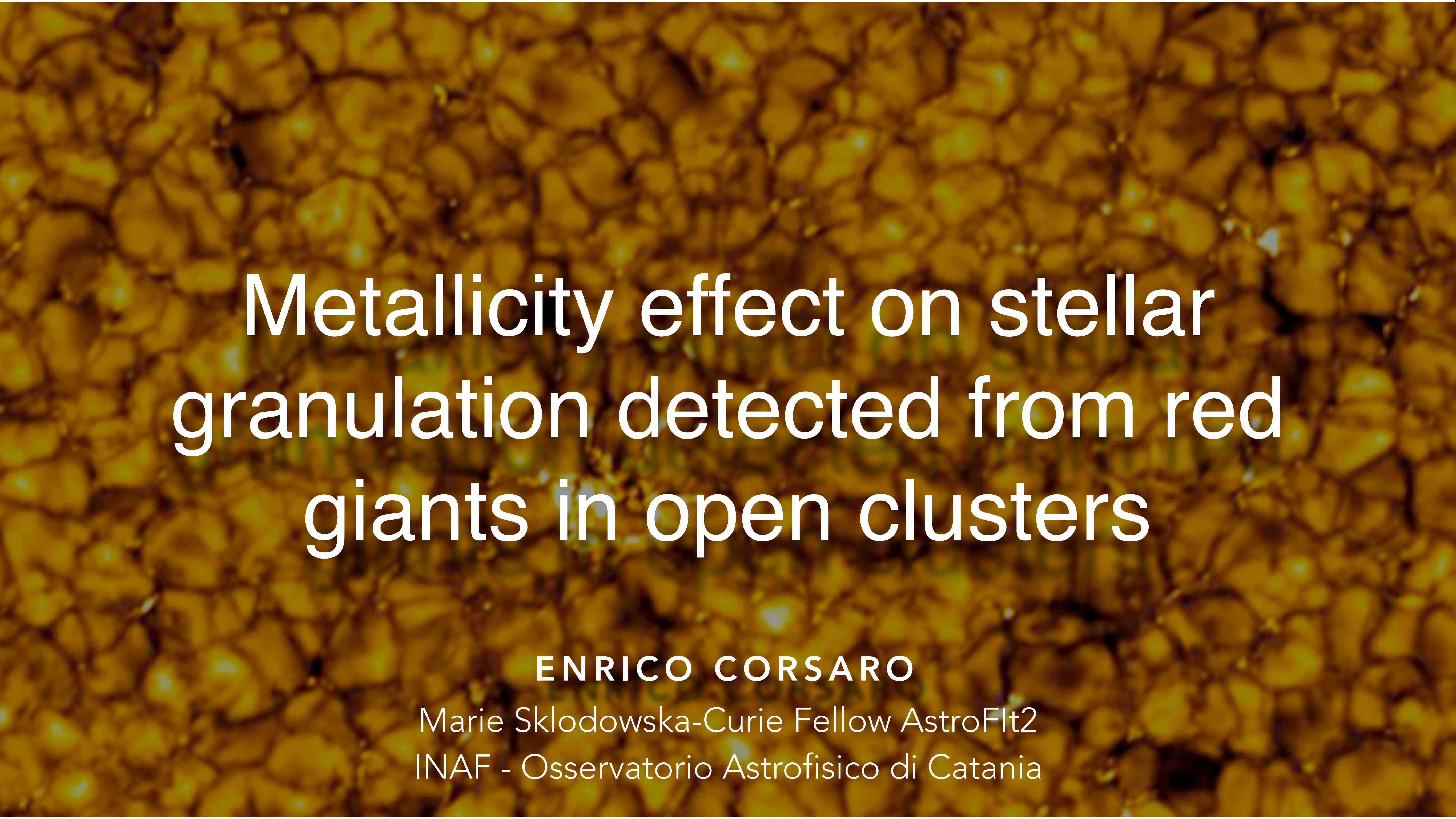
Asteroseismology and
Optical Interferometry
Workshop
5 October 2017



Metallicity effect on stellar granulation detected from red giants in open clusters

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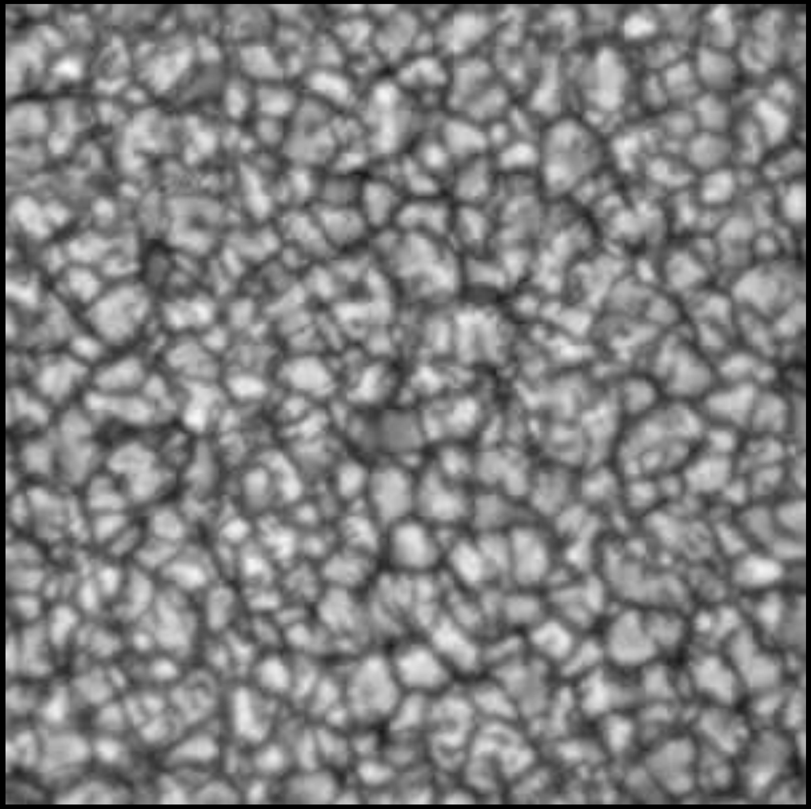
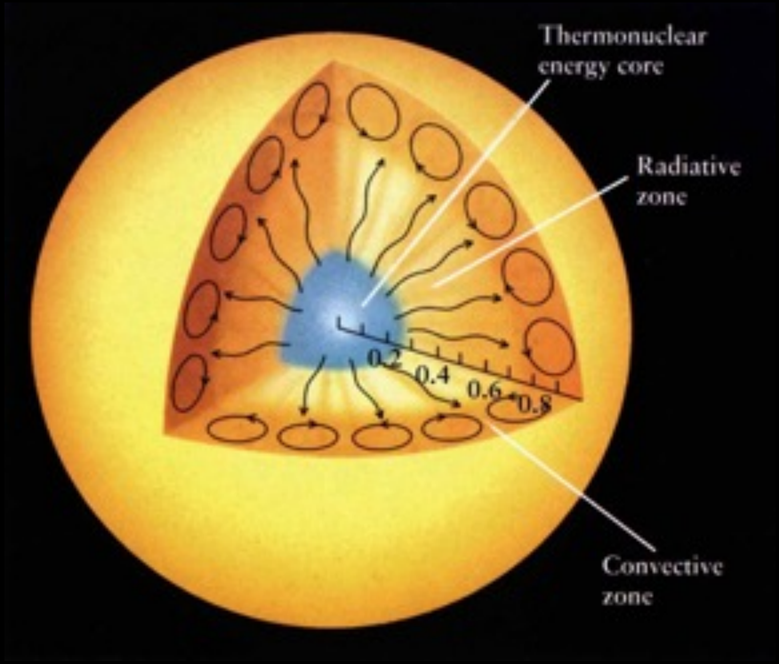
INTRODUCTION

STELLAR GRANULATION

- A type of stellar ***variability***
- Manifestation of surface convection
- First observed and studied in the Sun
  HERSCHEL 1801; HARVEY 1985
- Typical for low- and intermediate-mass stars (many!!)
  E.G. MATHUR ET AL. 2011; KAROFF ET AL. 2013; KALLINGER ET AL. 2014
- Time-scale accurately probes surface gravity
  BROWN ET AL. 1991; BASTIEN ET AL. 2013; KALLINGER ET AL. 2016
- Understand stellar granulation improves treatment of convection, hence **stellar models**



© SVST SOLAR GRANULATION



METALLICITY EFFECT

STELLAR GRANULATION

- 3D HD simulations predict dependency on [Fe/H]
  COLLET ET AL. 2007; TANNER ET AL. 2013; MAGIC ET AL. 2015A,B; LUDWIG & STEFFEN 2016
- Increased opacity makes granules bigger
- Amplitude of granulation signal increases because
  LUDWIG 2006

$$a_{\mathrm{gran}} \propto n_{\mathrm{gran}}^{-0.5}$$

METALLICITY EFFECT

STELLAR GRANULATION

- 3D HD simulations predict dependency on [Fe/H]
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- Increased opacity makes granules bigger
- Amplitude of granulation signal increases because
  LUDWIG 2006

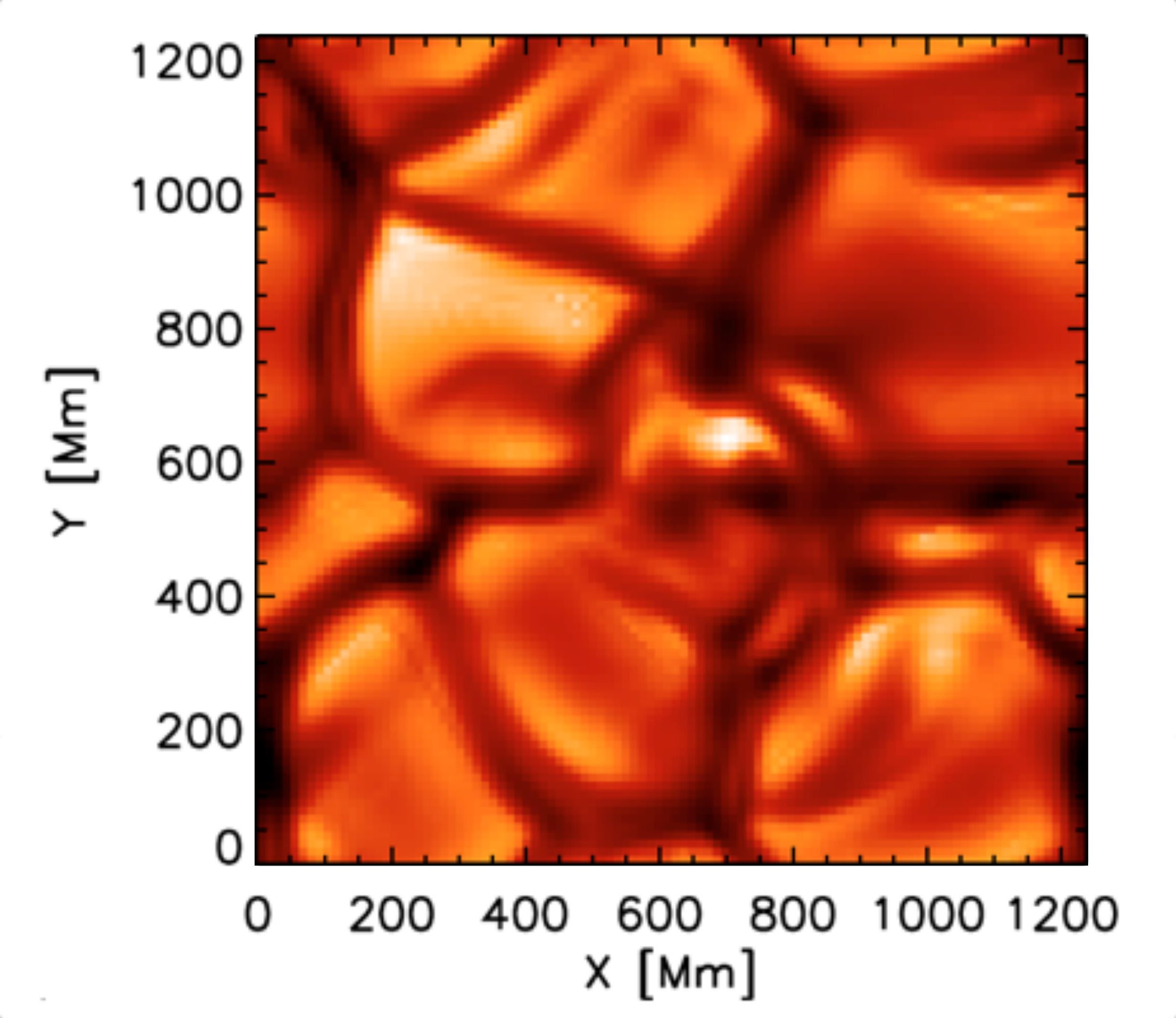
$$a_{\mathrm{gran}} \propto n_{\mathrm{gran}}^{-0.5}$$

- No evidence from past observations (e.g. CoRoT, Kepler)
  BROWN ET AL. 1991; MATHUR ET AL. 2011;
  BASTIEN ET AL. 2013; KALLINGER ET AL. 2014

Why?

Lack of accurate [Fe/H] for many stars

[Fe/H] = 0.0



© COLLET ET AL. 2007

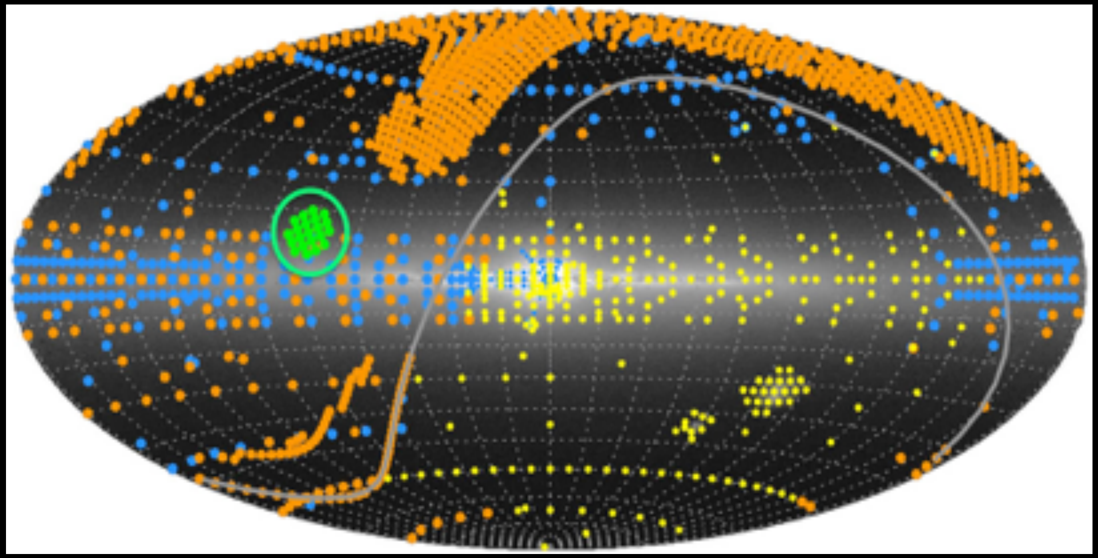
SELECTING THE SAMPLE

OBSERVATIONS AND DATA

- To better isolate and study effect of [Fe/H] we need:

stars with homogeneous set of stellar properties

accurate [Fe/H], T_{eff} for many stars



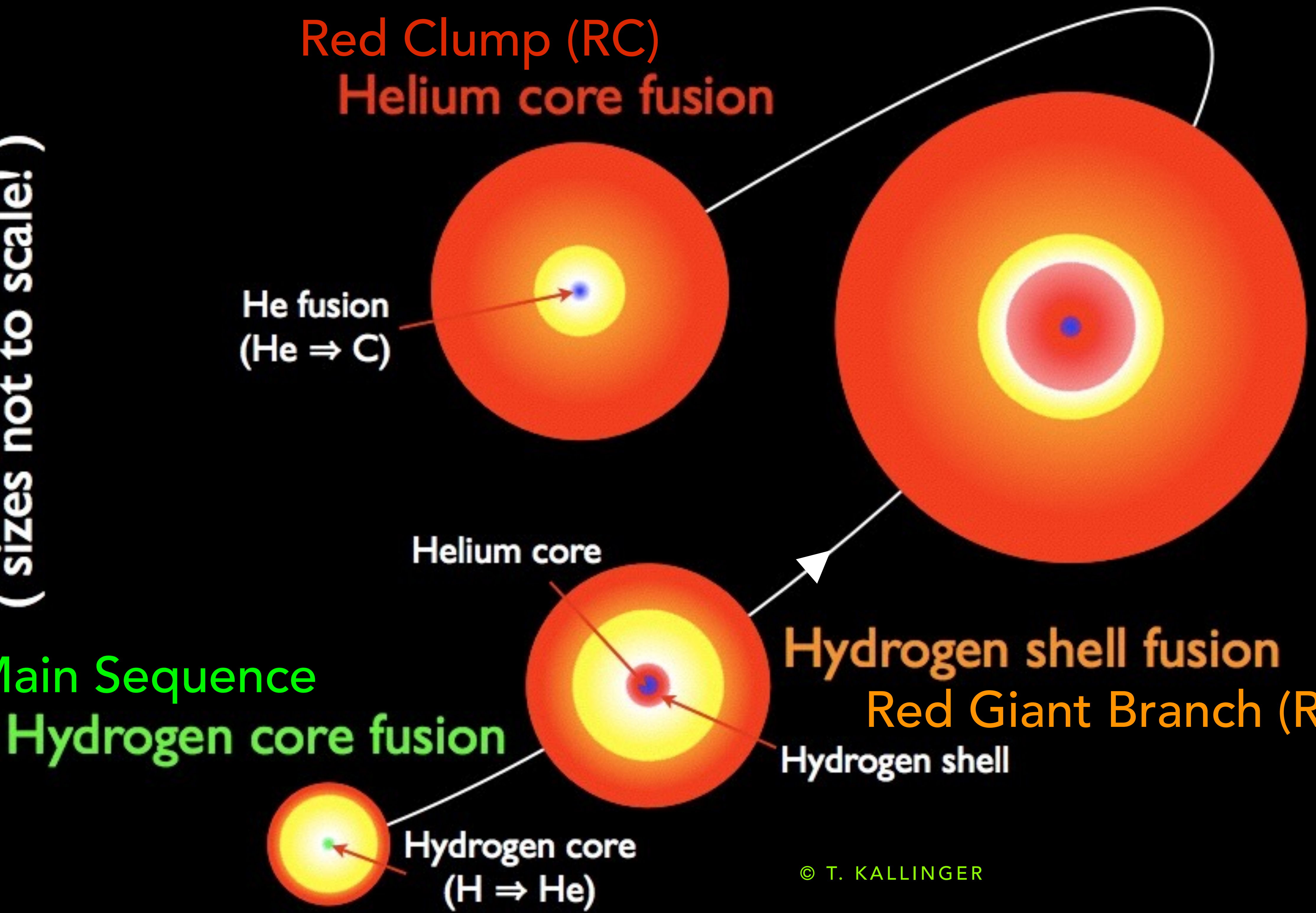
4 years photometry with *Kepler*

Spectroscopy with DR13 APOGEE-2 + KASC

PINSONNEAULT ET AL. 2014

EVOLVED SOLAR-TYPE STARS

RED GIANTS



Red Clump (RC)

Red Giant Branch (RGB)

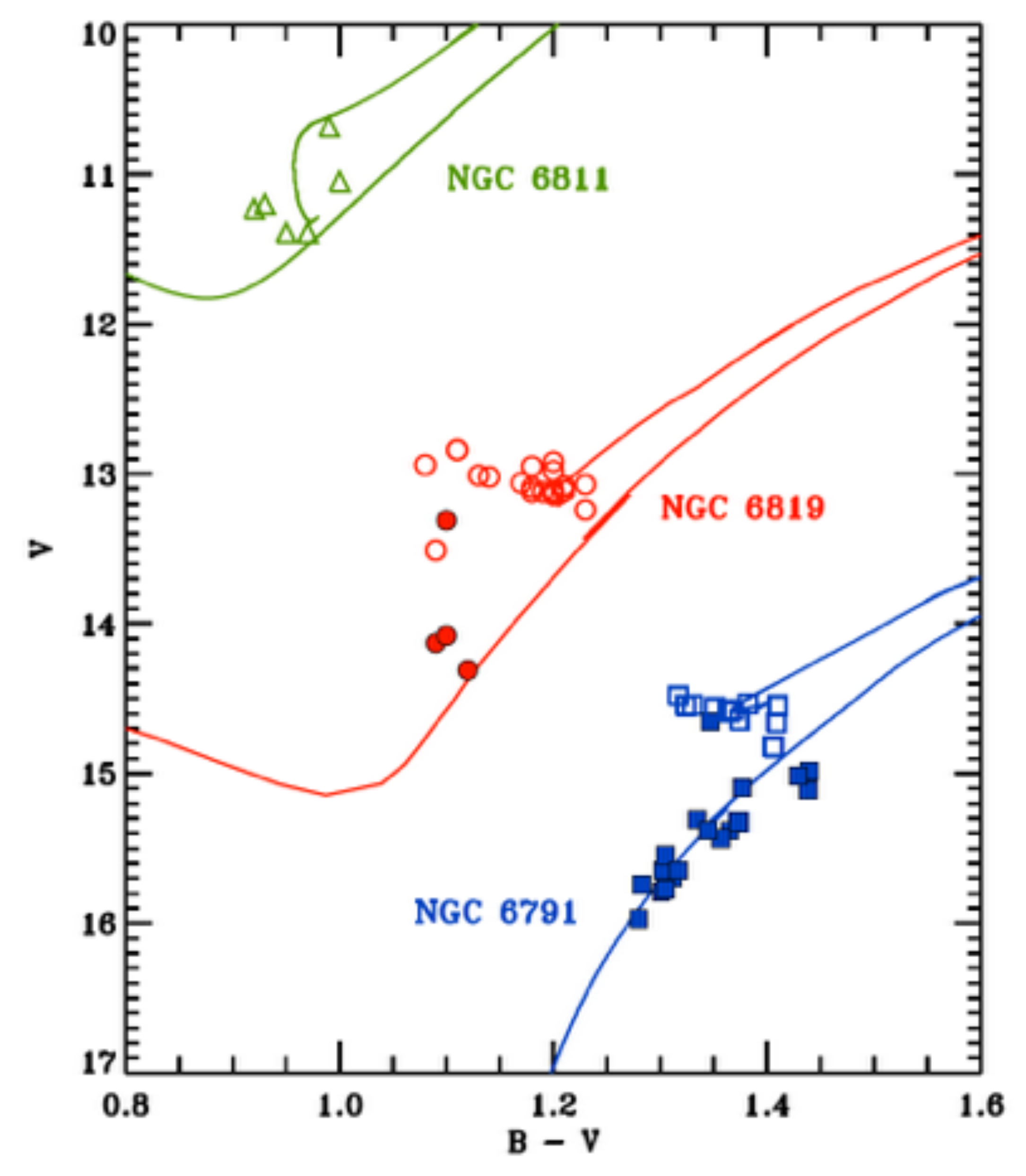
Main Sequence

(sizes not to scale!)

© T. KALLINGER

SELECTING THE SAMPLE

OBSERVATIONAL PROPERTIES



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60 Oscillating Red Giants

CORSARO ET AL. 2012; CORSARO ET AL. 2017A

NGC 6791

- $M_{RG} \sim 1.1\ M_{Sun}$
  MIGLIO ET AL. 2012
- $[Fe/H] \simeq 0.32$ dex
  BROGAARD ET AL. 2011;
  CORSARO ET AL. 2017B

NGC 6819

- $M_{RG} \sim 1.7\ M_{Sun}$
  MIGLIO ET AL. 2012
- $[Fe/H] \simeq 0.04$ dex
  BRAGAGLIA ET AL. 2001;
  CORSARO ET AL. 2017B

NGC 6811

- $M_{RG} \sim 2.3\ M_{Sun}$
  STELLO ET AL. 2011A,B
- $[Fe/H] \simeq -0.09$ dex
  MOLENDA-ZAKOWICZ ET AL.2014;
  CORSARO ET AL. 2017B

ASTEROSEISMOLOGY

STELLAR MASSES

- Masses computed from asteroseismology with acoustic modes $\nu_{\max}$ from global fit + $\Delta\nu$ from peak bagging

CORSARO ET AL. IN PREP.

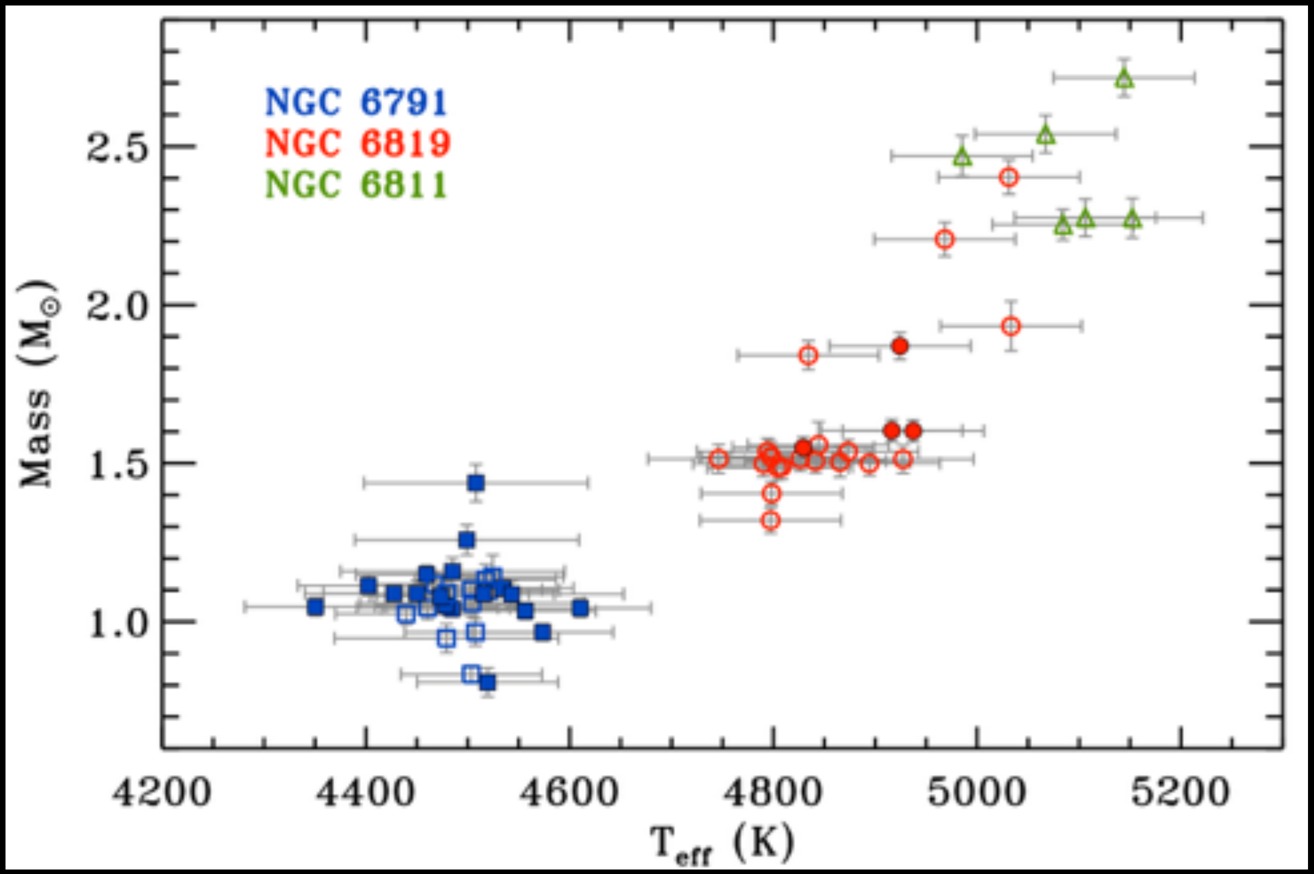
- Correction to $\Delta\nu$ with stellar population synthesis modeling

SHARMA ET AL. 2016

- Precision 3 - 4 %

$$\frac{M}{M_\odot} = \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\gamma\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\mathrm{eff}}}{T_{\mathrm{eff},\odot}}\right)^{1.5}$$

APOGEE



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MEASURING GRANULATION PROPERTIES

THE BACKGROUND MODELING

- Bayesian inference code ***DIAMONDS***
  https://github.com/EnricoCorsaro/DIAMONDS
  CORSARO & DE RIDDER, 2014, A&A, 571, 71
  CORSARO, DE RIDDER, GARCIA, 2015, A&A, 579, 83

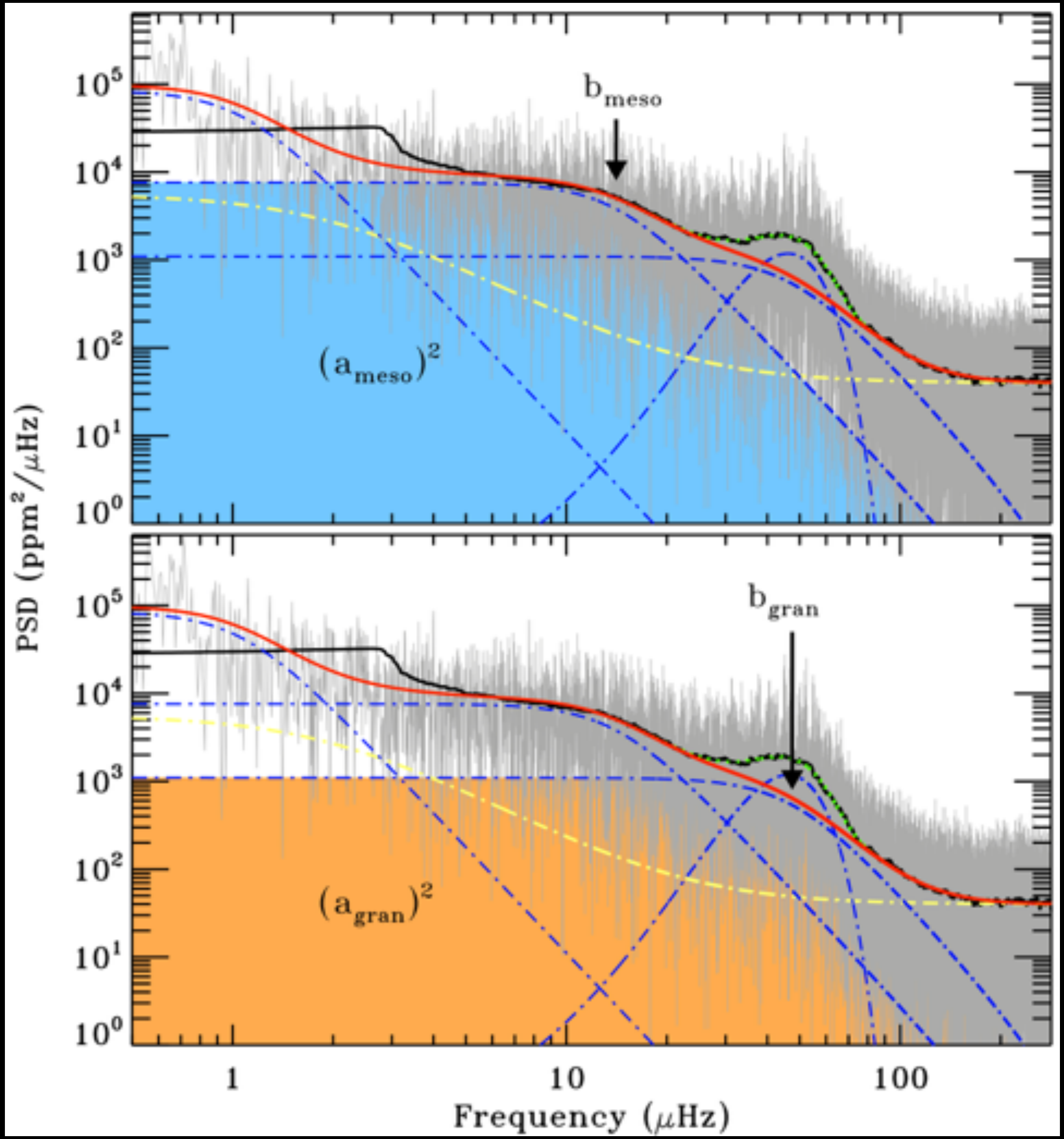
DIAMONDS™ BAYESIAN SOFTWARE

- Background signal modeled with **granulation** and **meso-granulation**
  HARVEY 1985; KALLINGER ET AL. 2014; 2016

- Both components scale linearly

$$a_{\mathrm{meso}}/a_{\mathrm{gran}} = 1.31 \pm 0.18$$
$$b_{\mathrm{meso}}/b_{\mathrm{gran}} = 0.32 \pm 0.04$$

CORSARO ET AL. 2017B



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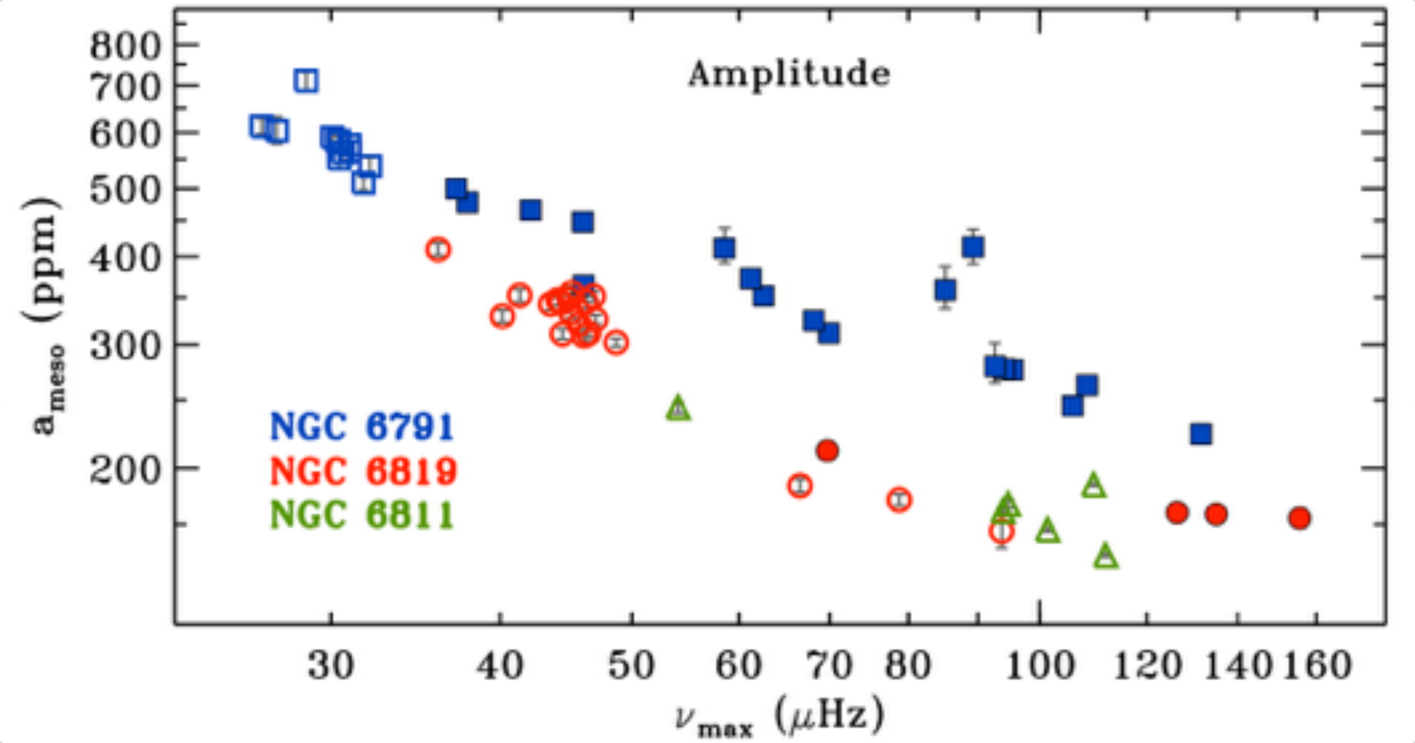
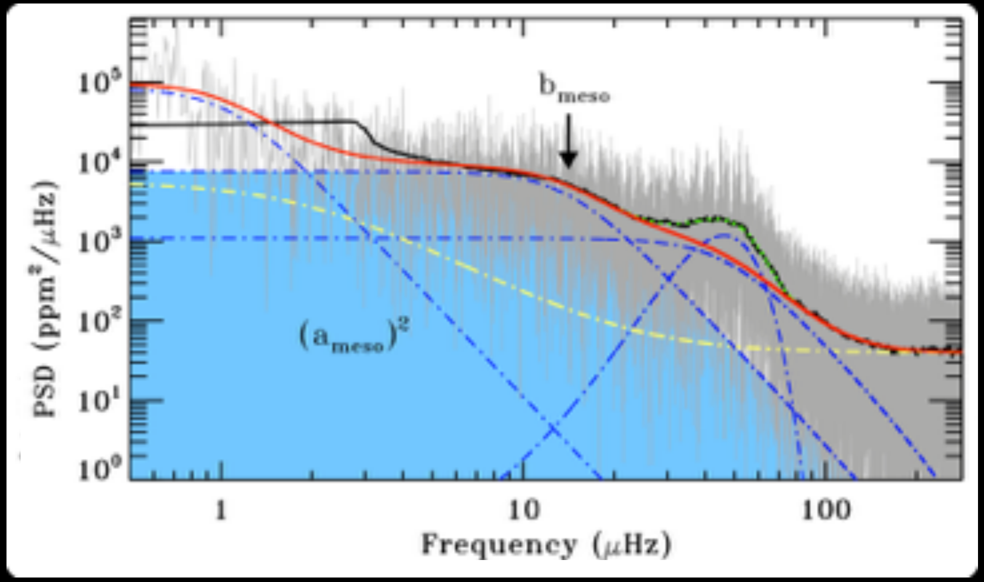
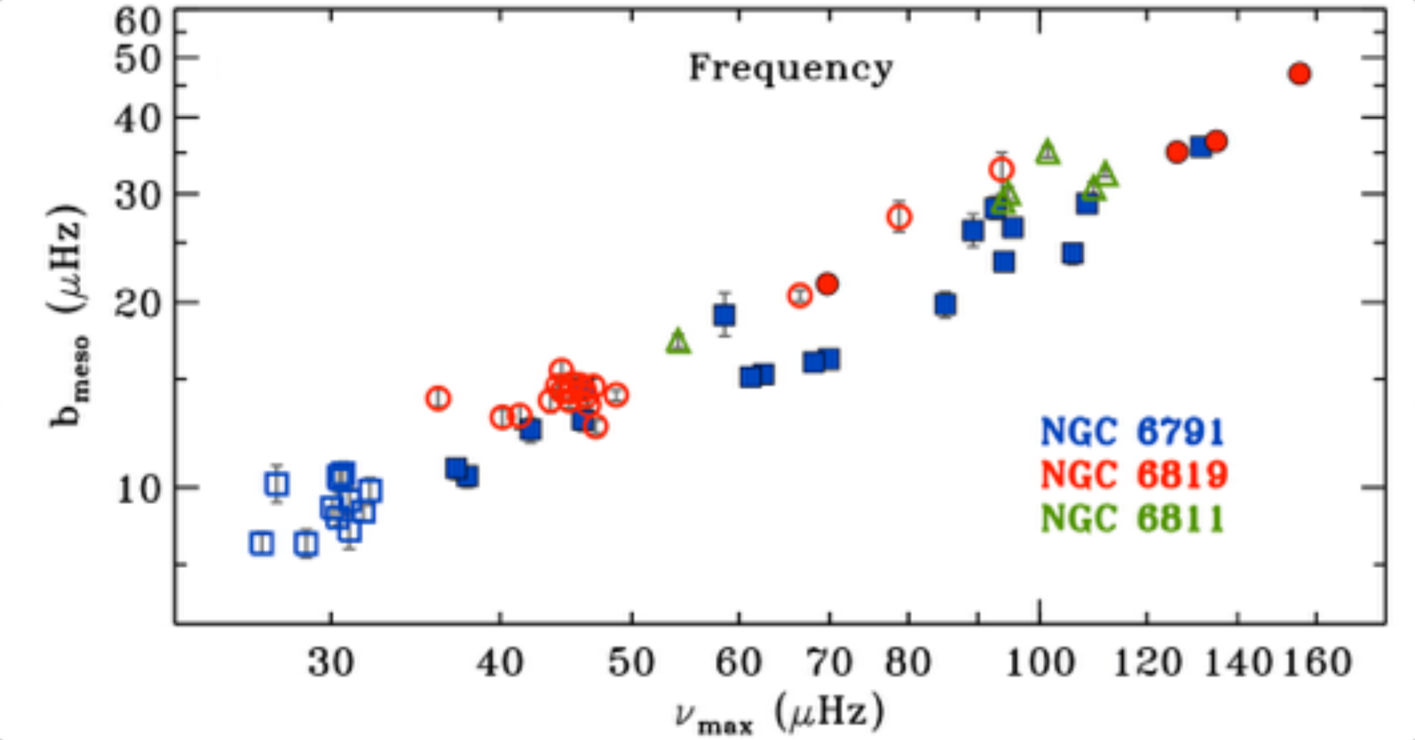
THE MESO-GRANULATION SIGNAL

BACKGROUND FIT RESULTS

- Two distinct groups, mostly coinciding with the two different [Fe/H] regimes
- Difference systematic along surface gravity range **$2.3 < \log g < 3.1$**







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BAYESIAN INFERENCE

GENERAL SCALING RELATIONS

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \boxed{\beta}\left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{\boxed{s}}\left(\frac{M}{M_\odot}\right)^{\boxed{t}} e^{\boxed{u}[\mathrm{Fe/H}]}$$

$$\left(\frac{b_{\mathrm{meso}}}{b_{\mathrm{meso},\odot}}\right) = \boxed{\beta}\left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{\boxed{s}}\left(\frac{M}{M_\odot}\right)^{\boxed{t}} e^{\boxed{u}[\mathrm{Fe/H}]}$$

BAYESIAN INFERENCE

GENERAL SCALING RELATIONS

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} e^{u[\mathrm{Fe/H}]}$$

$$\left(\frac{b_{\mathrm{meso}}}{b_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} e^{u[\mathrm{Fe/H}]}$$

LINEARIZATION

$$\ln\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \ln\beta + +s\ln\left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right) + t\ln\left(\frac{M}{M_{\odot}}\right) + u[\mathrm{Fe/H}]$$

TOTAL UNCERTAINTY

$$\widetilde{\sigma}^2_a(s,t,u) = \widetilde{\sigma}^2_{a_{\mathrm{meso}}} + s^2\widetilde{\sigma}^2_{\nu_{\mathrm{max}}} + t^2\widetilde{\sigma}^2_M + u^2\widetilde{\sigma}^2_{[\mathrm{Fe/H}]}$$

CORSARO ET AL. 2013; BONANNO ET AL. 2014

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} e^{u[\mathrm{Fe/H}]}$$

$$\widetilde{\sigma}_a^2(s,t,u) = \widetilde{\sigma}^2_{a_{\mathrm{meso}}} + s^2\widetilde{\sigma}^2_{\nu_{\mathrm{max}}} + t^2\widetilde{\sigma}^2_M + u^2\widetilde{\sigma}^2_{[\mathrm{Fe/H}]}$$

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \xcancel{\left(\frac{M}{M_{\odot}}\right)^{t}} \, e^{\xcancel{u[\mathrm{Fe/H}]}}$$

$$\widetilde{\sigma}_{a}^{2}(s, \xcancel{t}, \xcancel{u}) = \widetilde{\sigma}_{a_{\mathrm{meso}}}^{2} + s^{2}\widetilde{\sigma}_{\nu_{\mathrm{max}}}^{2} + \xcancel{t^{2}\widetilde{\sigma}_{M}^{2}} + \xcancel{u^{2}\widetilde{\sigma}_{[\mathrm{Fe/H}]}^{2}}$$

$t = u = 0$ → ***M_1***

surf. gravity

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} \xcancel{e^{u[\mathrm{Fe/H}]}}$$

$$\widetilde{\sigma}_{a}^{2}(s,t,\xcancel{u}) = \widetilde{\sigma}^{2}_{a_{\mathrm{meso}}} + s^{2}\widetilde{\sigma}^{2}_{\nu_{\mathrm{max}}} + t^{2}\widetilde{\sigma}^{2}_{M} + \xcancel{u^{2}\widetilde{\sigma}^{2}_{[\mathrm{Fe/H}]}}$$

$t = u = 0$ → M_1 surf. gravity

$u = 0$ → M_2 + mass

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \cancel{\left(\frac{M}{M_{\odot}}\right)^{t}} e^{u[\mathrm{Fe/H}]}$$

$$\widetilde{\sigma}^2_a(s,\cancel{t},u) = \widetilde{\sigma}^2_{a_{\mathrm{meso}}} + s^2\widetilde{\sigma}^2_{\nu_{\mathrm{max}}} + \cancel{t^2\widetilde{\sigma}^2_M} + u^2\widetilde{\sigma}^2_{[\mathrm{Fe/H}]}$$

$t = u = 0$	→	**M_1**	surf. gravity
$u = 0$	→	**M_2**	+ mass
$t = 0$	→	**M_3**	+ metallicity

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} e^{u[\mathrm{Fe/H}]}$$

$$\widetilde{\sigma}^{2}_{a}(s,t,u) = \widetilde{\sigma}^{2}_{a_{\mathrm{meso}}} + s^{2}\widetilde{\sigma}^{2}_{\nu_{\mathrm{max}}} + t^{2}\widetilde{\sigma}^{2}_{M} + u^{2}\widetilde{\sigma}^{2}_{[\mathrm{Fe/H}]}$$

$t = u = 0$ → M_1 surf. gravity

$u = 0$ → M_2 + mass

$t = 0$ → M_3 + metallicity

$t \neq 0;\ u \neq 0$ → M_4 + mass & metallicity

BAYESIAN INFERENCE

SELECTING THE BEST MODEL

$$\left(\frac{a_{\mathrm{meso}}}{a_{\mathrm{meso},\odot}}\right) = \beta \left(\frac{\nu_{\mathrm{max}}}{\nu_{\mathrm{max},\odot}}\right)^{s} \left(\frac{M}{M_{\odot}}\right)^{t} e^{u[\mathrm{Fe/H}]}$$

$$\tilde{\sigma}_a^2(s,t,u) = \tilde{\sigma}^2_{a_{\mathrm{meso}}} + s^2\tilde{\sigma}^2_{\nu_{\mathrm{max}}} + t^2\tilde{\sigma}^2_M + u^2\tilde{\sigma}^2_{[\mathrm{Fe/H}]}$$

$t = u = 0$ → ~~M_1~~ surf. gravity

$u = 0$ → ~~M_2~~ + mass

$t = 0$ → ~~M_3~~ + metallicity

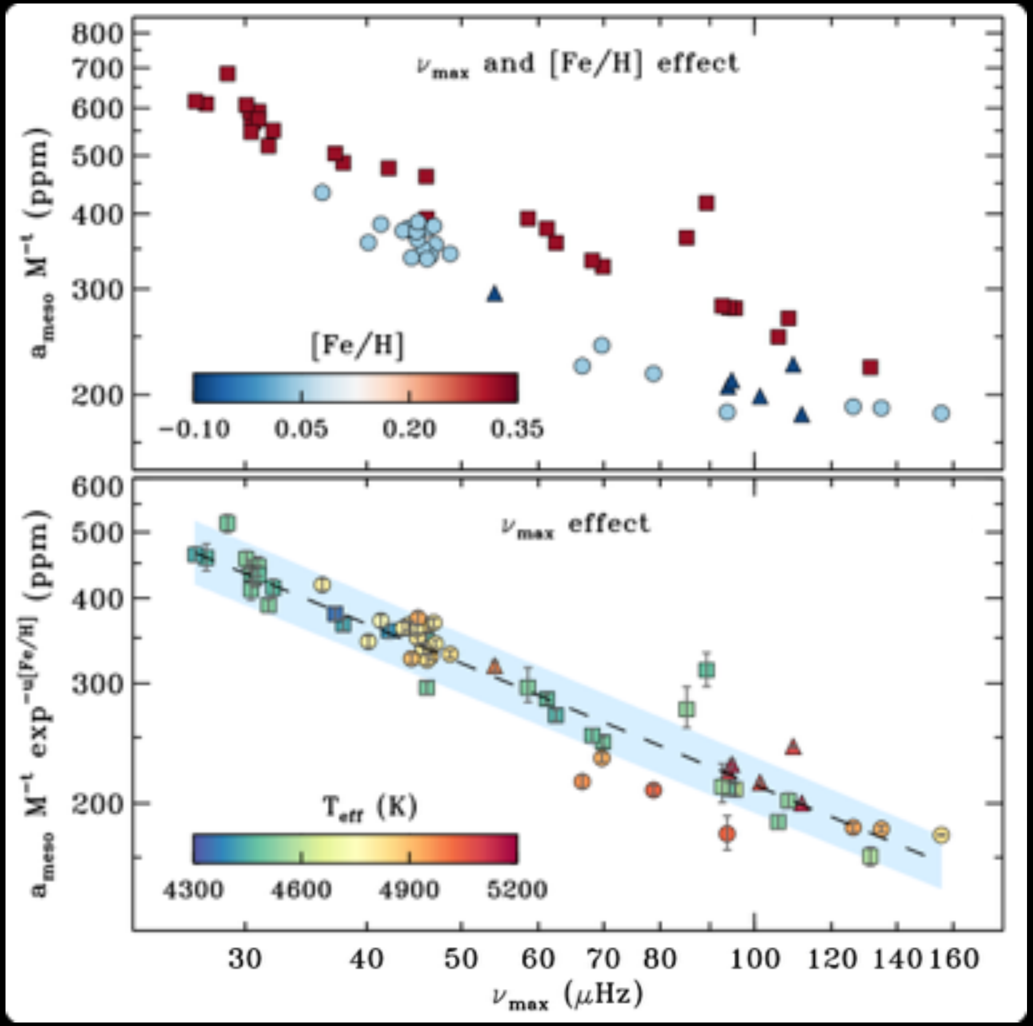
$t \neq 0; u \neq 0$ → **M_4** + mass & metallicity

ODDS RATIO

$$\mathcal{O}_{ij} = \frac{\mathcal{E}_i}{\mathcal{E}_j}\frac{\pi_i}{\pi_j}$$

RESULTS FROM THE FAVORED SCALING RELATION

METALLICITY EFFECT ON AMPLITUDE



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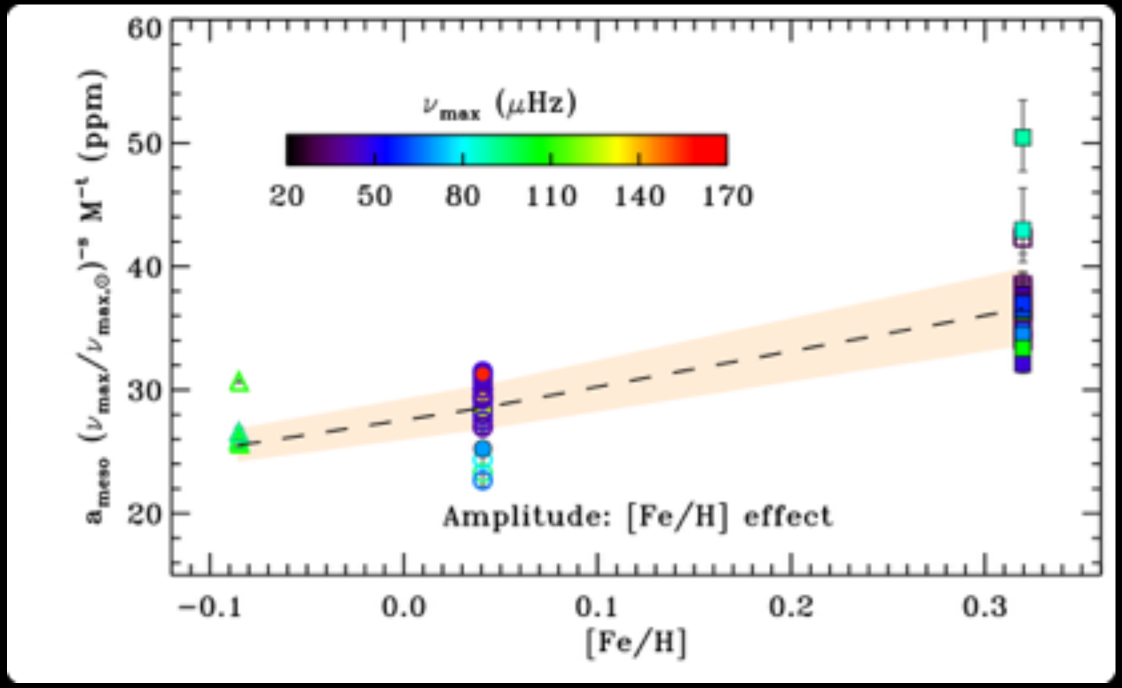

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- Amplitude increases with increasing ***[Fe/H]***
- No dependency on ev. stage (RC vs RGB)

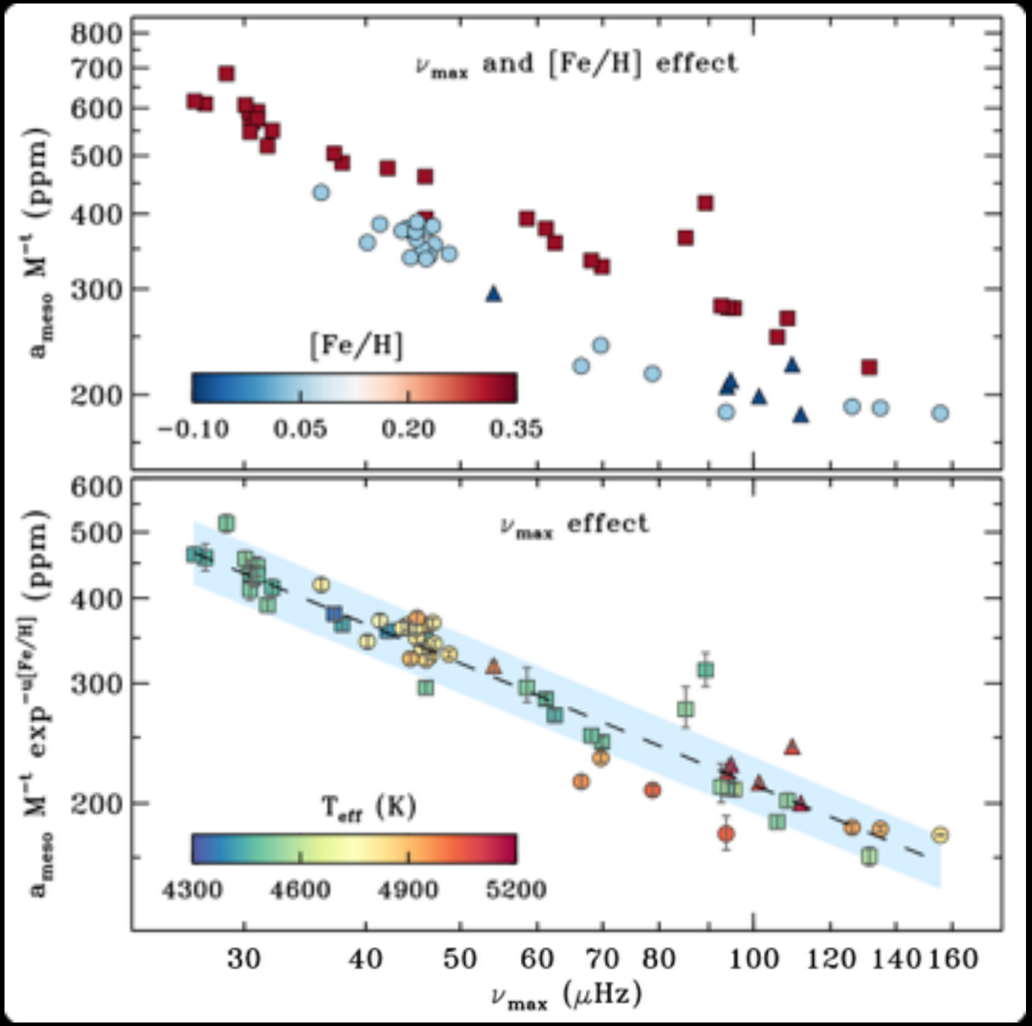
$$s = -0.59^{+0.01}_{-0.01}$$

$$a_{\rm gran} \propto \nu_{\rm max}^{-0.5}$$

KALLINGER ET AL. 2014

RESULTS FROM THE FAVORED SCALING RELATION

METALLICITY EFFECT ON AMPLITUDE



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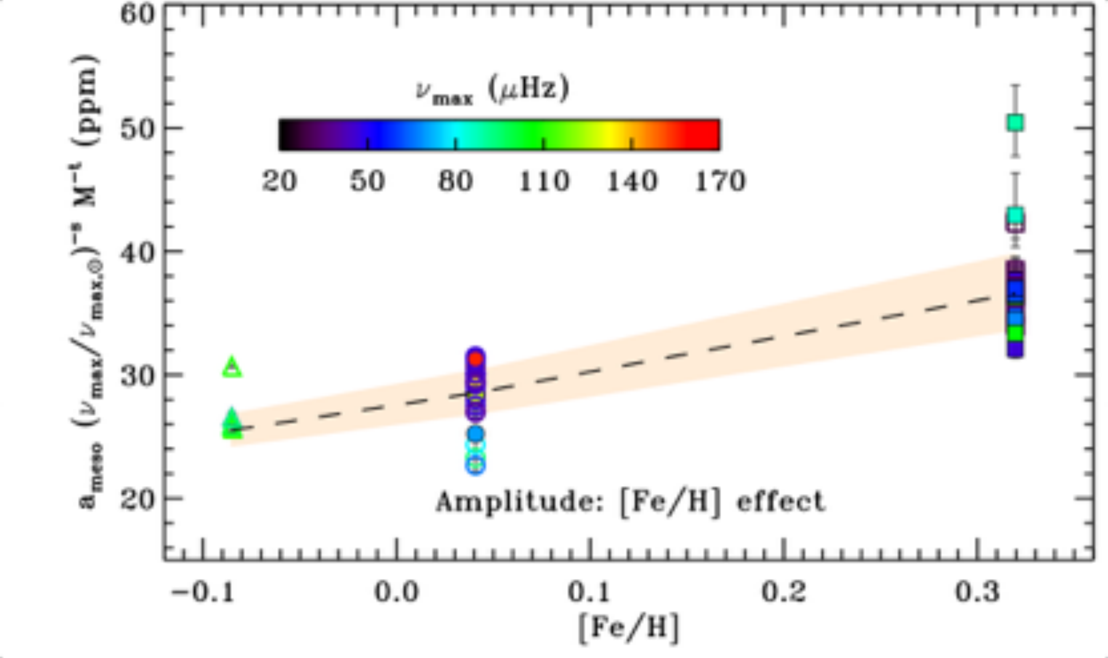

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$$s = -0.59^{+0.01}_{-0.01}$$

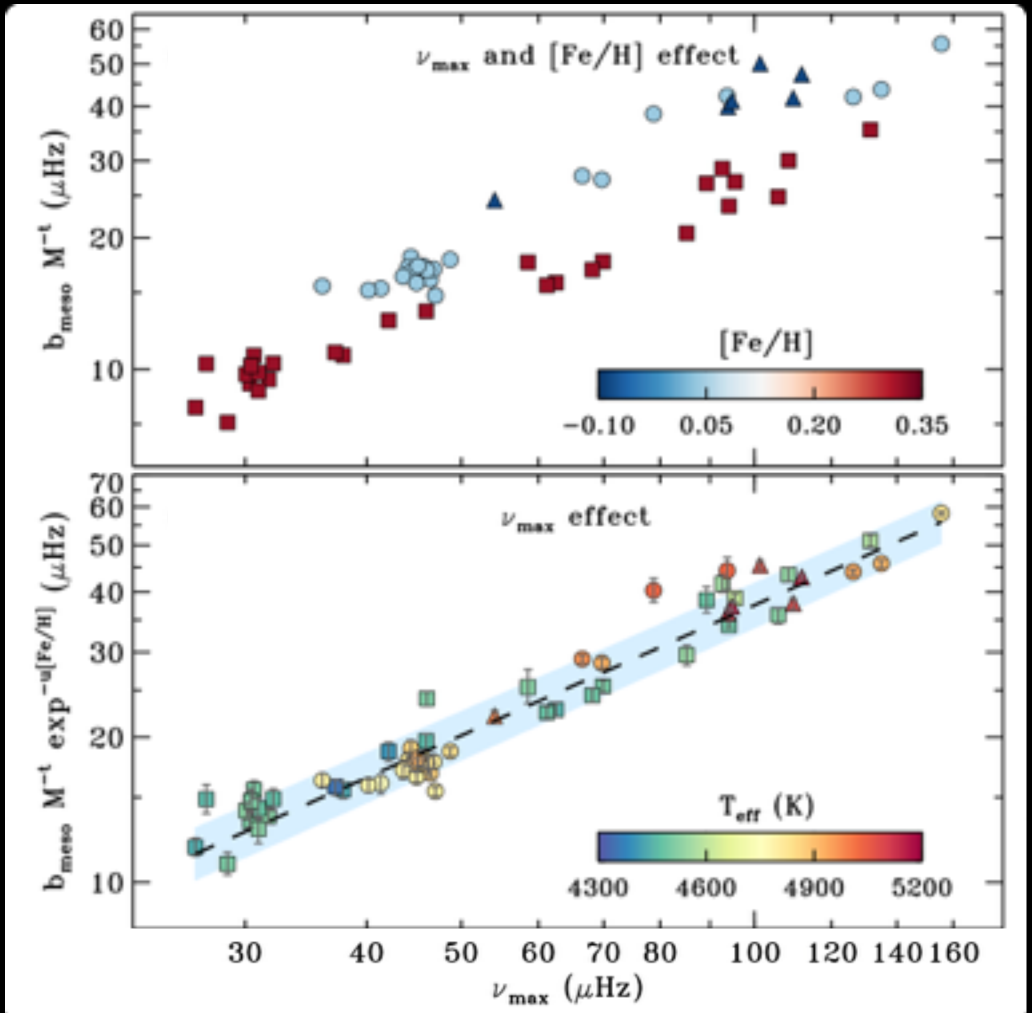
$$u = 0.89^{+0.08}_{-0.08}$$

- Amplitude increases with increasing ***[Fe/H]***
- No dependency on ev. stage (RC vs RGB)
- 11% increase in amplitude for 0.32 dex increase in [Fe/H] vs. 12% from 3D HD simulations

  LUDWIG & STEFFEN 2016
- Metallicity dependence 1.5 times stronger than ***g***

RESULTS FROM THE FAVORED SCALING RELATION

METALLICITY EFFECT ON FREQUENCY



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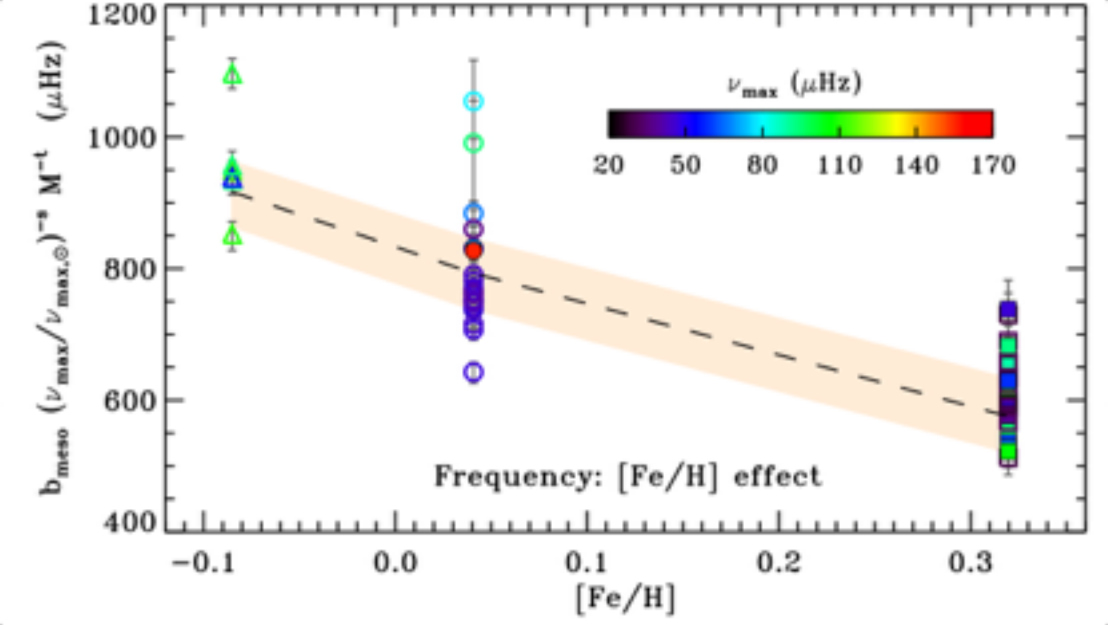

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- Frequency decreases with increasing ***[Fe/H]***
- No clear evidence from 3D HD simulations
  LUDWIG & STEFFEN 2016
- Metallicity dependence has strength comparable to that of ***g***
- No dependency on ev. stage (RC vs RGB)

$$s = 0.90^{+0.01}_{-0.01}$$

$$b_{\rm max} \propto \nu_{\rm max}$$

$$u = -1.15^{+0.12}_{-0.10}$$

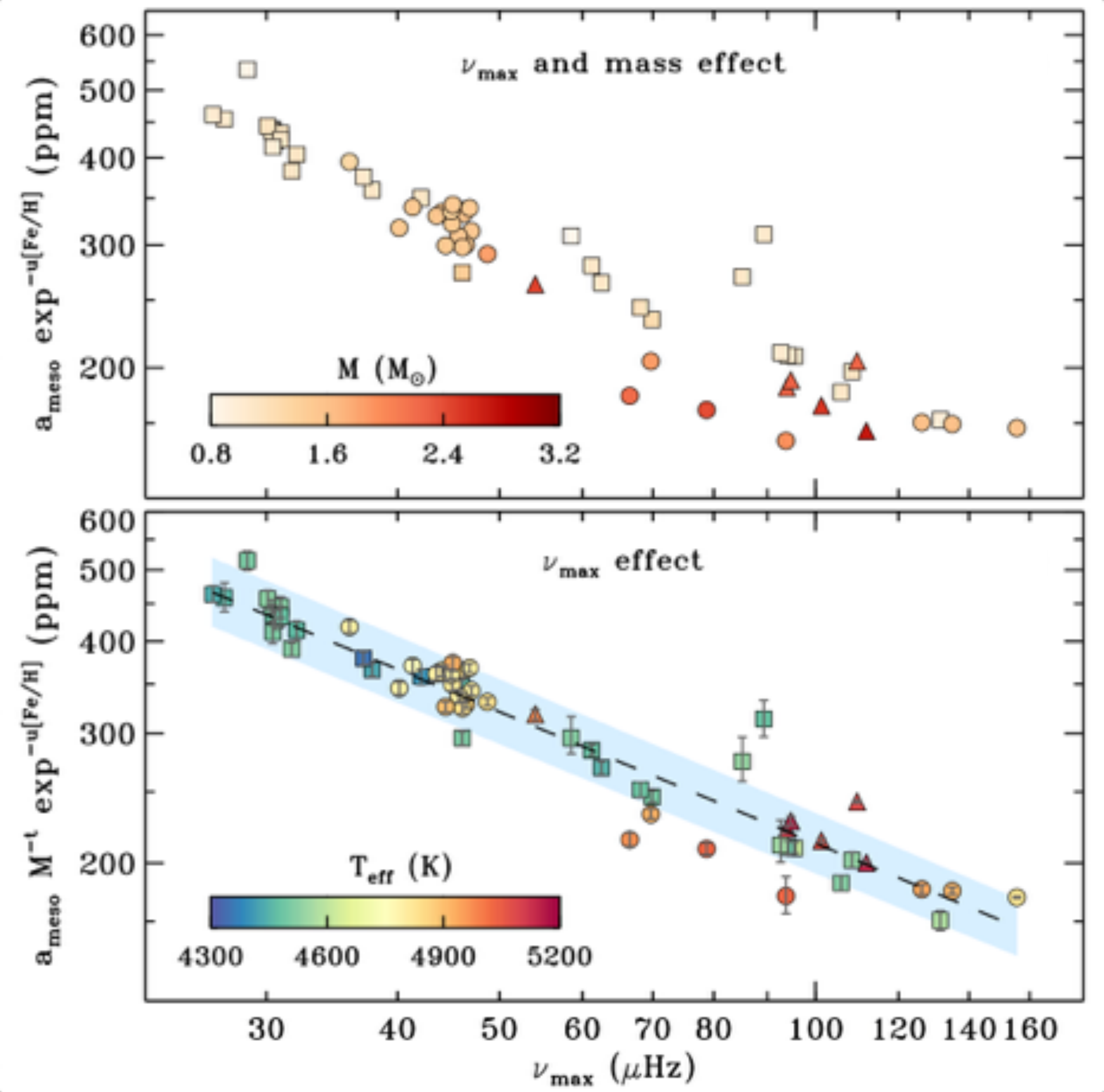
RESULTS FROM THE FAVORED SCALING RELATION

MASS (RADIUS) EFFECT ON AMPLITUDE

- Amplitude decreases with increasing ***M***

  KALLINGER ET AL. 2014

- Real effect comes from increasing ***R*** for constant **g**



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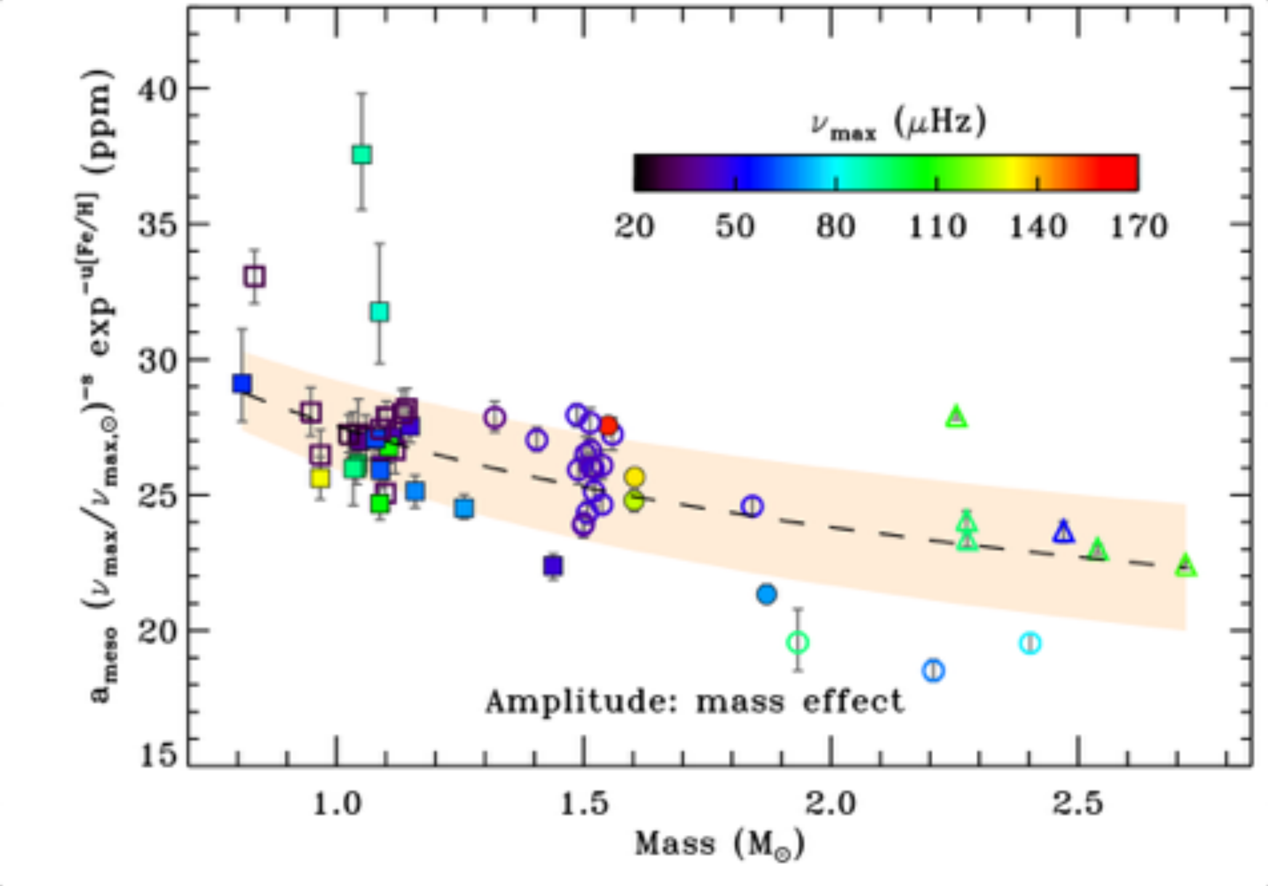

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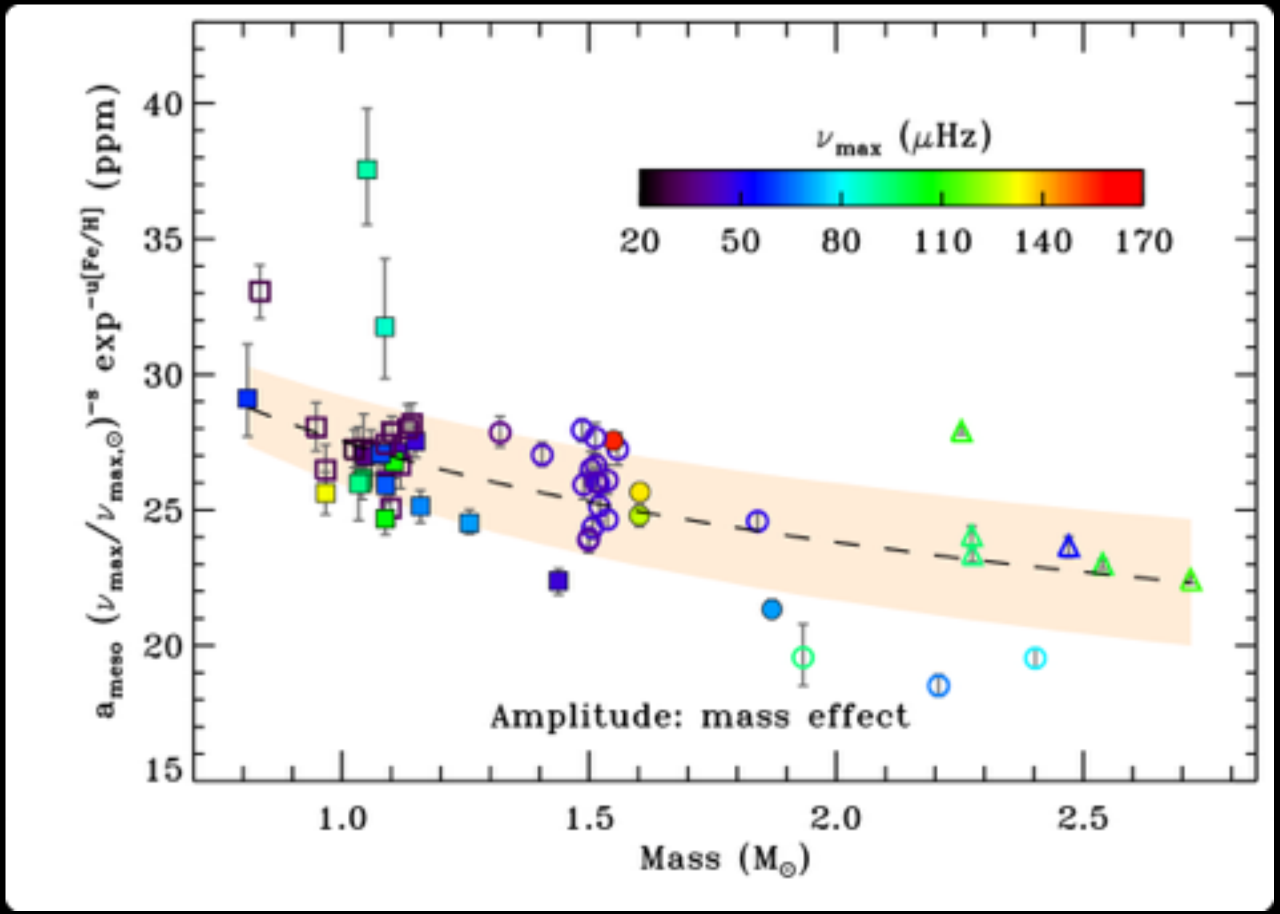

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$$a_{\rm gran} \propto n_{\rm gran}^{-0.5}$$

$$n_{\rm gran} \propto R^2$$

$$a_{\rm gran} \propto R^{-1}$$

$$g \propto M R^{-2}$$

CONSTANT

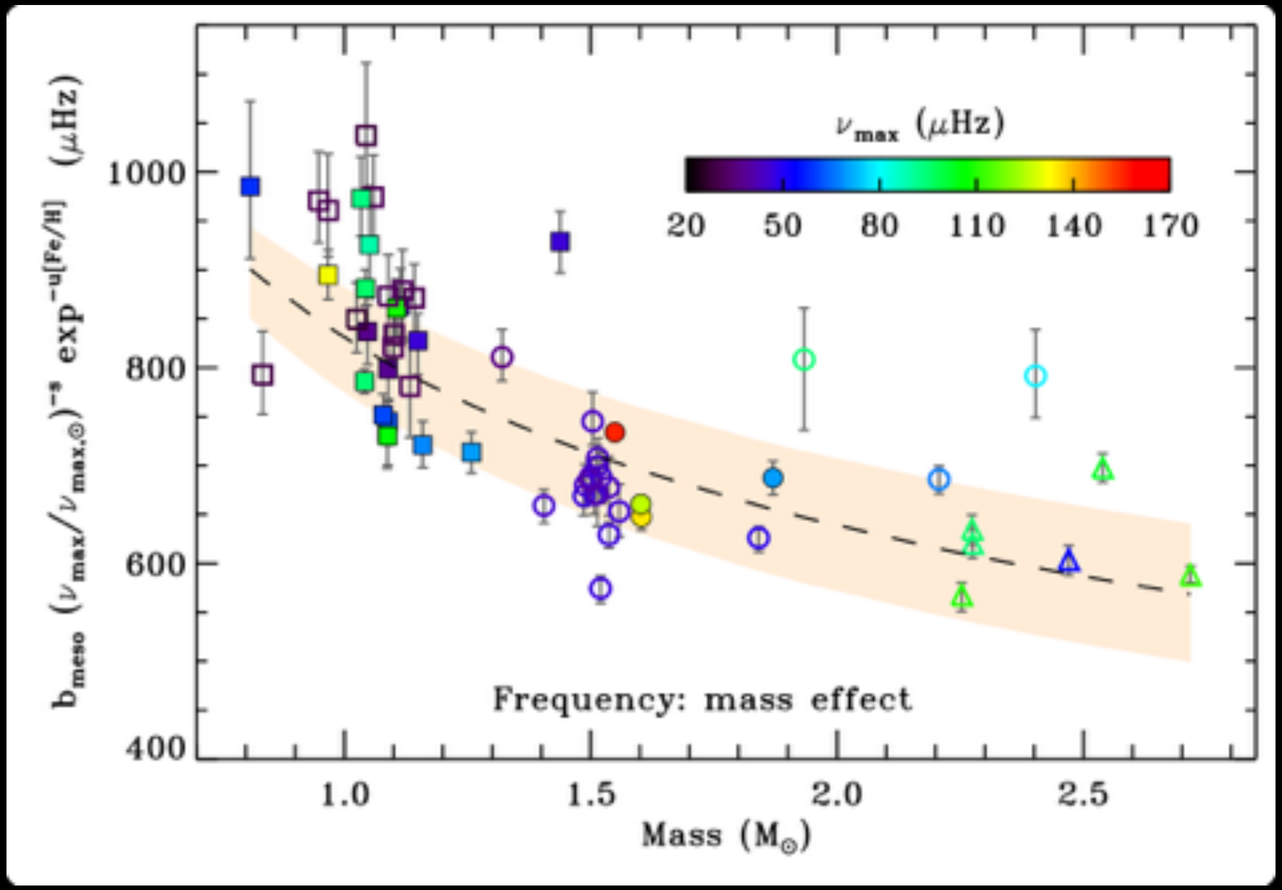
$$a_{\rm gran} \propto M^{-0.5}$$

$$t = -0.21^{+0.04}_{-0.05}$$

- Mass effect weaker than [Fe/H]

RESULTS FROM THE FAVORED SCALING RELATION

MASS (RADIUS) EFFECT ON FREQUENCY



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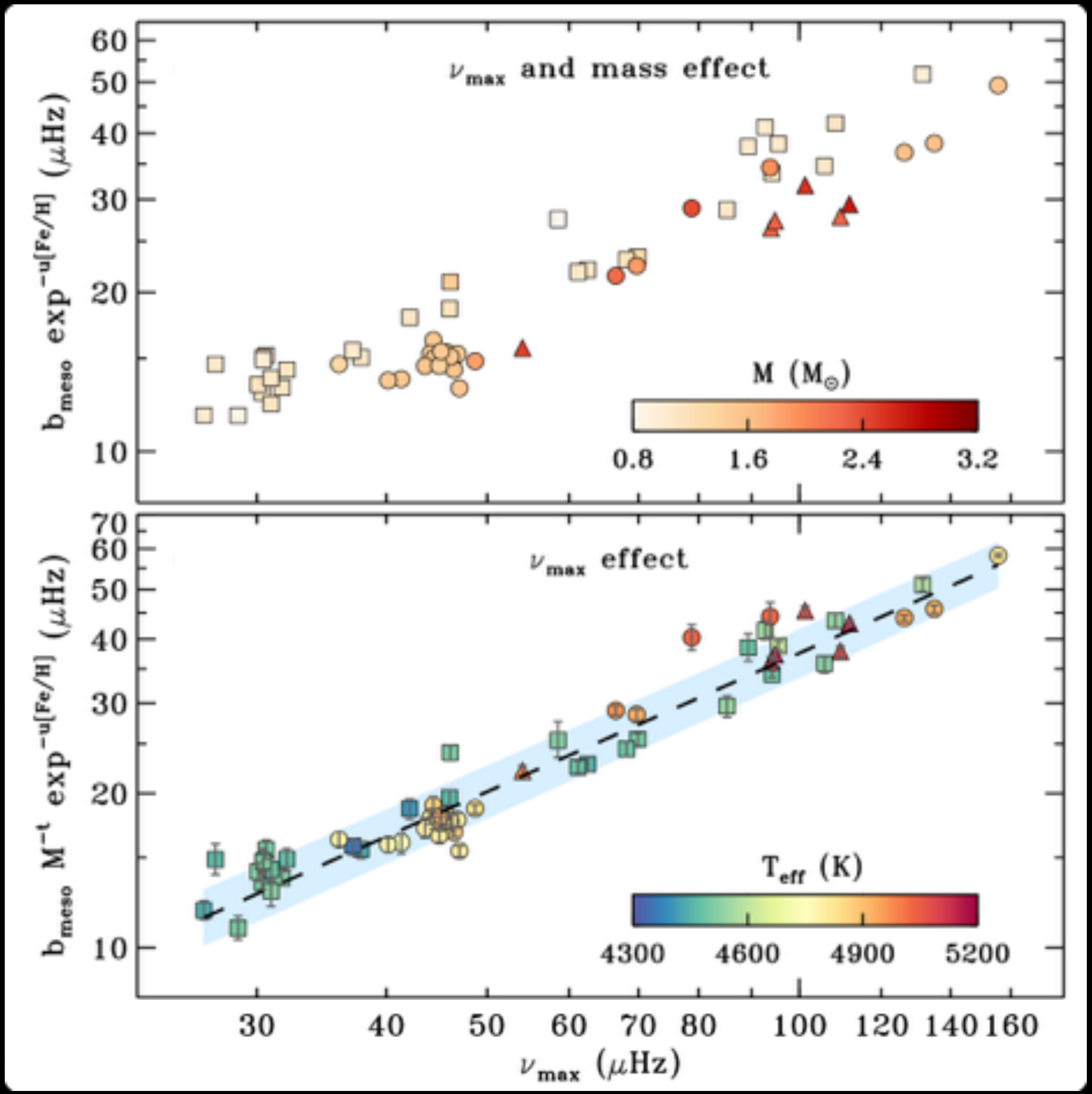

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- Frequency decreases with increasing ***M*** (like amplitude)
- Mass effect weaker than [Fe/H]

$$t = -0.38^{+0.06}_{-0.06}$$

SUMMARY & CONCLUSION

- Both metallicity and mass play a ***significant*** role in changing the granulation properties — [Fe/H] more important

$a_{\rm meso}, a_{\rm gran}$ ↓ **[Fe/H]** ↑

$a_{\rm meso}, a_{\rm gran}$ ↓ ***M*** ↑ because ***R*** ↑

In agreement with simulations

$b_{\rm meso}, b_{\rm gran}$ ↓ **[Fe/H]** ↑

$b_{\rm meso}, b_{\rm gran}$ ↓ ***M*** ↑ because ***R*** ↑

Needs more/new models to compare

- No influence from ev. stage — Granulation depends on ***atmospheric*** parameters ***only***

TAKE HOME MESSAGES

- We can obtain accurate+precise ***surface gravity*** for many stars
- If accurate+precise ***radii*** provided (e.g. asteroseismology, interferometry), we get accurate+precise ***mass***
- If mass known, scaling relations can be used to estimate ***[Fe/H]*** for large samples of stars without spectroscopy

Thank you!

ENRICO CORSARO