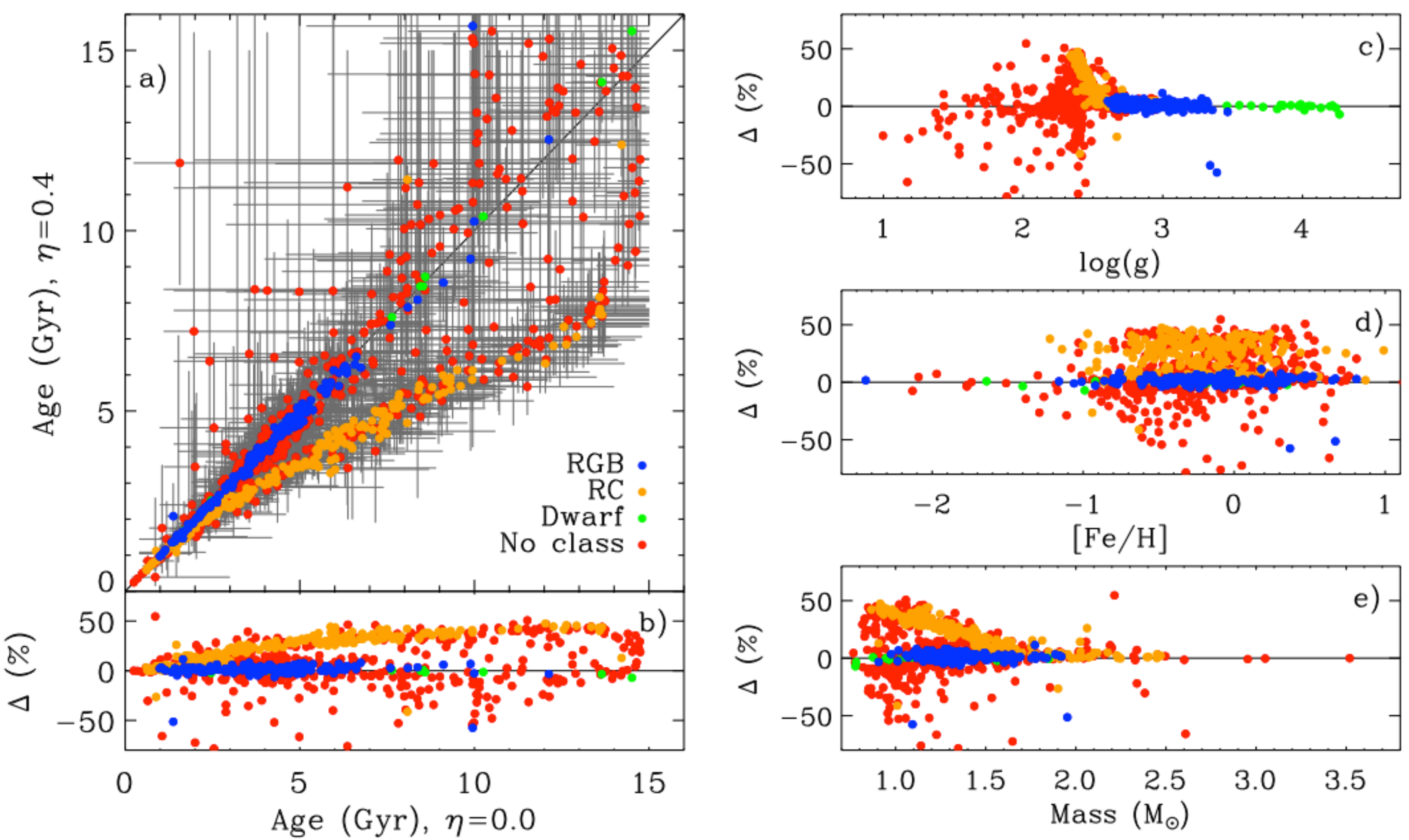
$$\nu_{\rm max} = \nu_{\rm max,\odot} \frac{g/g_\odot}{\sqrt{T_{\rm eff}/T_{\rm eff,\odot}}} \qquad \Delta\nu = \Delta\nu_\odot \sqrt{\frac{\bar\rho}{\bar\rho_\odot}}$$

Pipeline	$\Delta\nu_\odot$ (μHz)	$\nu_{\rm max,\odot}$ (μHz)
A2Z	135.20 ± 3.14	3097.9 ± 0.1
CAN	134.88 ± 0.04	3120.0 ± 5
COR	133.72 ± 0.02	3104.0 ± 2
OCT	135.045 ± 0.013	3139.0 ± 5
SYD	135.10 ± 0.10	3090.0 ± 30

$$\longrightarrow \vec{M} \equiv (\mathcal{M}, \tau, Z, Y, \nu_{\rm max,\odot}, \Delta\nu_\odot)$$

$$p(\vec{M}) = \mathrm{IMF} \times \mathrm{SFR} \times \mathrm{AMR} \times \mathcal{F}_1(Y,Z) \times \mathcal{F}_2(\nu_{\rm max,\odot}) \times \mathcal{F}_3(\Delta\nu_\odot)$$

SAGA Ages



a)
b)
c)
d)
e)
Age (Gyr), η=0.4
Age (Gyr), η=0.0
Δ (%)
log(g)
[Fe/H]
Mass (M⊙)
RGB
RC
Dwarf
No class

Mass Loss

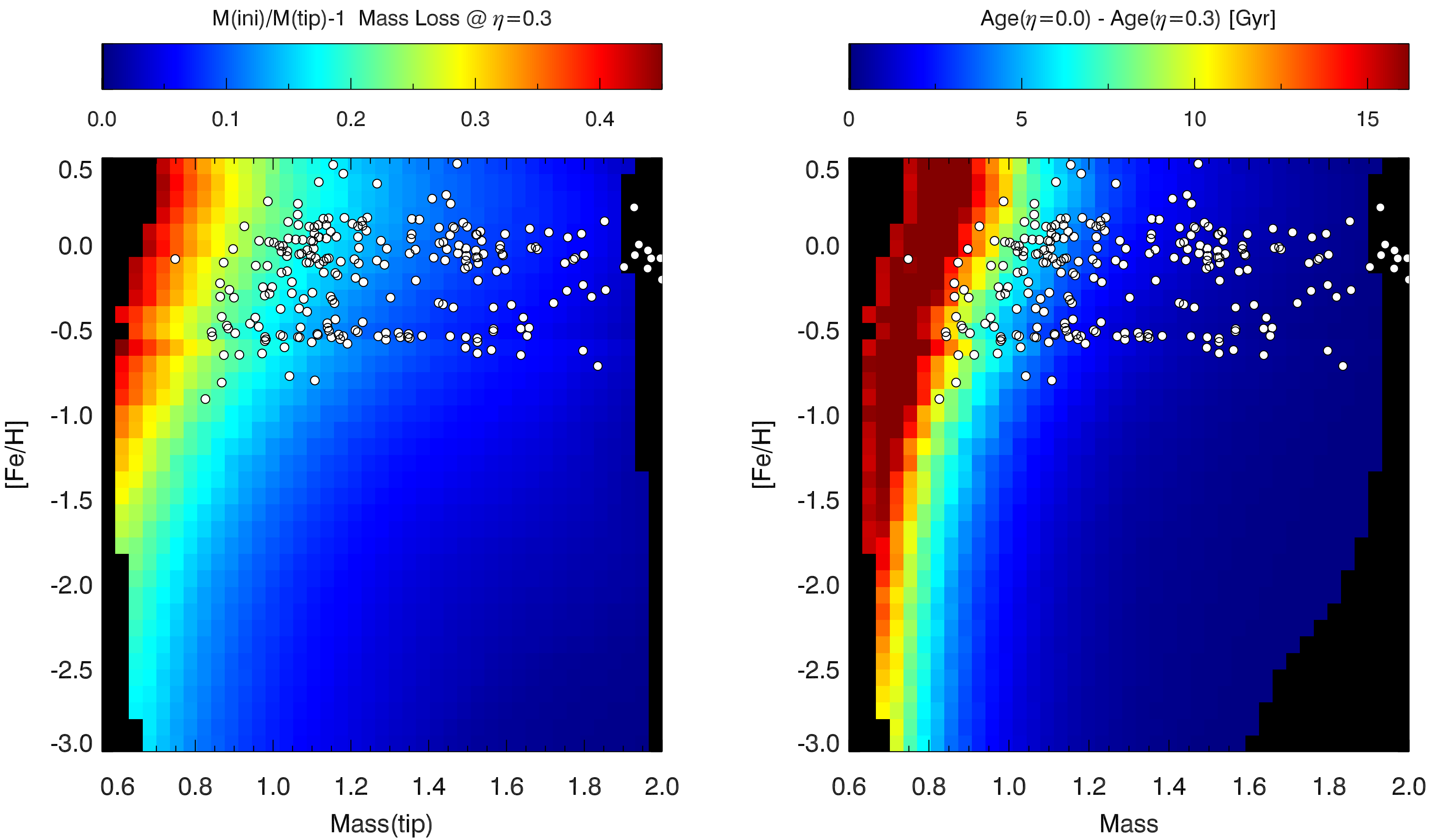
Mass Loss Rates (MLRs) of Modeled Stars

ID No.	MLR Average ($M_\odot$ yr^{-1})	MLR Fit ($M_\odot$ yr^{-1})	MLR Reimers[a] ($M_\odot$ yr^{-1})	MLR SC[b] ($M_\odot$ yr^{-1})	MLR Origlia[c] ($M_\odot$ yr^{-1})
			M13		
L72	2.8e-09	3.8e-09	4.1e-08	2.1e-08	4.0e-08
L96	4.8e-09	3.6e-09	3.0e-08	1.4e-08	3.6e-08
L592	2.6e-09	2.8e-09	8.8e-09	3.5e-09	2.2e-08
L954	3.1e-09	4.6e-09	1.0e-07	7.1e-08	5.8e-08
L973	1.6e-09	4.8e-09	1.2e-07	9.2e-08	6.2e-08
			M15		
K87	1.4e-09	1.4e-09	8.8e-09	3.9e-09	2.2e-08
K341	2.2e-09	2.0e-09	5.2e-08	3.2e-08	4.5e-08
K421	1.9e-09	2.0e-09	5.6e-08	3.5e-08	4.6e-08
K479	2.3e-09	2.1e-09	6.5e-08	4.3e-08	4.9e-08
K757	1.8e-09	2.1e-09	5.7e-08	3.5e-08	4.6e-08
K969	1.4e-09	1.5e-09	1.5e-08	7.1e-09	2.7e-08
			M92		
VII-18	2.0e-09	2.1e-09	9.0e-08	4.8e-08	5.5e-08
X-49	1.9e-09	2.0e-09	7.8e-08	4.2e-08	5.2e-08
XII-8	2.0e-09	1.7e-09	2.7e-08	1.0e-08	3.4e-08
XII-34	1.2e-09	1.4e-09	7.9e-09	2.5e-09	2.1e-08

Meszaros et al. 2009

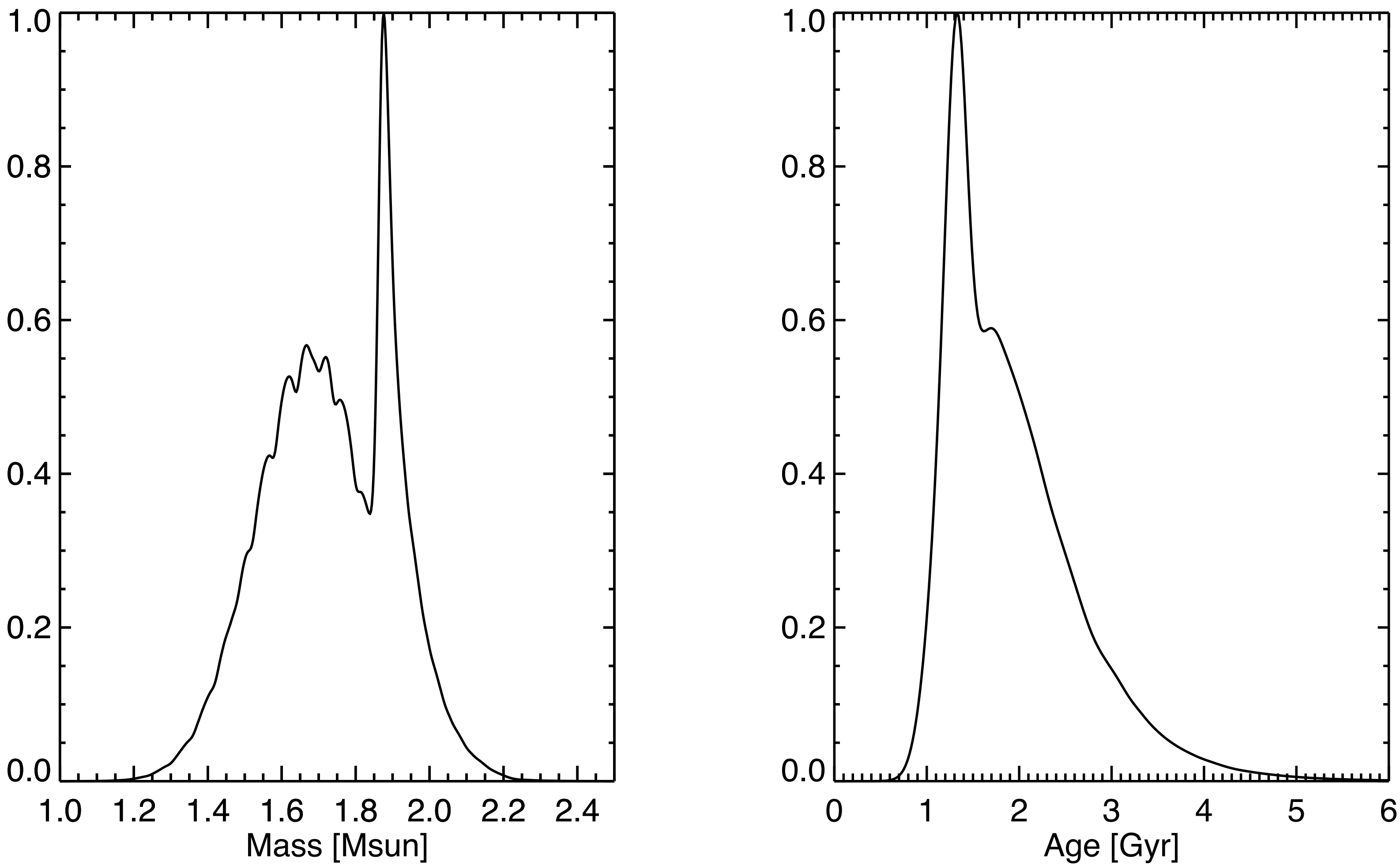
“Empirical” MLR differ by > order magnitude

Mass Loss



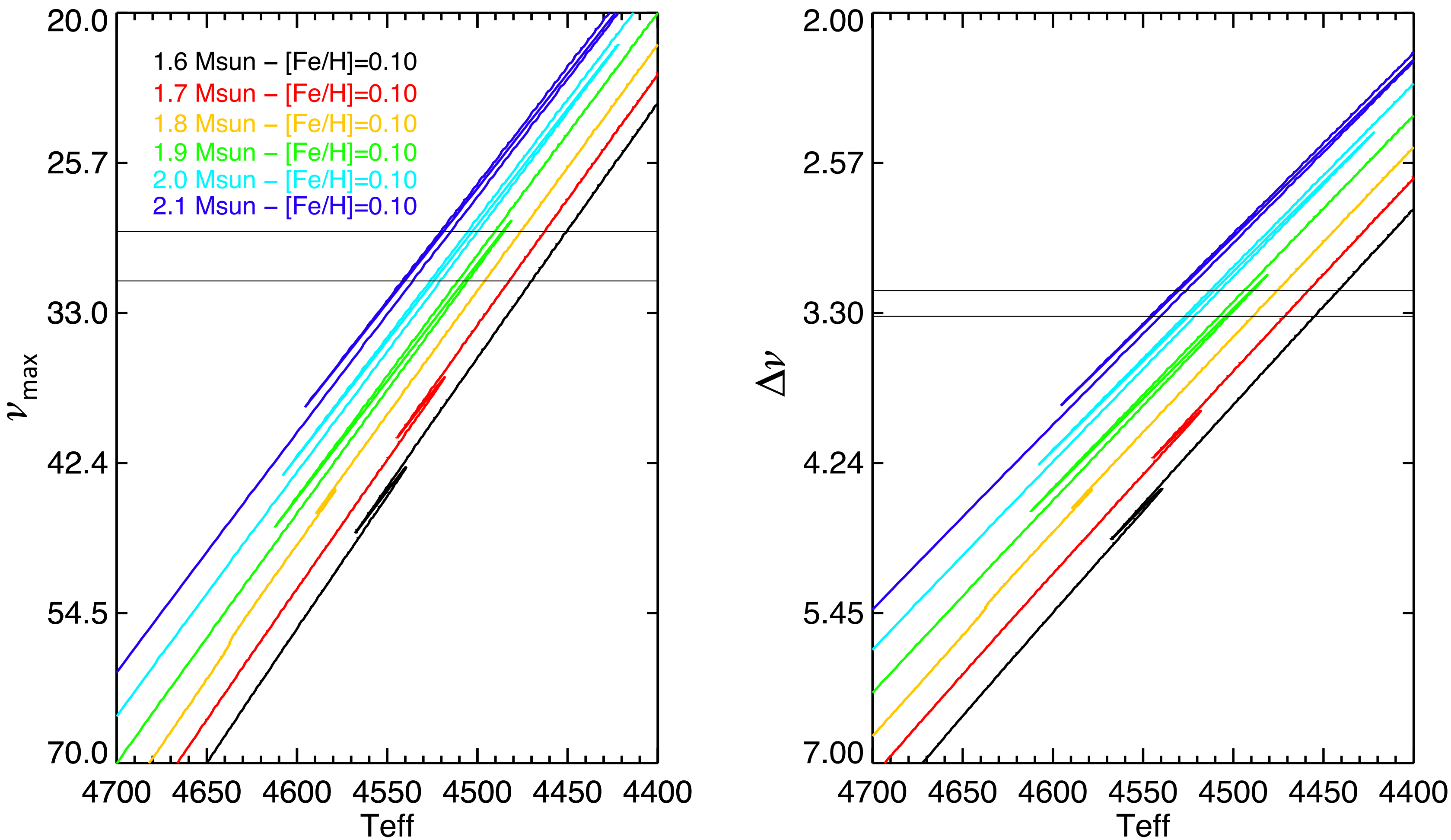
M(ini)/M(tip)-1 Mass Loss @ η=0.3
0.0
0.1
0.2
0.3
0.4
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
[Fe/H]
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Mass(tip)
Age(η=0.0) - Age(η=0.3) [Gyr]
0
5
10
15
[Fe/H]
Mass

Full PDFs



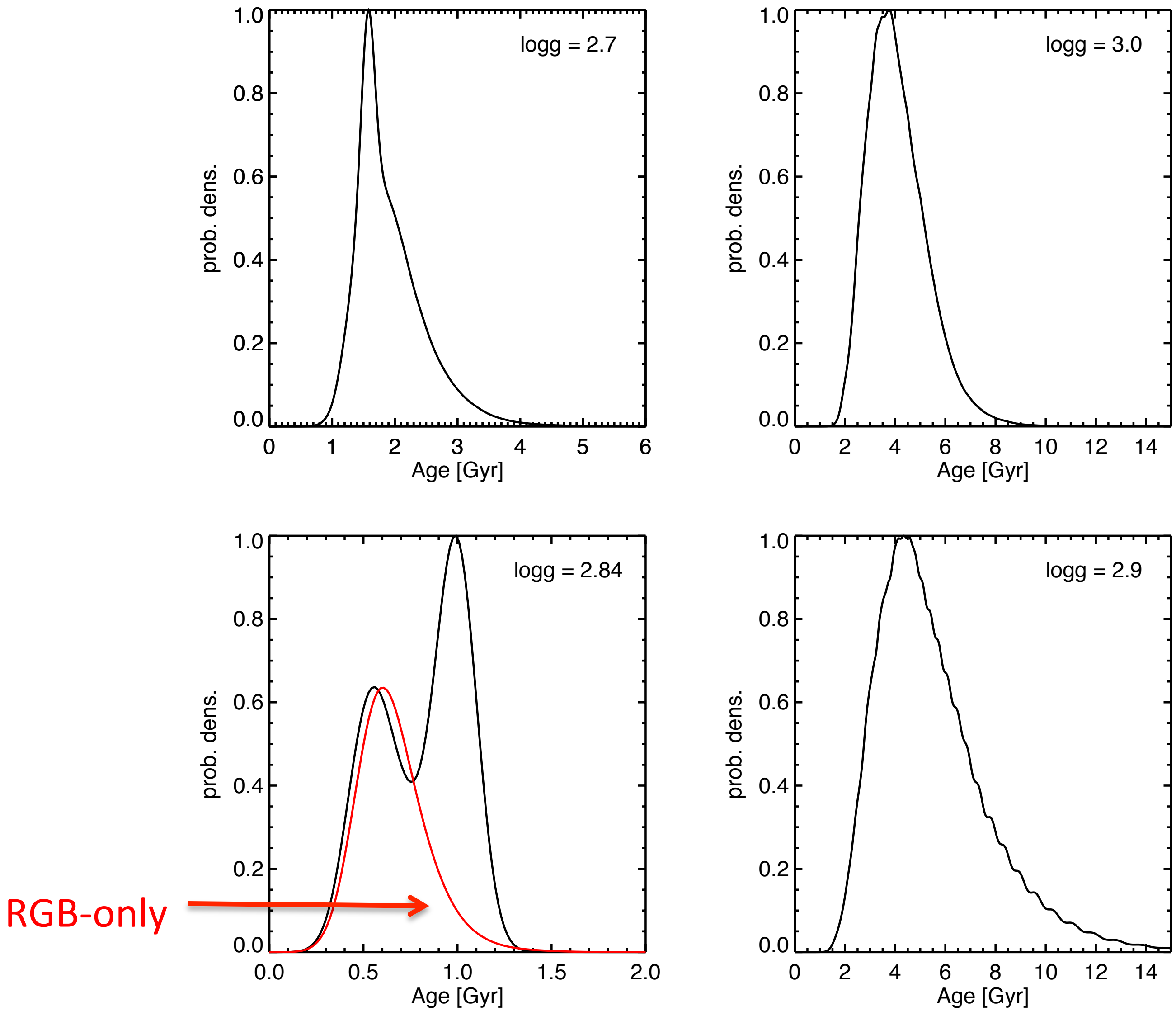
KIC2444348 from APOKASC Catalog (Pinsonneault et al 2014)

BEYOND $\Delta\nu$ & ν_{MAX}



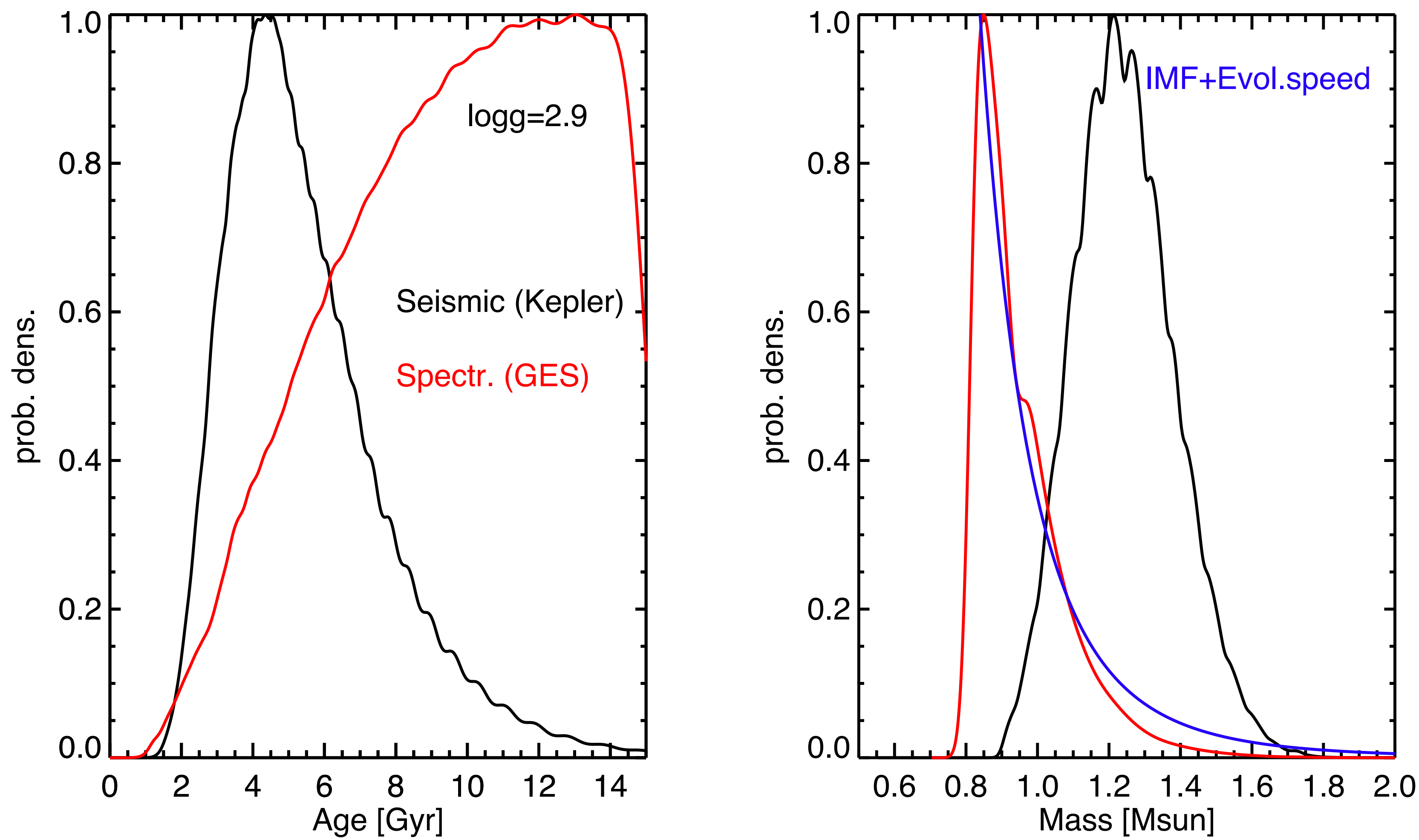
Period spacing may provide further mass discrimination – to be explored

Full PDFs

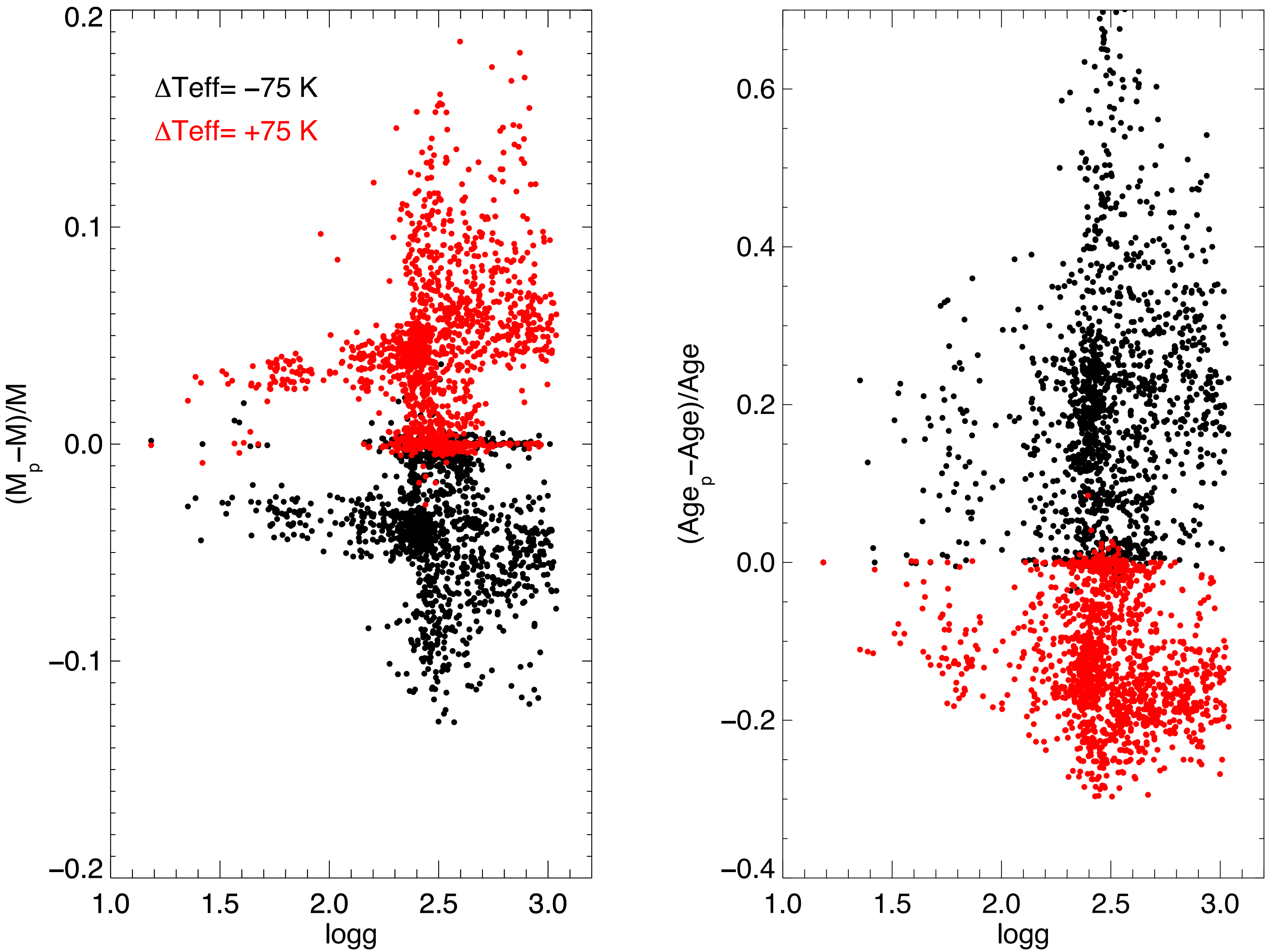


Spectroscopic data from APOKASC Catalog (Pinsonneault et al 2014)

Not Perfect but a Giant Step Forward

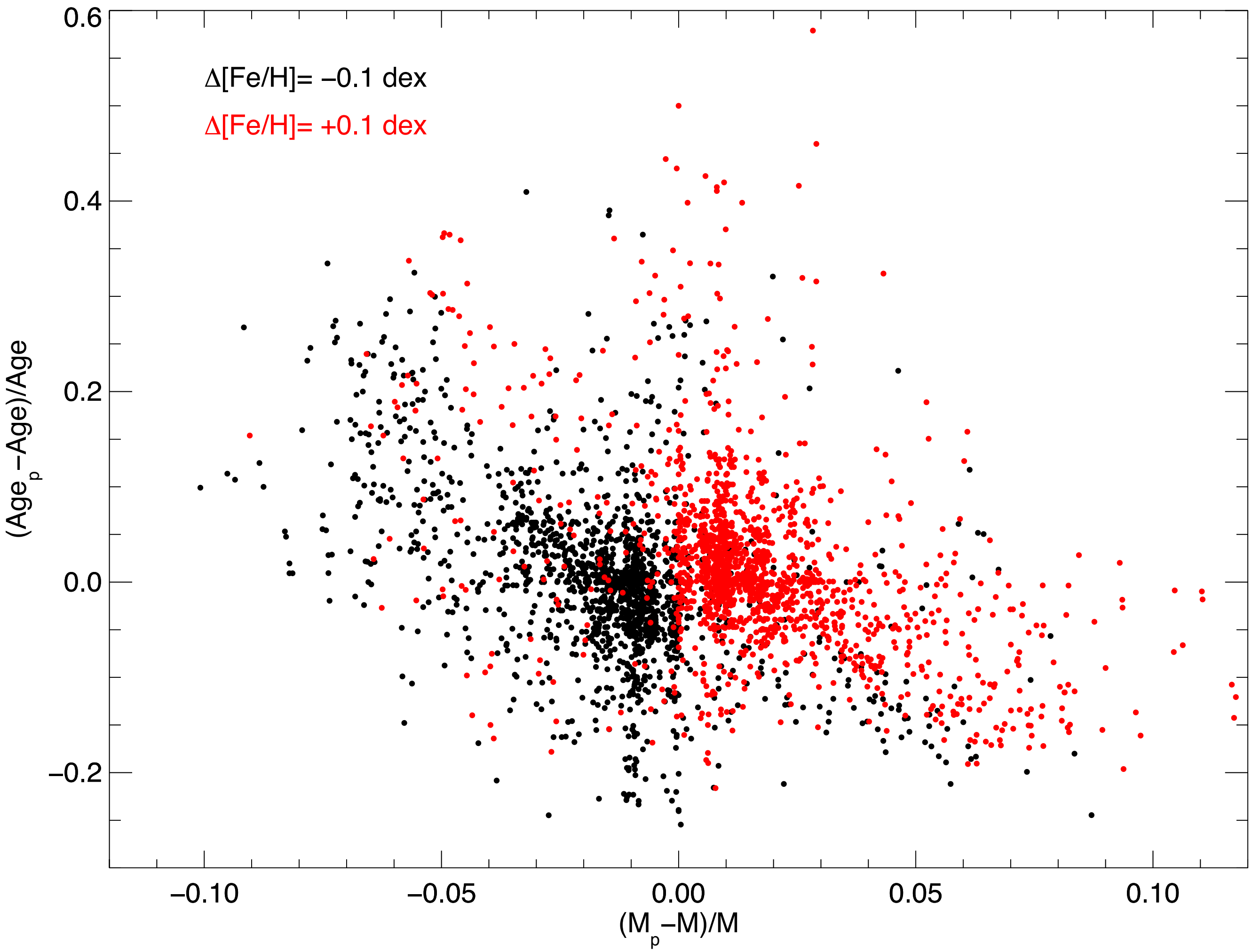


Good Spectr/Phot Data



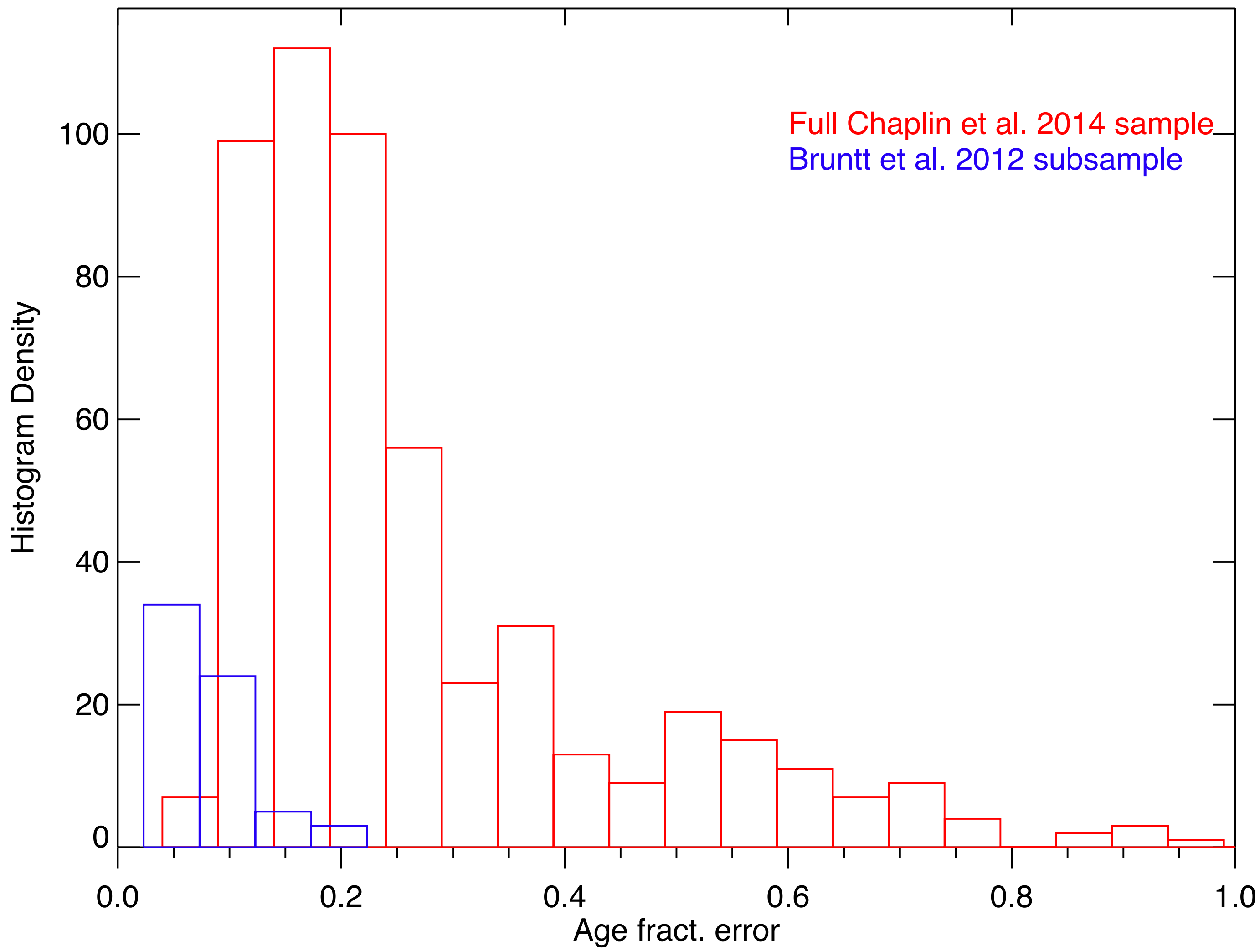
Spectroscopic data from APOKASC Catalog (Pinsonneault et al 2014)
No evolutionary state assumed

Good Spectr/Photom. Data

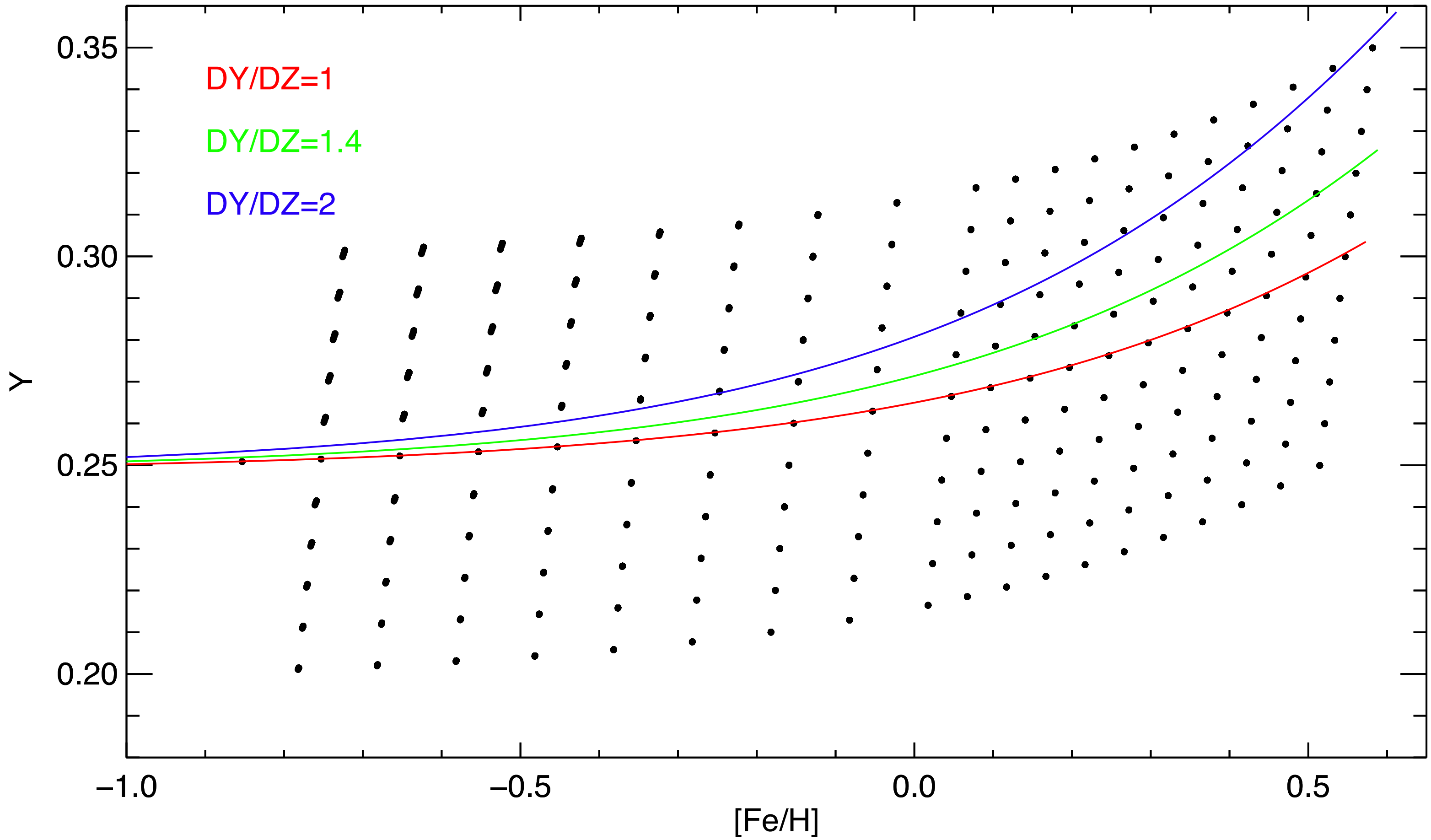


Spectroscopic data from APOKASC Catalog (Pinsonneault et al 2014)
No evolutionary state assumed

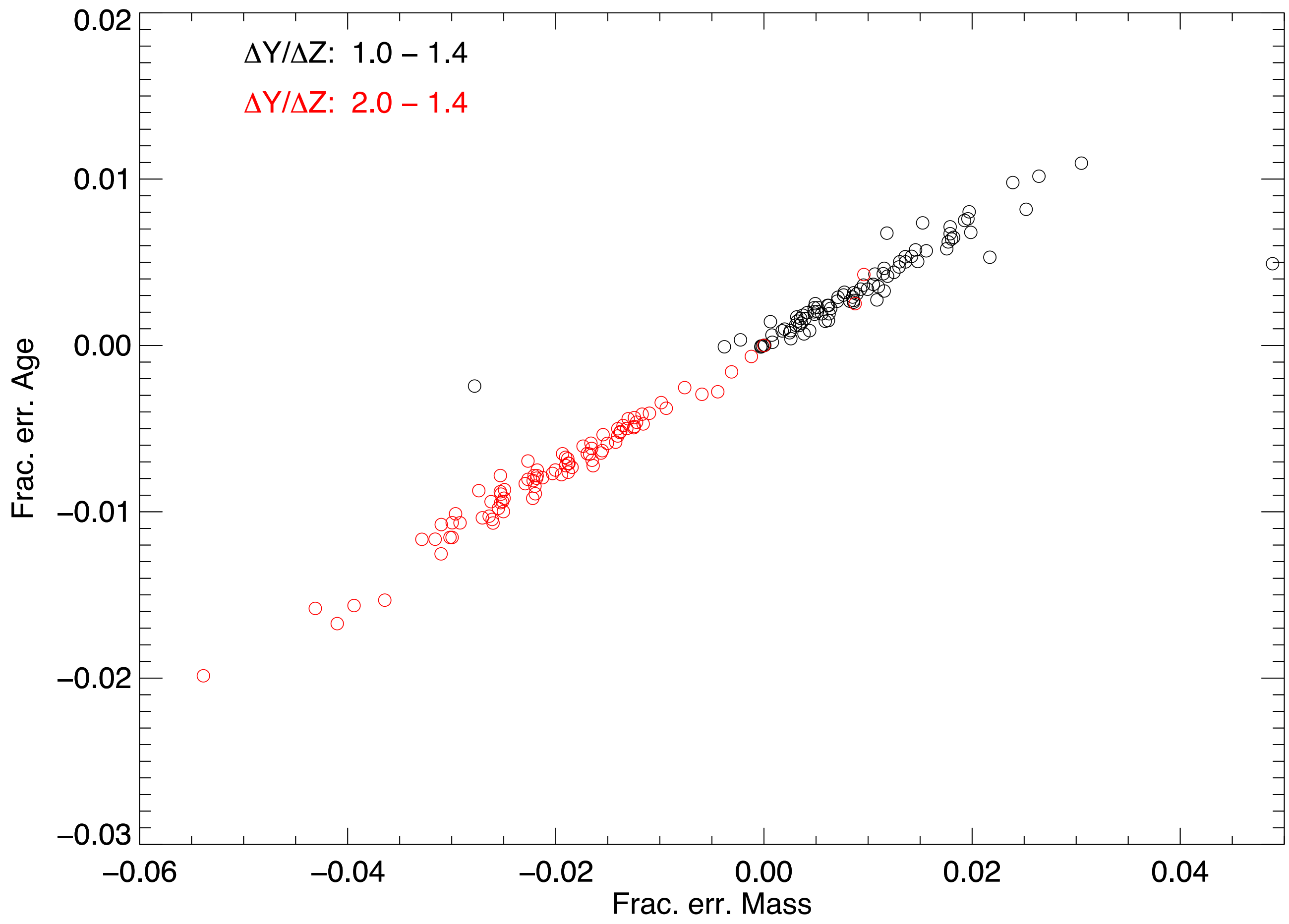
Don't Forget about Dwarfs



Helium as a Source of Syst. Uncertainty



Helium as a Source of Syst. Uncertainty



Uncertainty in helium does not seem a big problem (... not talking about clusters)

Conclusions

Obvious conclusions

seismology has opened the door for ages of giants

best way for dwarfs as well

much more info in full pdf than just a mean/median/mode & conf. interv.

Not so obvious

how to deal with mass loss for clump/low mass evolved RGBs

how to make use of full age pdf in galactic studies

using period spacing as further discriminant for mass