Metallicity effects on granulation in red giants

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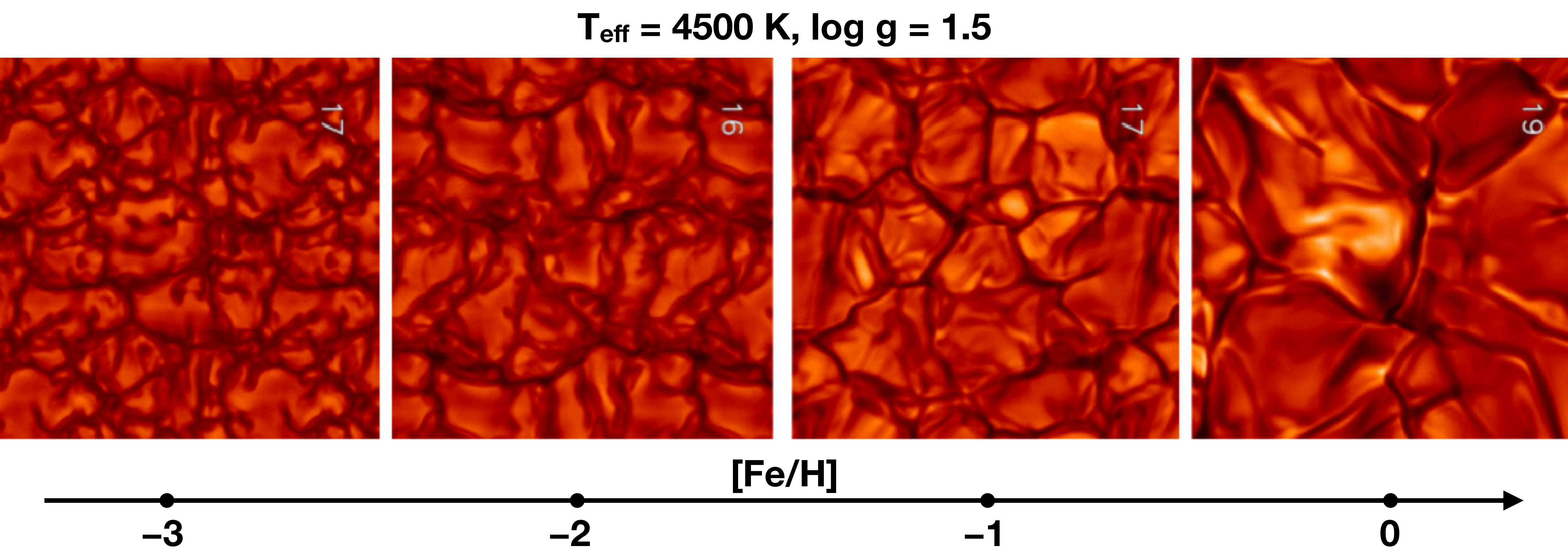
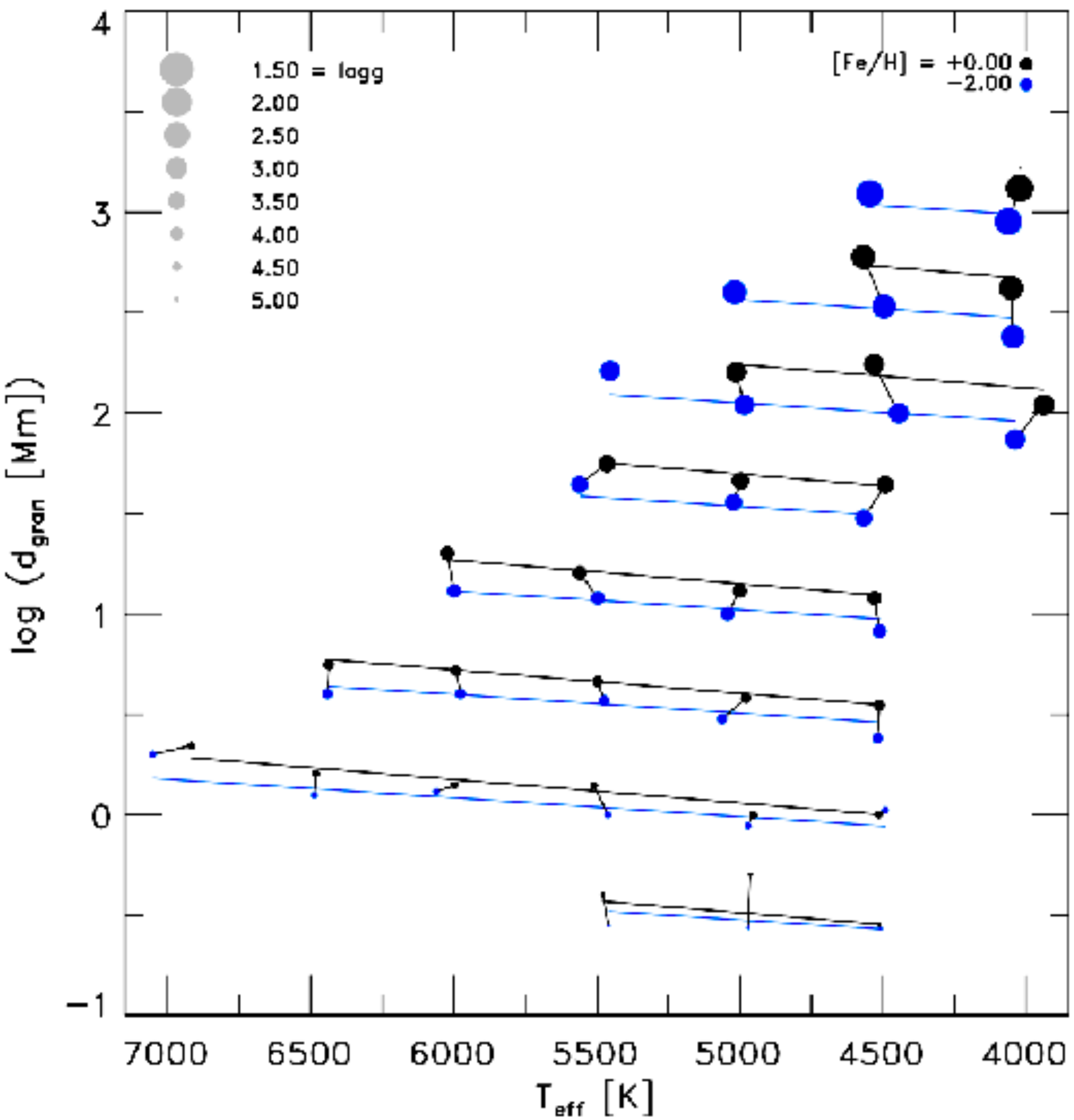
Metallicity and stellar granulation: 3D models

- 3D surface convection simulations of red giants and other late-type stars including realistic micro-physics predict that the **characteristic size of granules increases with metallicity** (Collet et al. 2007; Magic et al. 2015; Ludwig & Steffen 2016)



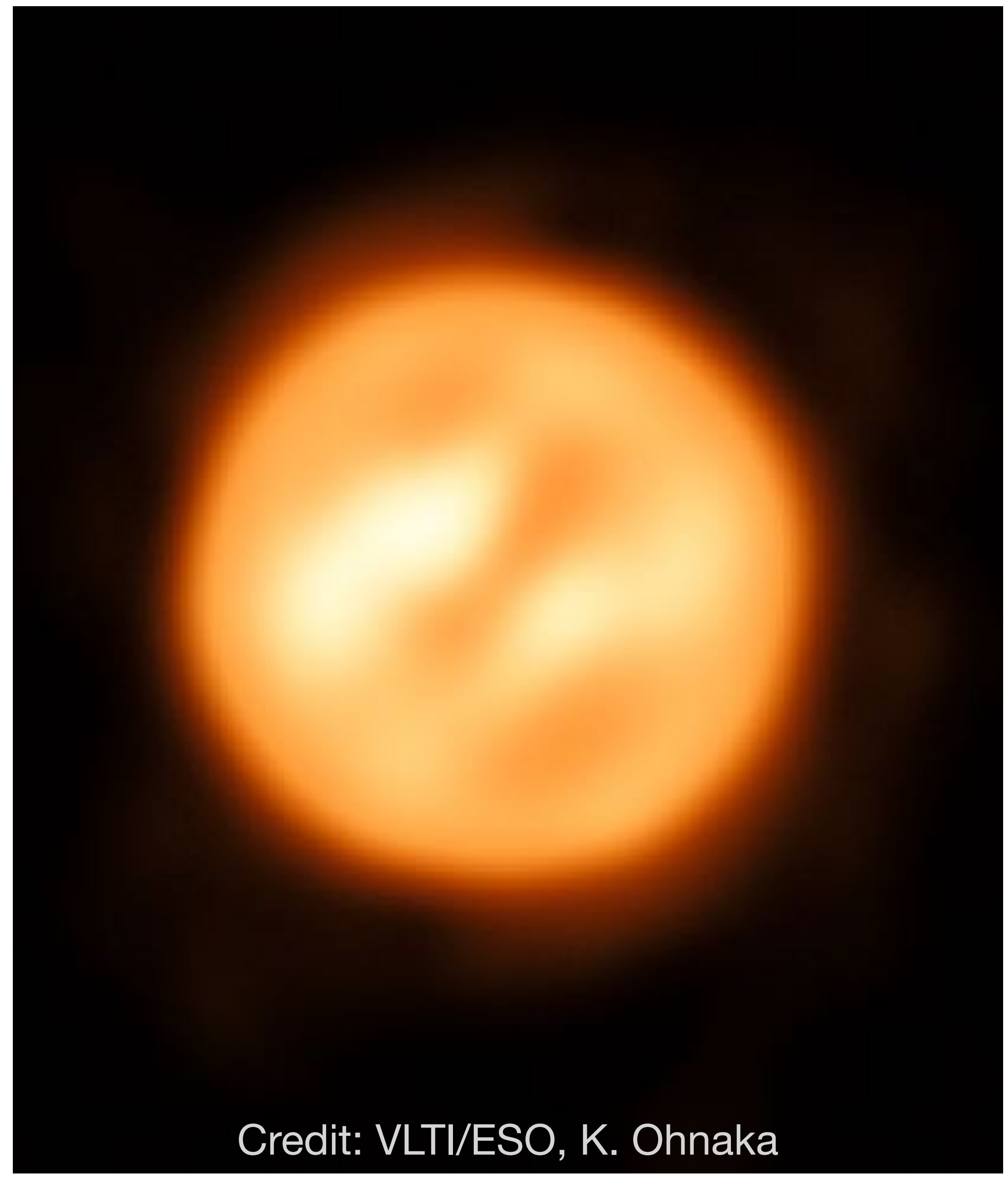
Granules: predicted sizes



Magic, Collet, Asplund et al. (2013)

Metallicity and stellar granulation: observations

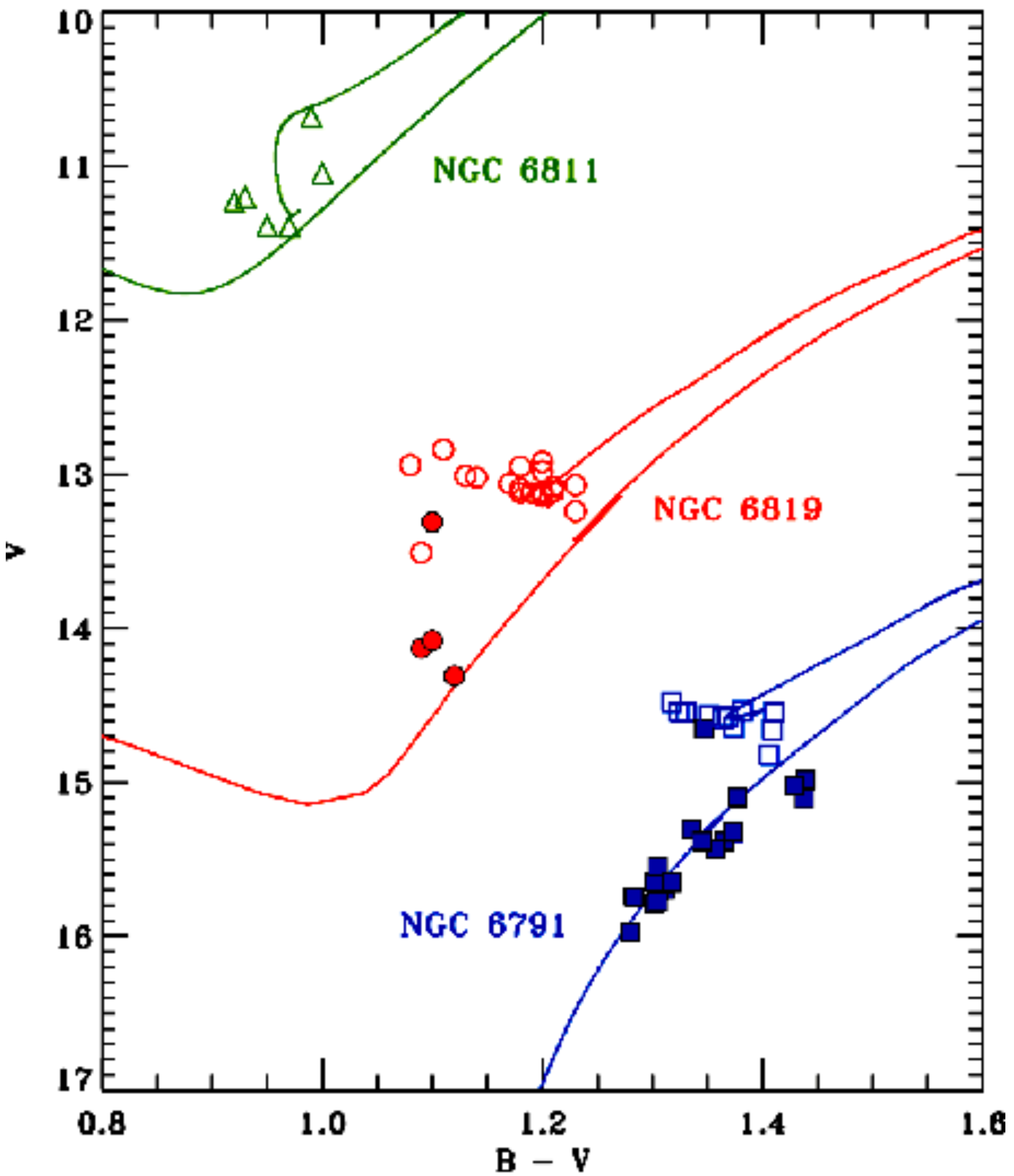
- Direct and interferometric imaging of stellar granulation limited to nearby stars
- Asteroseismic studies of granulation spatial and temporal time-scales with CoRoT, Kepler
- Accurate [Fe/H] values needed for many stars to study metallicity dependence
- Corsaro et al. (2017, A&A 603, A3): **Metallicity effect on stellar granulation detected from oscillating red giants in open clusters**



Credit: VLTI/ESO, K. Ohnaka

Red giants in open clusters

- Corsaro et al. (2017): sample of ~60 RGB and RC stars in three open clusters:
  - NGC 6811, [Fe/H] = −0.09
  - NGC 6819, [Fe/H] = +0.04
  - NGC 6791, [Fe/H] = +0.32



Stellar oscillation power spectral densities

- Corsaro et al. (2017): Bayesian analysis of background signal in observed stellar and solar (VIRGO) power spectra

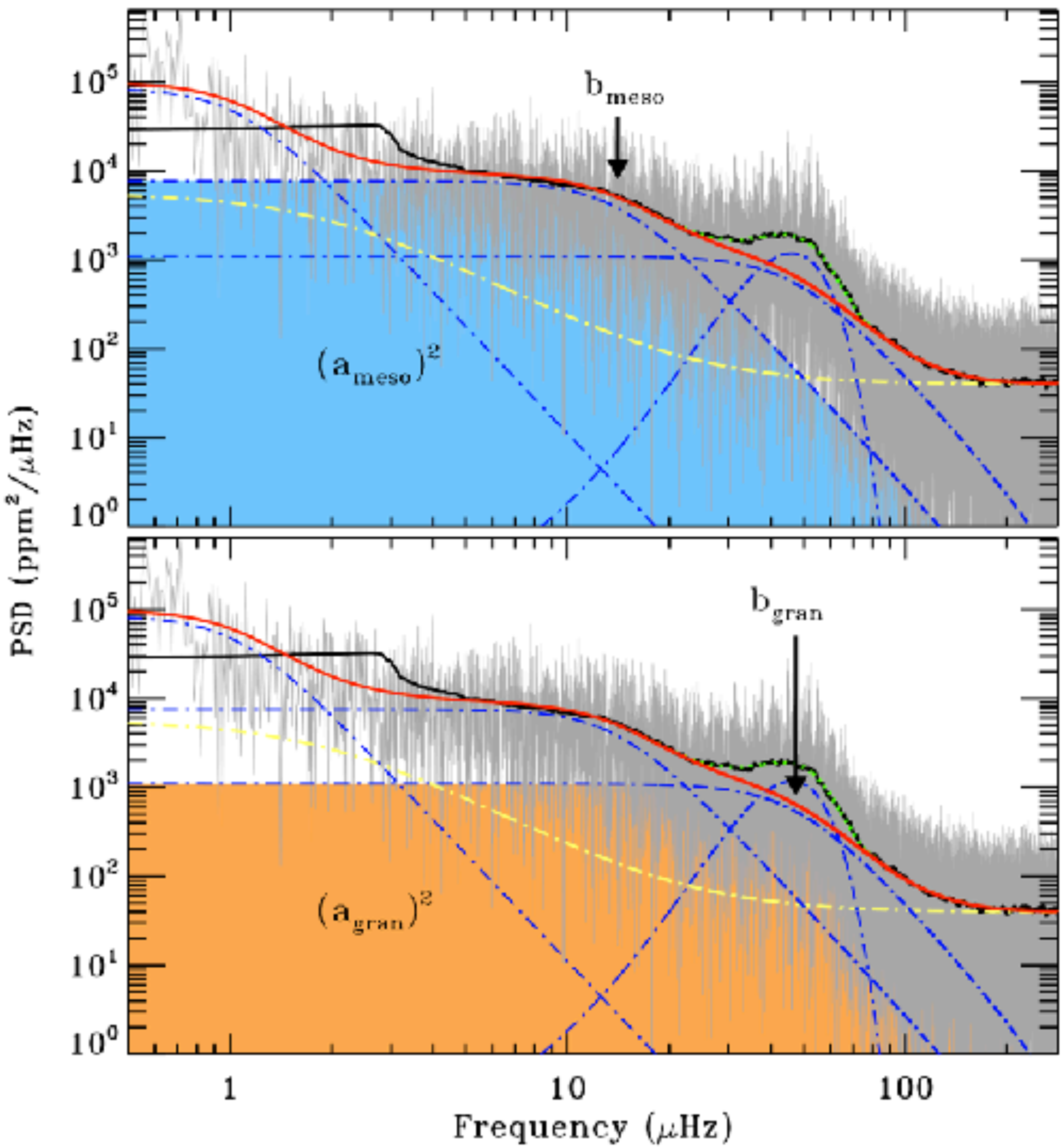
- Adopted model by Kallinger et al. (2014, 2016):

$$P_{\mathrm{bkg}} = N(\nu) + R(\nu) \cdot [B(\nu) + G(\nu)]$$

- Granulation background, three components (“gran”, “meso”, “super”):

$$B(\nu) \sim \sum_{i=1}^{3} \frac{a_i^2 / b_i}{1 + (\nu / b_i)^4}$$

Background fit



Example: KIC 4937056 (NGC 6819), [Fe/H]=0.04 (Corsaro et al. 2017)

Scaling relations

- Corsaro et al. (2017): Modified scaling relation for stellar mass:

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

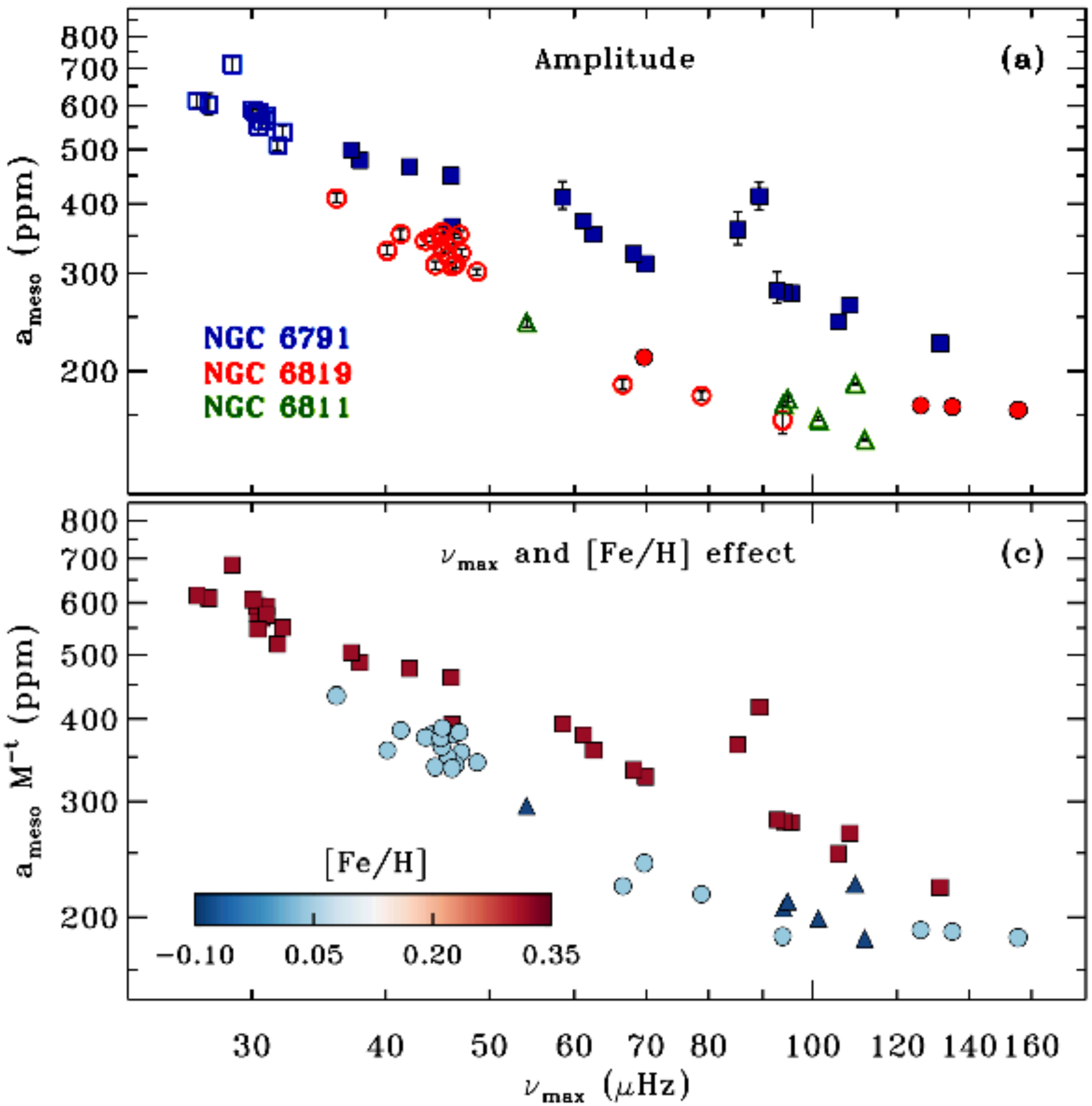
- From fit: linear relations between meso-granulation and granulation spatial (“*a*”) and frequency (“*b*”) parameters:

$$a_{\rm meso}/a_{\rm gran} \approx 1.31 \qquad b_{\rm meso}/b_{\rm gran} \approx 0.32$$

- Scaling relations for granulation spatial (temporal) parameter:

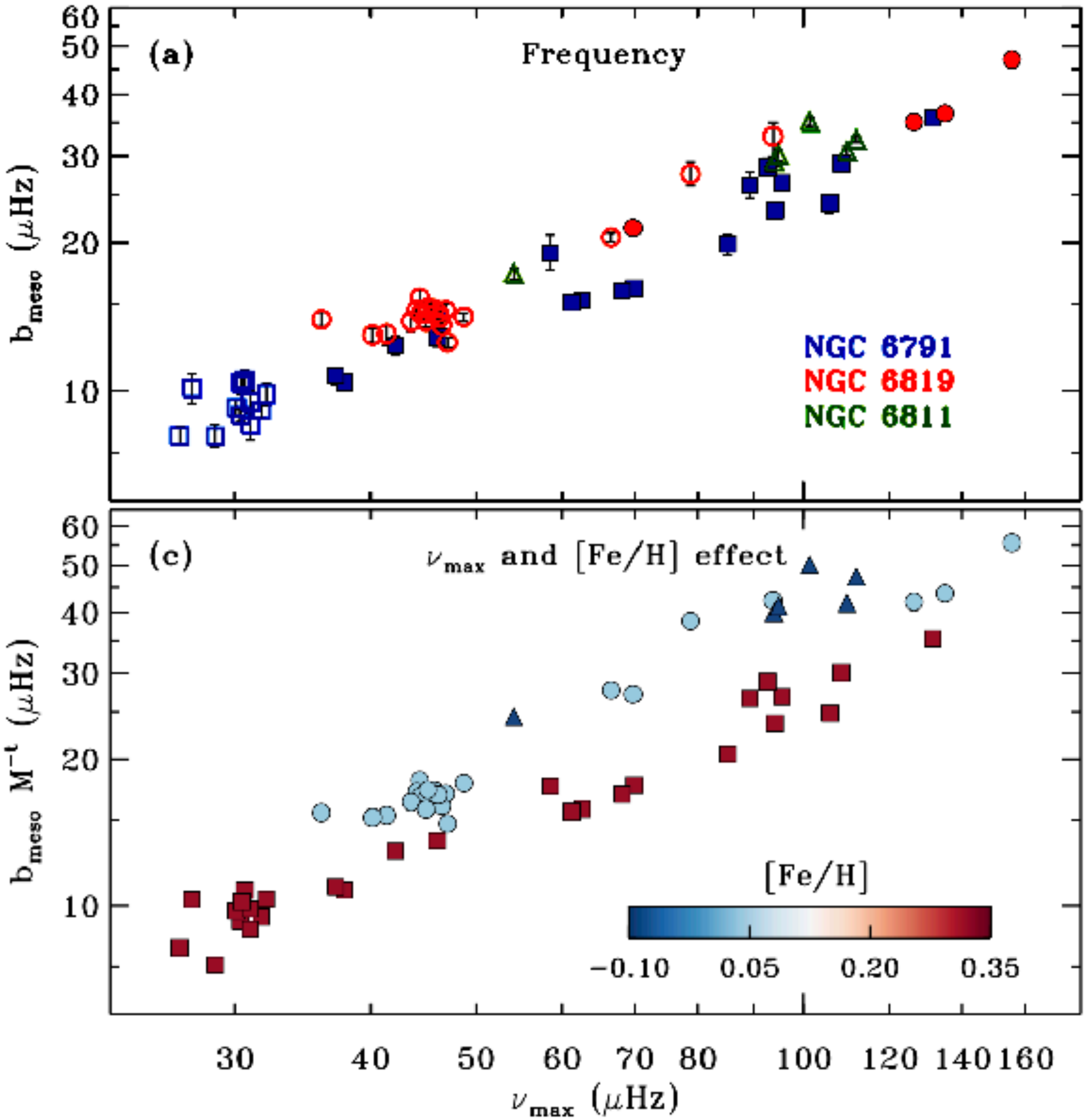
$$\left(\frac{a_{\rm meso}}{a_{\rm meso,\odot}}\right) = \beta \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^s \left(\frac{M}{M_\odot}\right)^t e^{u[{\rm Fe/H}]}$$

Results: amplitude parameter



Corsaro et al. (2017)

Results: frequency parameter



Corsaro et al. (2017)

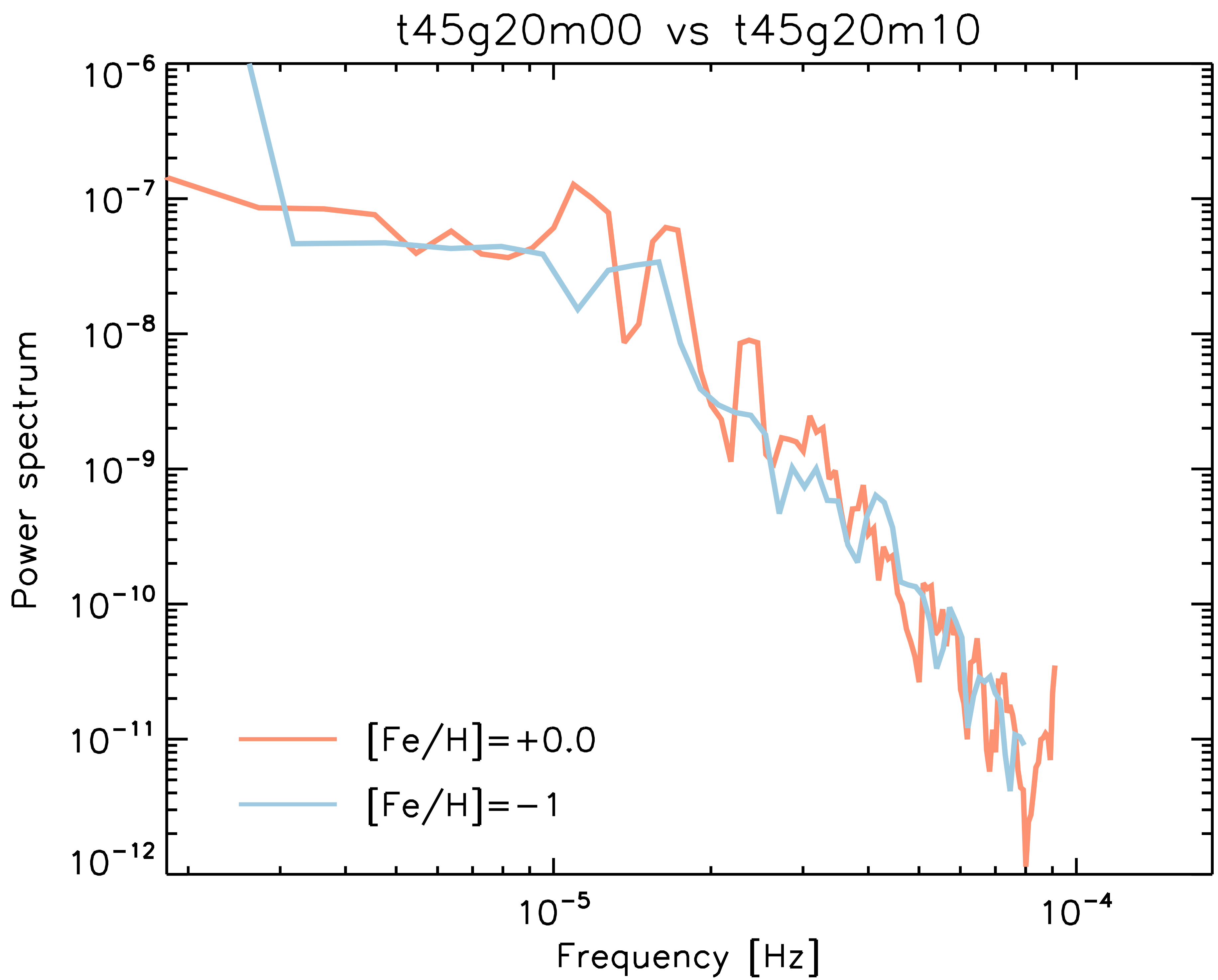
Trends

- $\mathbf{a_{meso}}$ and $\mathbf{a_{gran}}$ amplitudes **increase with metallicity**, **decrease with mass** (radius), as in simulations

- $\mathbf{b_{meso}}$ and $\mathbf{b_{gran}}$ frequencies **decrease with metallicity and mass (radius)**, counter to simulations (Ludwig & Steffen 2016)

Simulations: power spectra

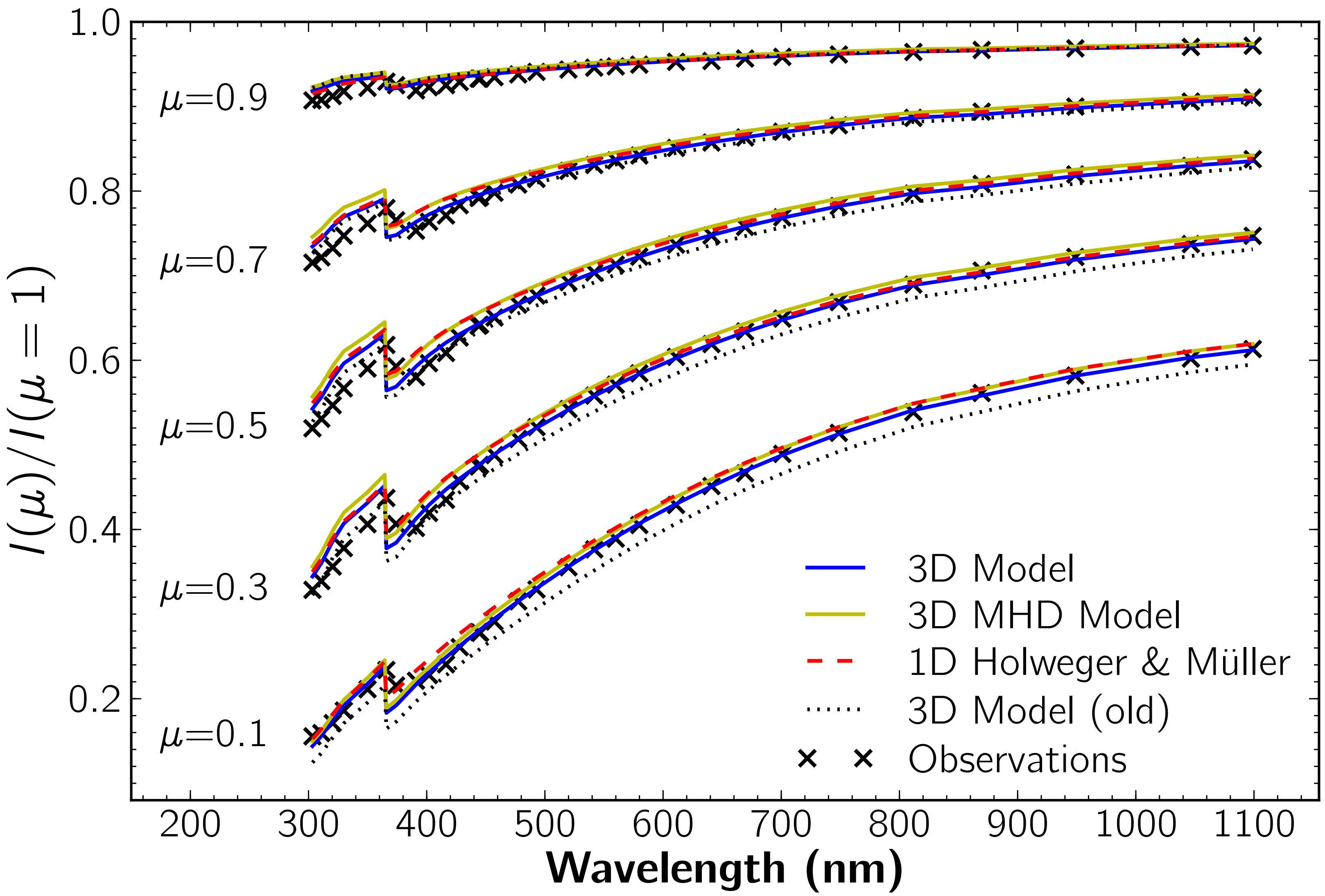
Stagger-grid models, surface intensity time series



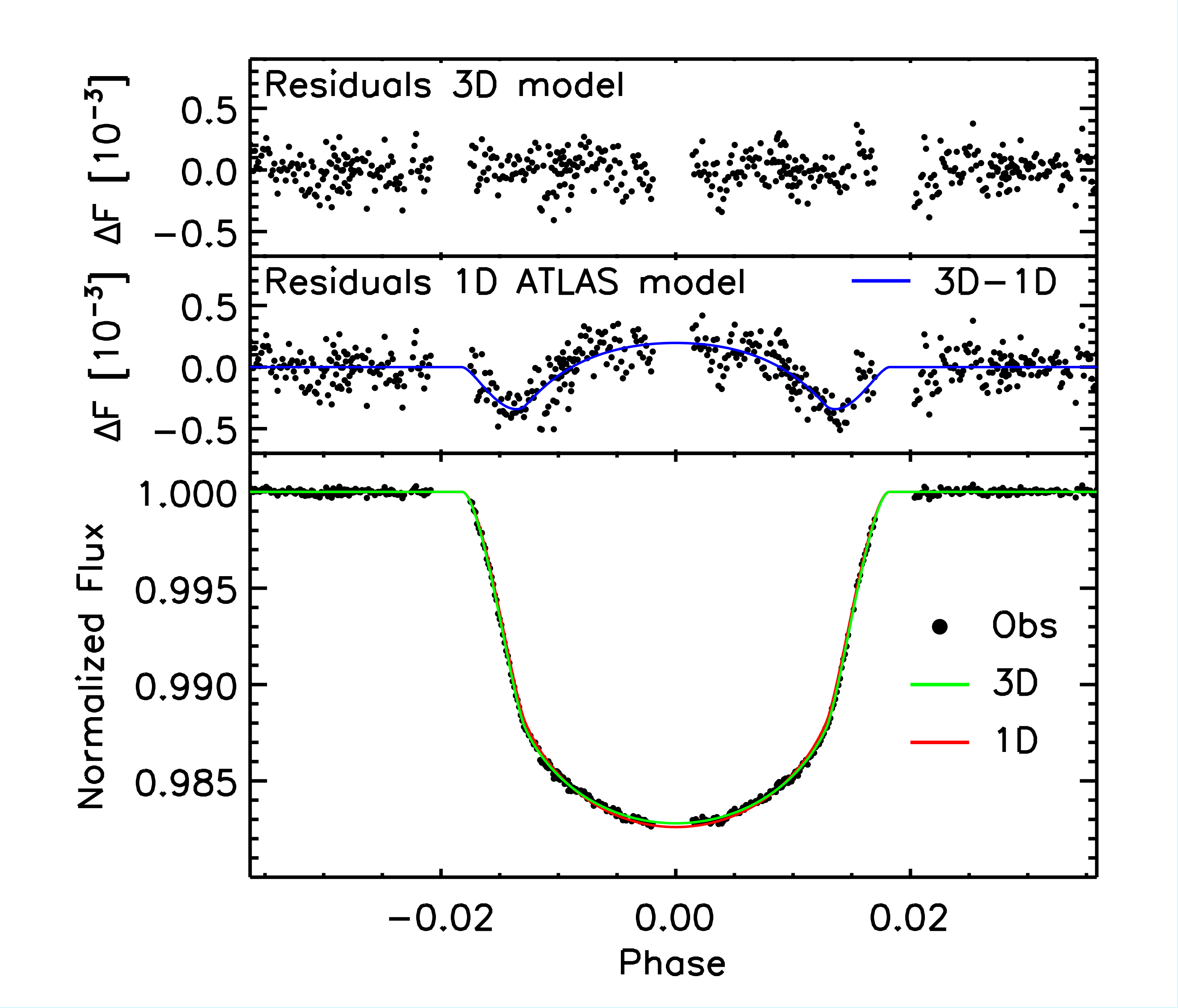
Limb darkening

Limb darkening: Sun

- Calculations based on 3D models give very good agreement with observations in UV and visible (Pereira, Asplund, Collet et al. 2013)



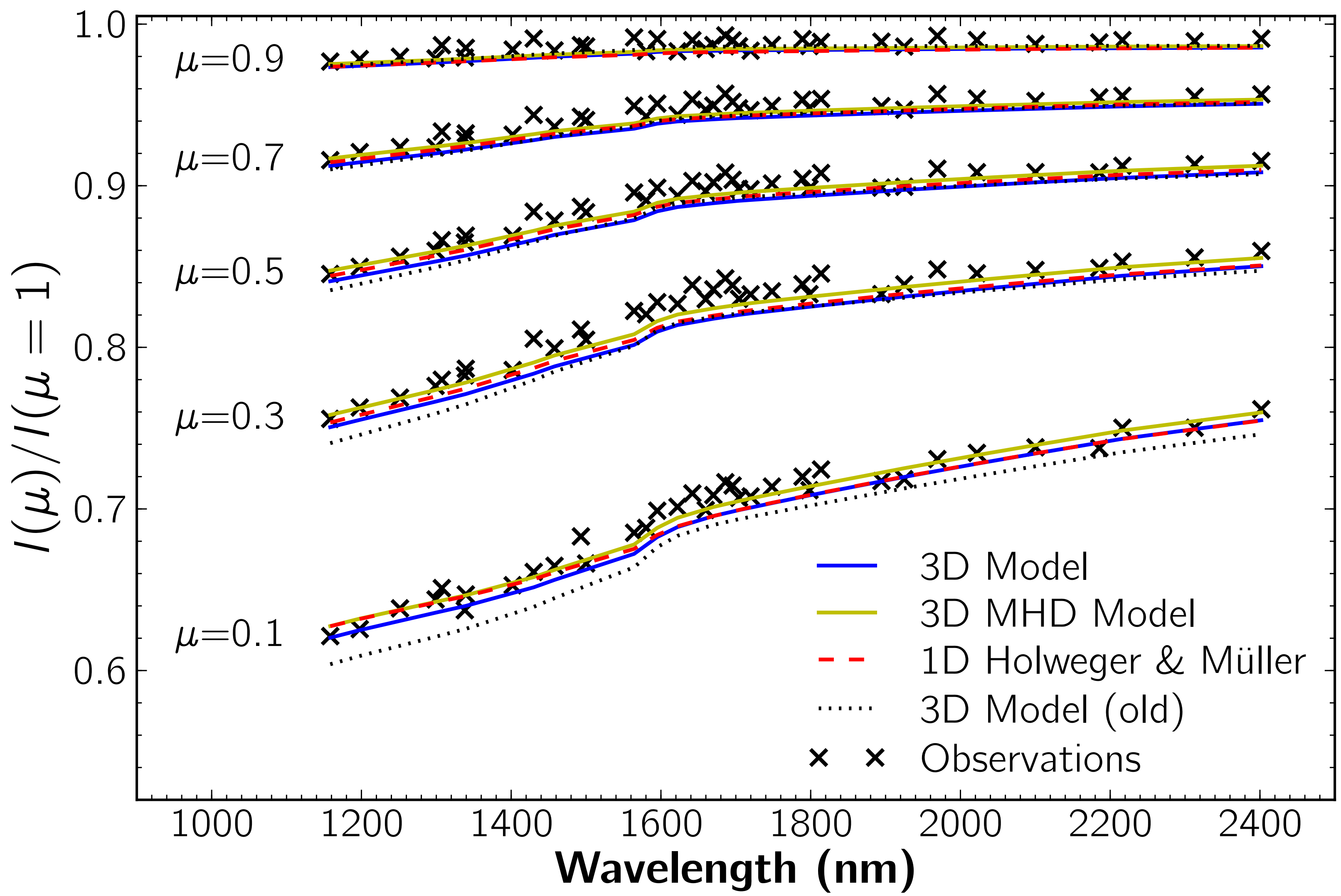
Exoplanet transits



HD209458b transit, HST 2900 Å - 5700 Å band (Hayek et al. 2012)

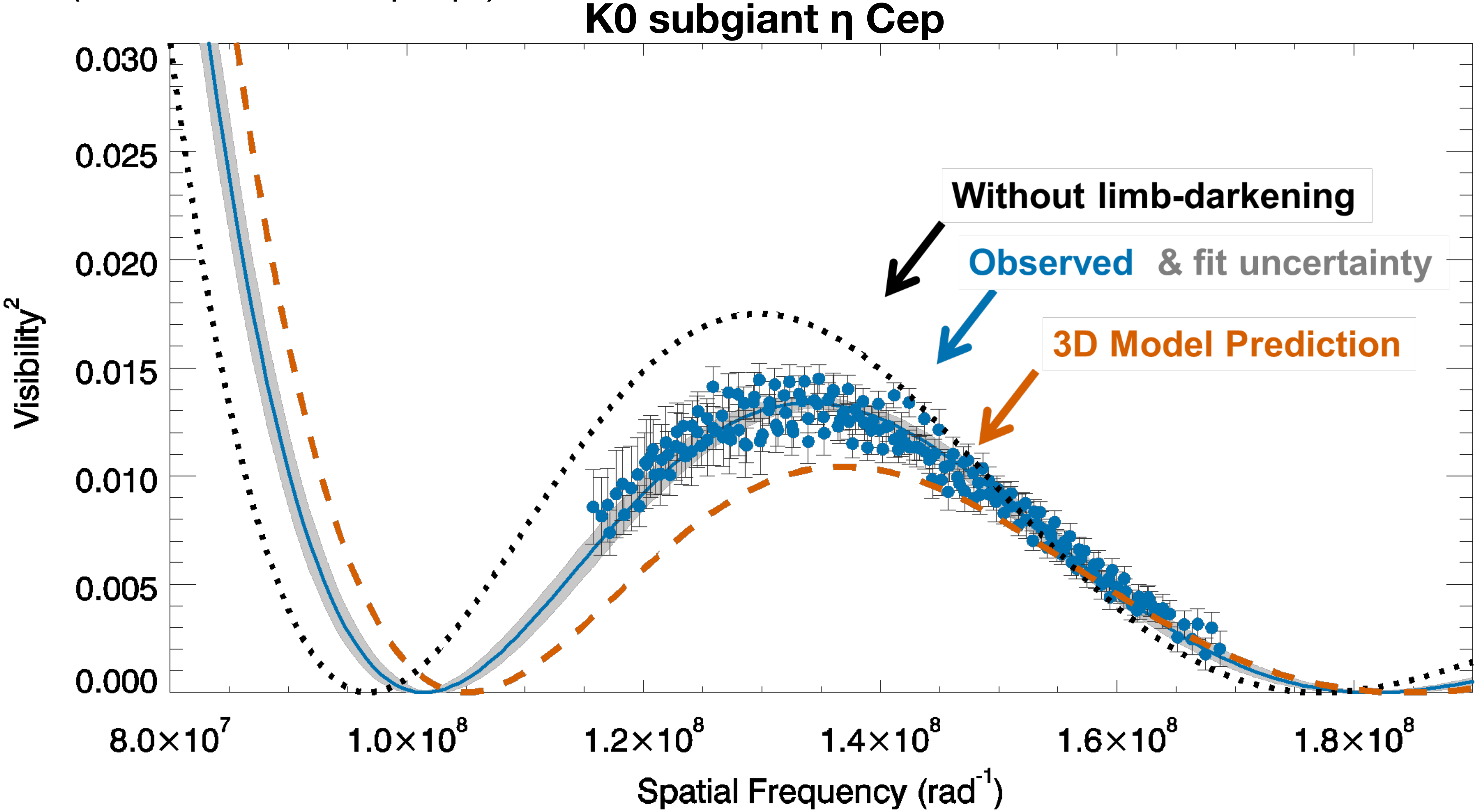
Limb darkening: Sun (2)

- Poorer agreement with observations at long wavelengths (Pereira, Asplund, Collet et al. 2013)



Interferometric tests

- Limb darkening from 3D/1D models: **predicted visibility of first lobe lower than observed** with CHARA/PAVO at visible wavelengths for evolved stars (T. White et al. in prep.)



Interferometric tests (2)

- Comparative study of limb darkening in α Cen A & B using VLTI/PIONIER data (Kervella, Bigot, Gallene, Thévenin 2017)
- Observed squared visibilities: 2-3 side lobes for dwarfs!
- 3D squared visibilities: overall in good agreement with observations but underestimation of first side lobe in the IR
- Simple power-law model (μ^{α}) for limb darkening performs better…

α Cen B