Measuring RGB Mass Loss in Globular Clusters with Asteroseismology

Madeline Howell

Collaborators: Simon Campbell (Monash), Dennis Stello (UNSW), Gayandhi De Silva (Macquarie)

Globular Clusters (GCs)

- *Relatively* simple stellar populations
  - Coeval - old, ~10 Gyrs
  - Isometallic - metal-poor
  - similar initial masses - low mass, ~$0.8 M_{\odot}$
- Cluster members in a variety of evolutionary phases

GCs are ideal objects to study stellar evolution

“Globular clusters are the closest approximation to a physicist’s laboratory in astronomy” (Moehler, 2001)

Globular Clusters (GCs)

Type I
'Classic GC'

Type II
'Iron complex GC'

Globular Clusters (GCs)

Type I
‘Classic GC’

- Homogenous heavy element distribution
- Unknown formation channel

Type II
‘Iron complex GC’

Globular Clusters (GCs)

Type I
'Classic GC'

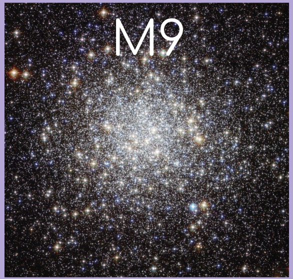
- Homogenous heavy element distribution
- Unknown formation channel

Type II
'Iron complex GC'

- Non-homogenous heavy element distribution (Fe and s-process abundances)
- Likely nucleus of stripped dwarf galaxy

Globular Clusters (GCs)

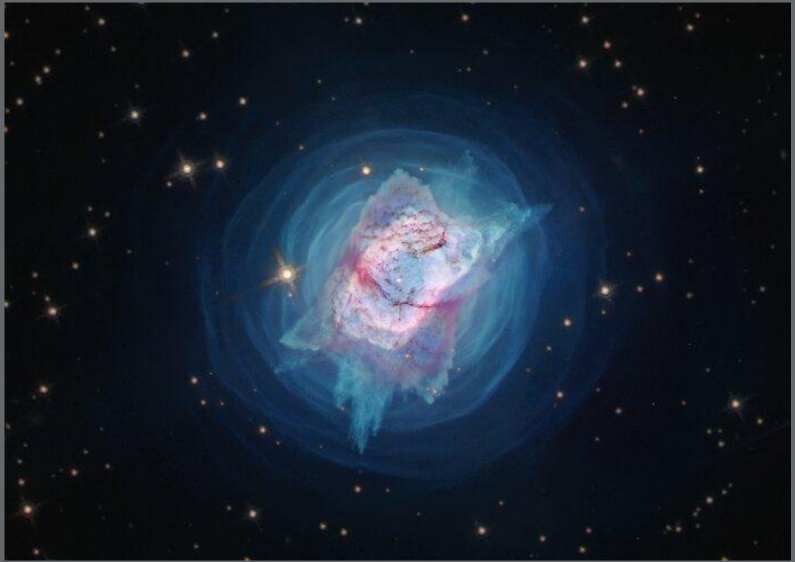
Type I



Type II

Stellar Mass Loss of Low Mass Stars

- Most mass loss on RGB (~0.2 $M_\odot$)
- RGB mass loss is metallicity-dependent
  - Metal-poor -> less mass loss



Mass loss envelopes (blue spherical shells) shown surrounding a pink planetary nebula and white dwarf stellar remnant. Photo source: NASA, ESA/Hubble and J. Kastner (RIT)

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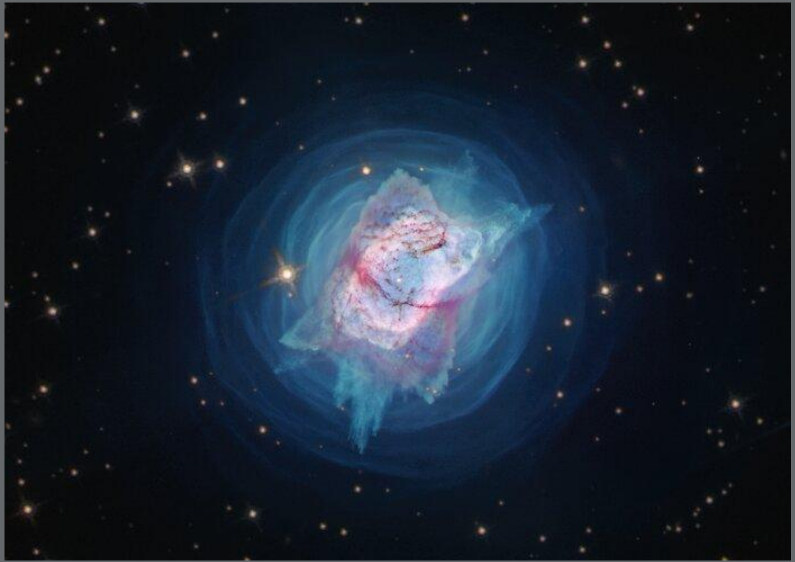
Mass loss rates are a major uncertainty in stellar models



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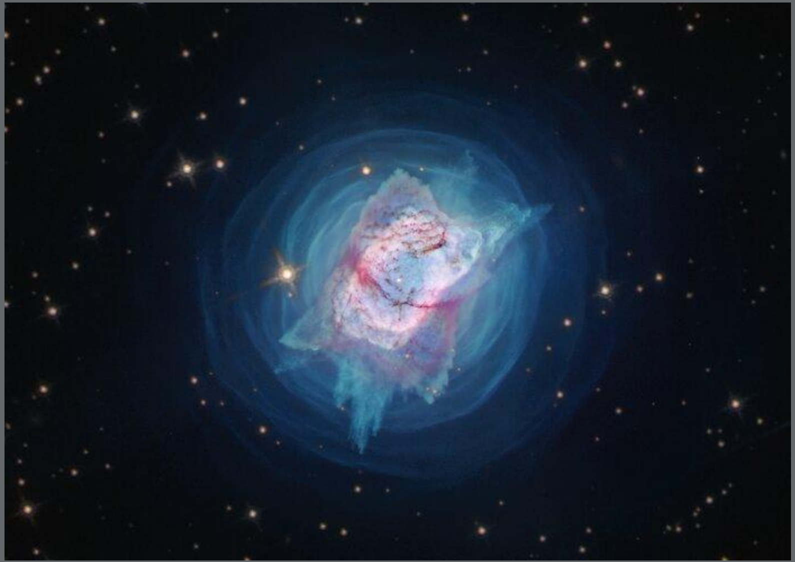
Mass loss rates are a major uncertainty in stellar models

Measure an accurate integrated mass loss on the RGB for low-mass stars



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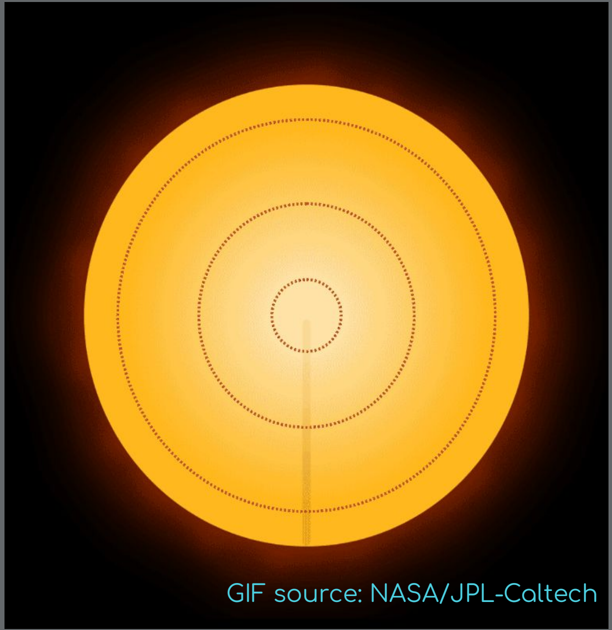
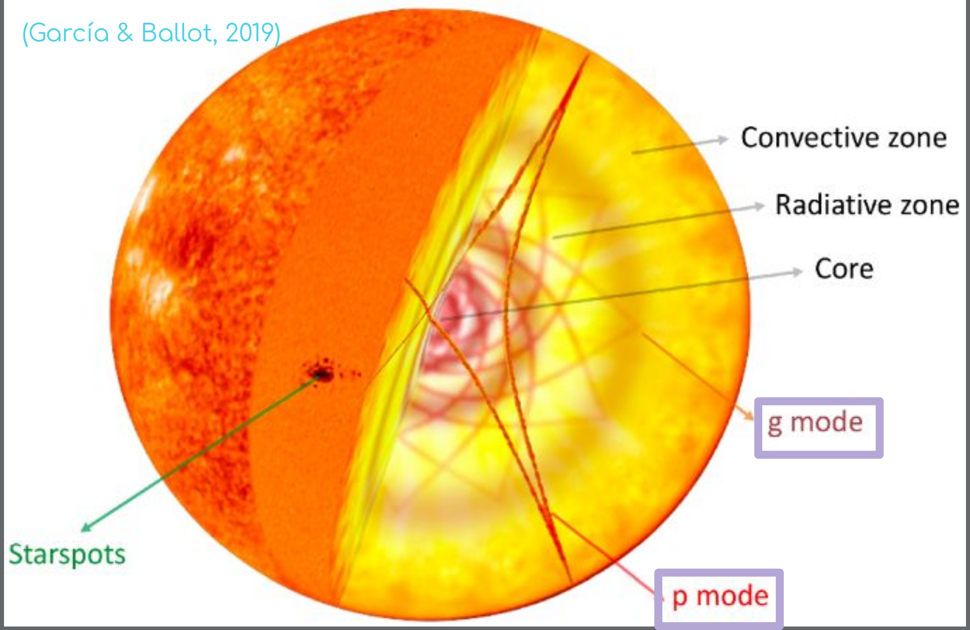
'The Music of Stars': Asteroseismology

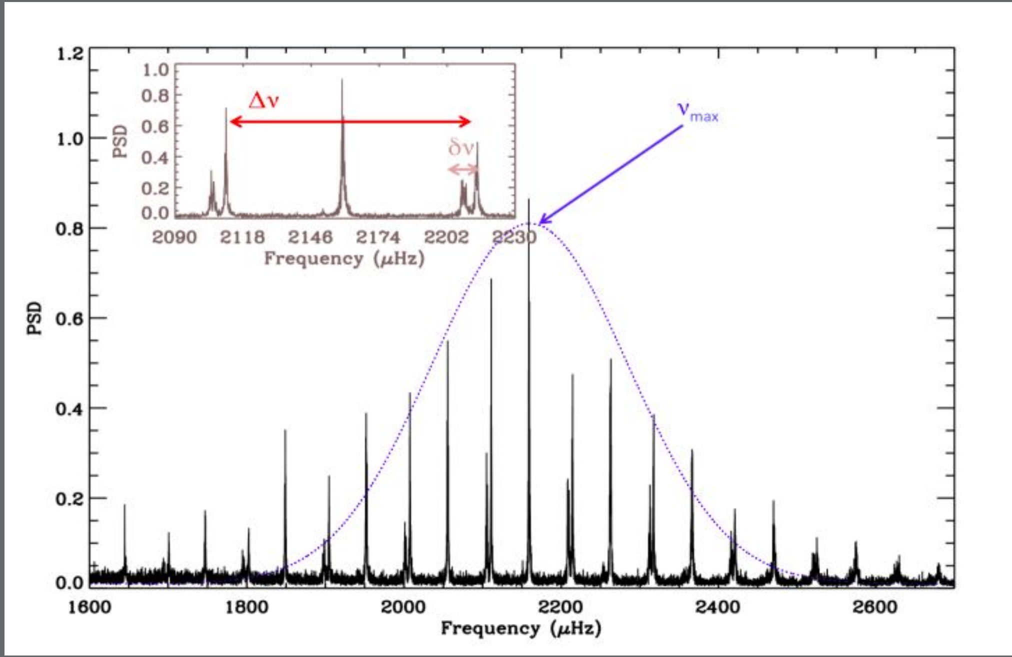




Or acoustic waves/solar-like oscillations (in Sun like or red giant stars)

Solar-like Oscillations

Solar-like oscillation of a main sequence star (García, 2015)



Global Asteroseismic parameters:

ν_{max} & $\Delta\nu$

Correlated to stellar properties:

$$\nu_{\text{max}} \propto g T_{\text{eff}}^{-1/2}$$

$$\Delta\nu \propto \rho^{1/2}$$

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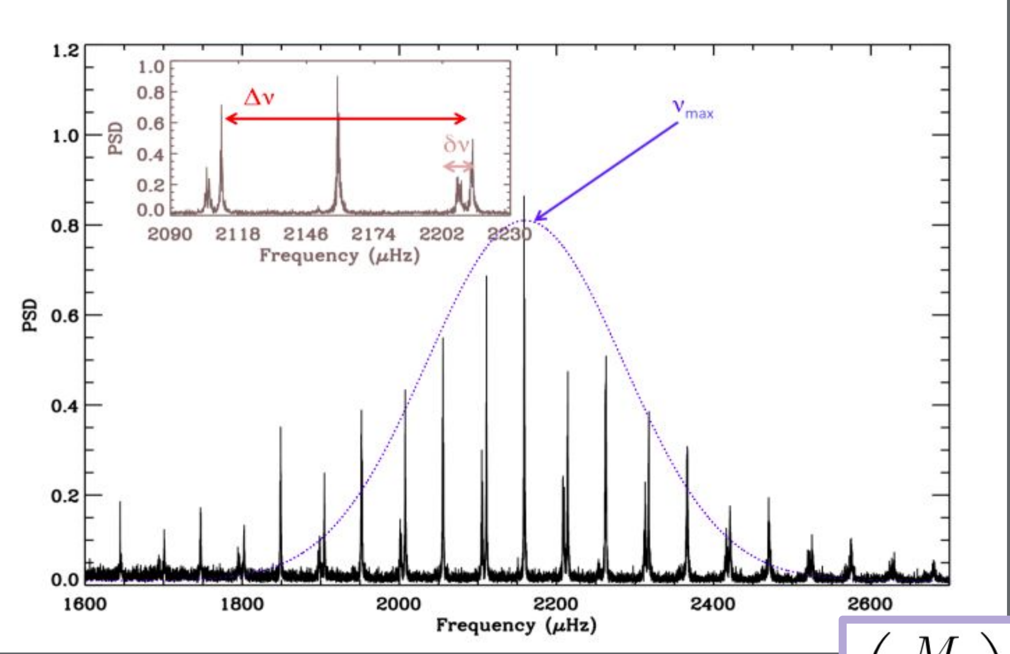


Global Asteroseismic parameters:

ν_{max} & $\Delta\nu$

Correlated to stellar properties:

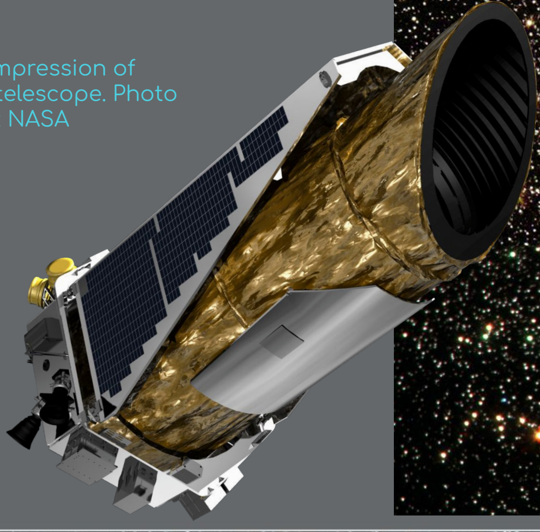
$$\nu_{max} \propto g T_{eff}^{-1/2}$$

$$\Delta\nu \propto \rho^{1/2}$$

Seismic mass scaling relation:

$$\left(\frac{M}{M_\odot}\right) \simeq \left(\frac{\nu_{max}}{\nu_{max,\odot}}\right) \left(\frac{L}{L_\odot}\right) \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{-7/2}$$

Kepler 2 (K2) Photometry



Artist impression of Kepler telescope. Photo Source: NASA

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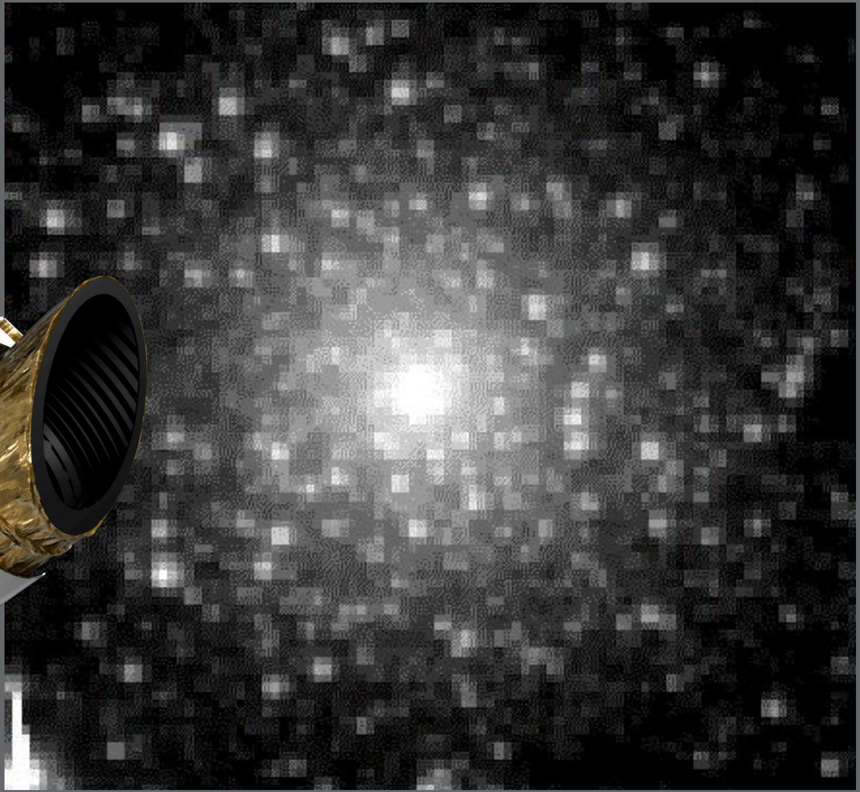

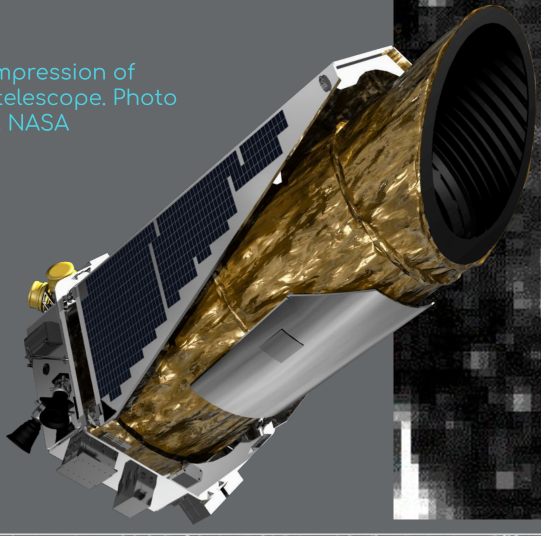

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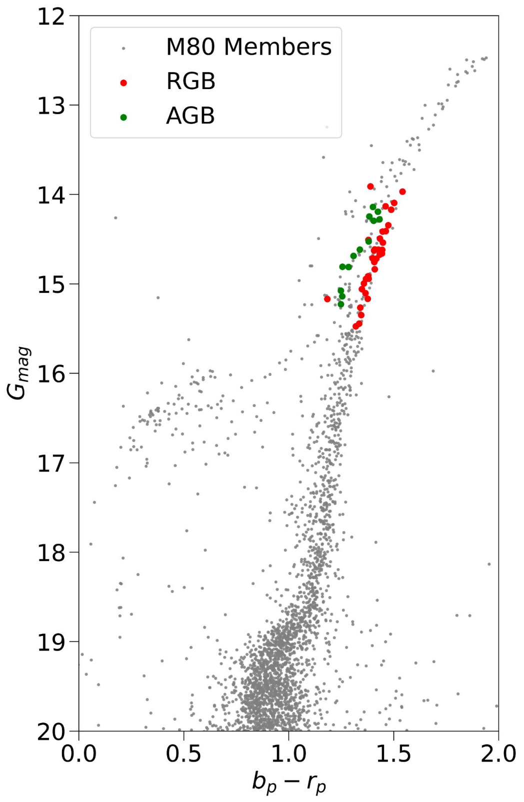
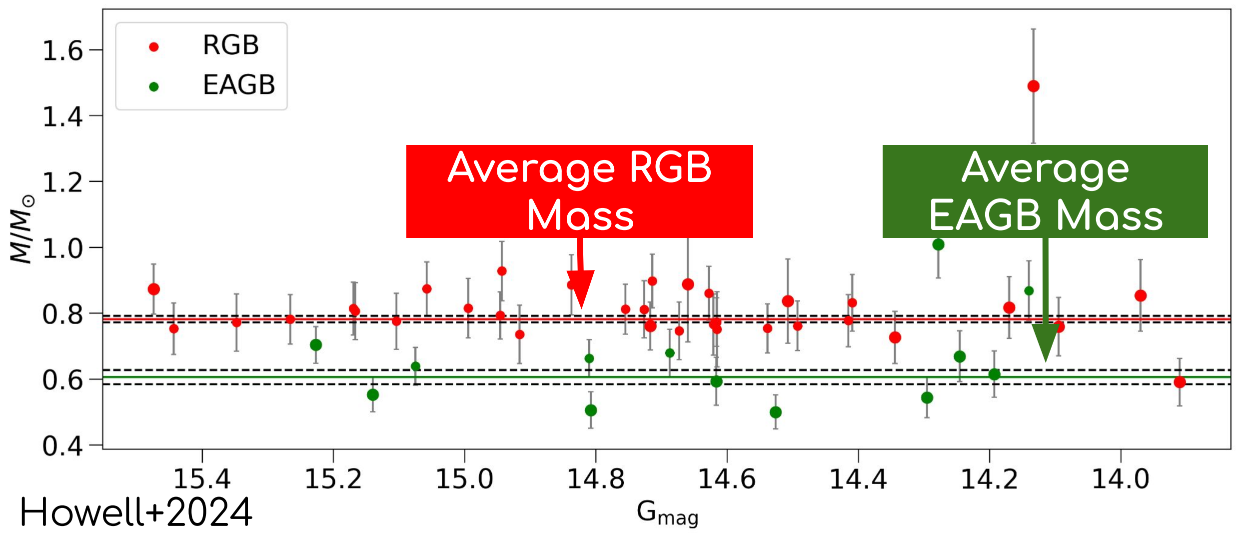
Measuring the Stellar Mass Loss (ΔM)





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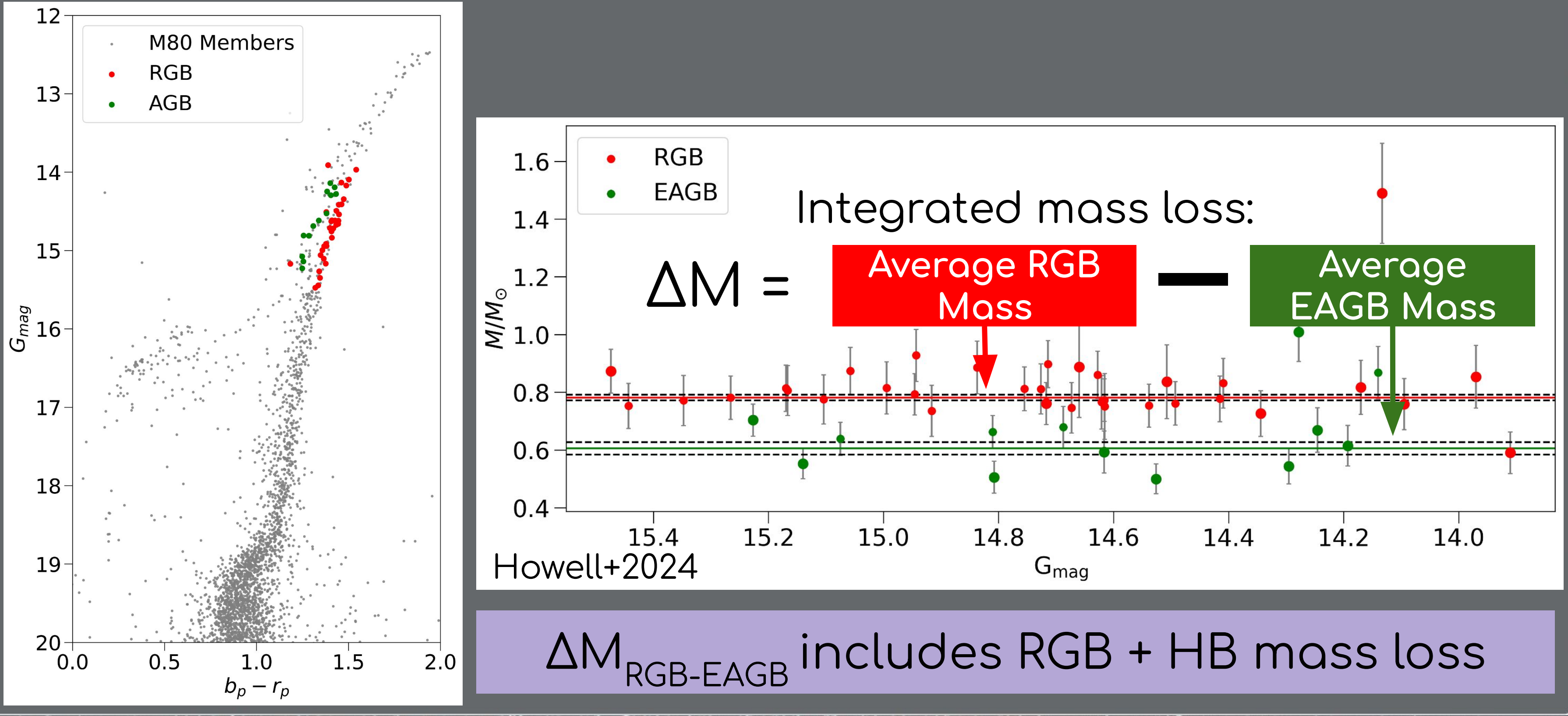
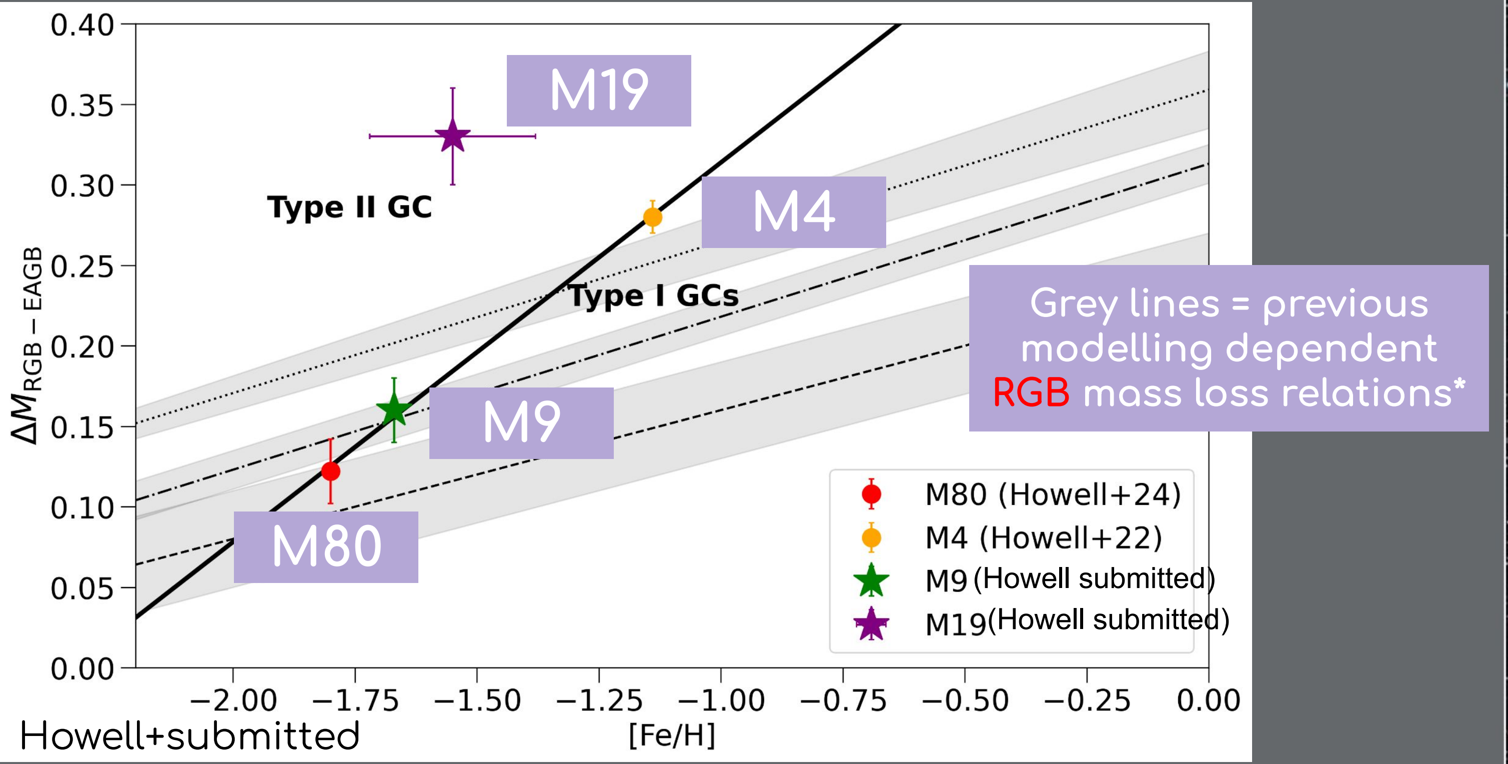


$\Delta M_{RGB\text{-}EAGB}$ includes RGB + HB mass loss

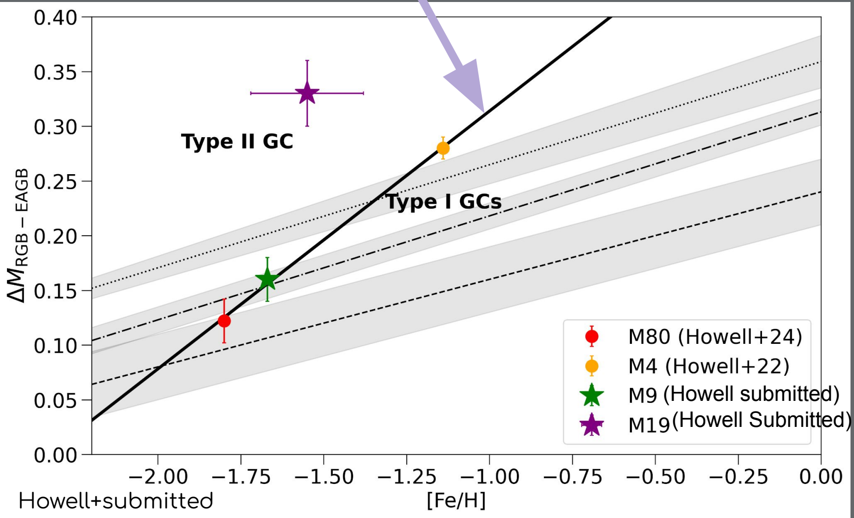
* (Gratton+2010, Origlia+2014, Tailo+2020)

Mass Loss-Metallicity Trend



Mass Loss-Metallicity Trend (Type I)

$$\Delta M = (0.24 \pm 0.02)\,[Fe/H] + (0.55 \pm 0.03)$$



Caveats

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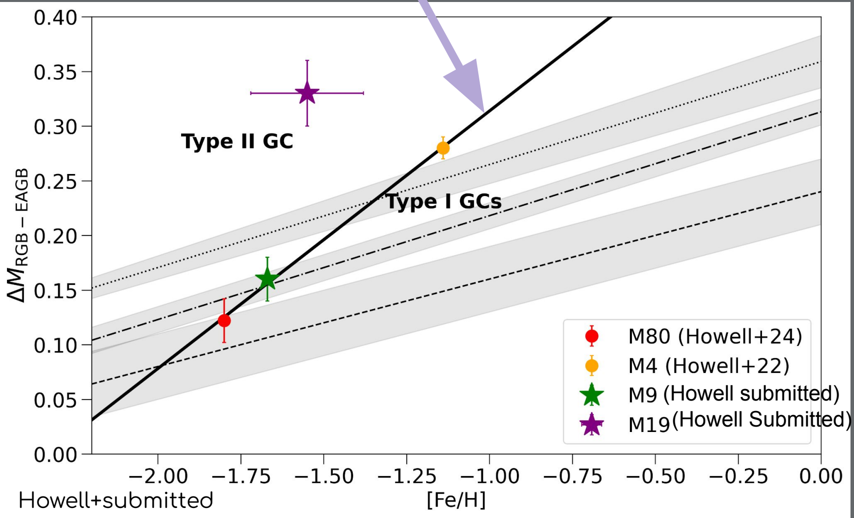

Caveats

- Based on three data points

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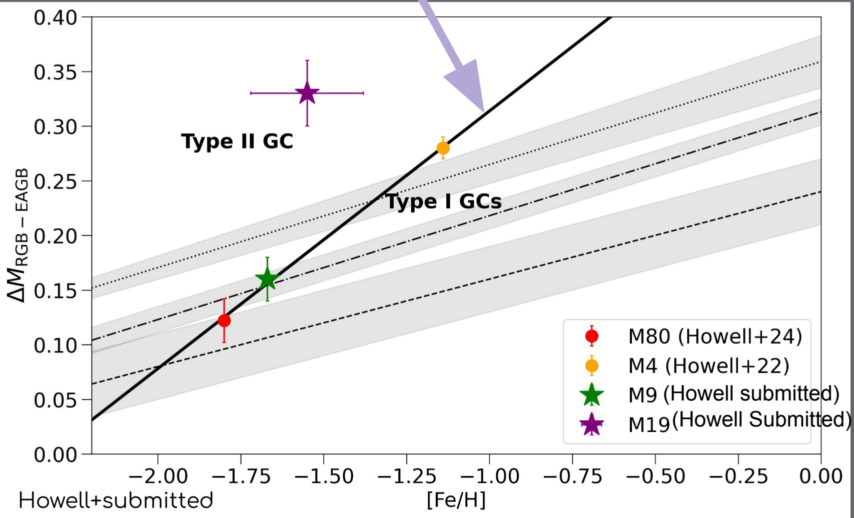

Caveats

- Based on three data points
- Mass loss measured as difference between RGB and EAGB
  - Includes potential HB mass loss

Mass Loss-Metallicity Trend (Type I)*

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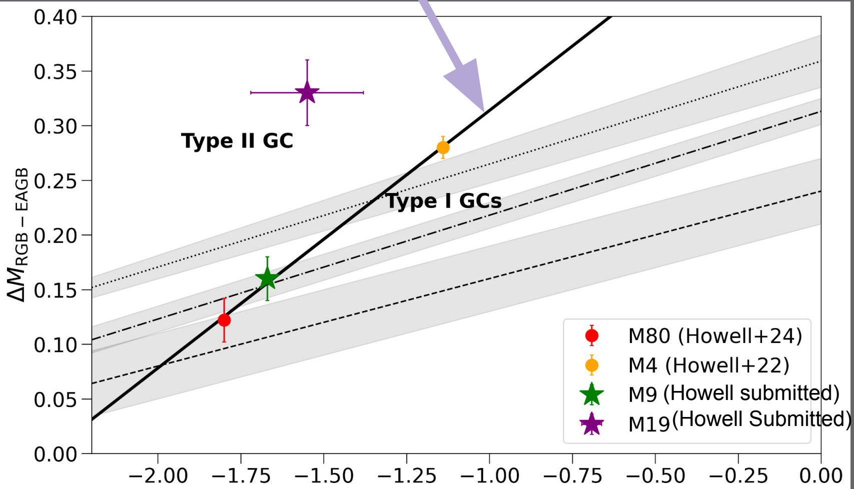
* Preliminary



Howell+submitted

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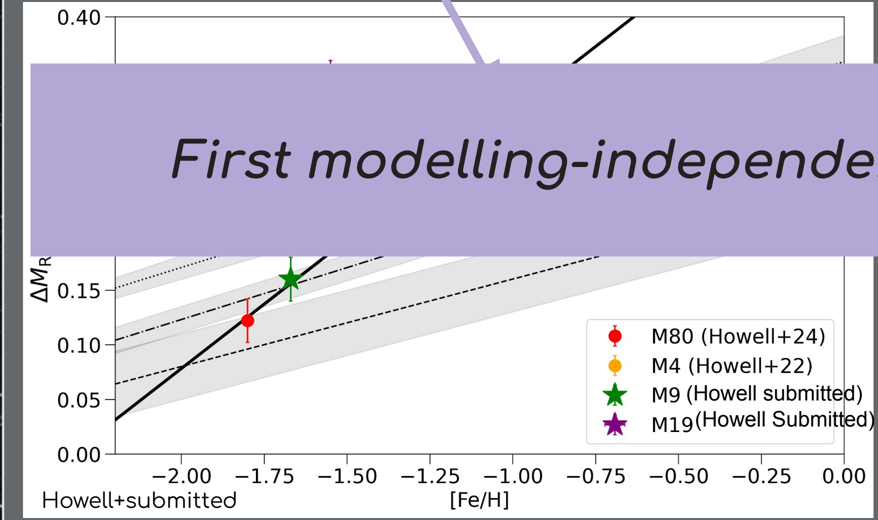


Caveats

First modelling-independent mass loss-metallicity trend

difference between RGB and EAGB

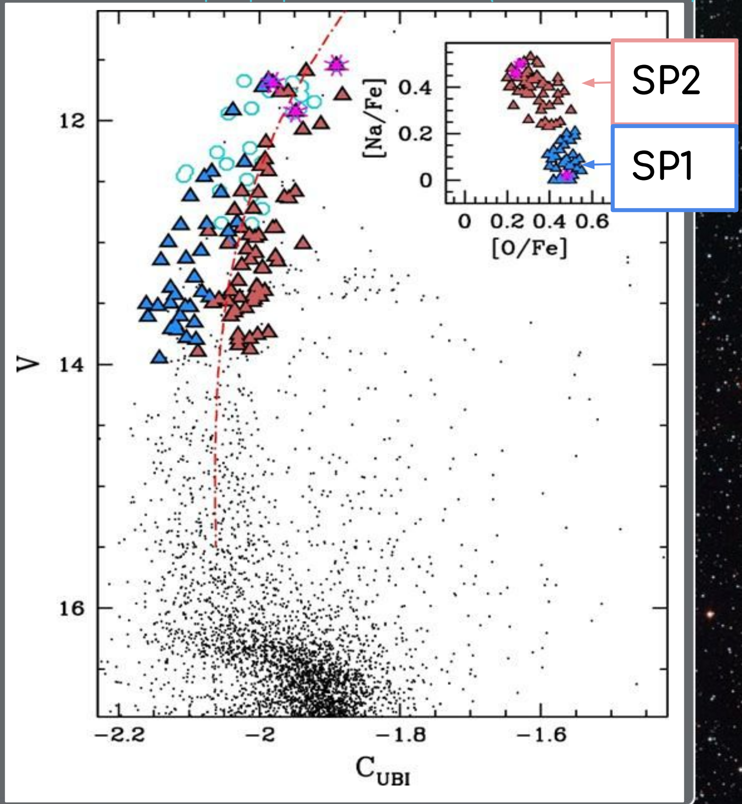
- Includes potential HB mass loss

Multiple Populations in GCs

- Sub-populations vary in light elements
  - e.g. He, O, Na, Mg, CN (Sneden, 1999; Gratton et al. 2012)
  - Can be classified Na-O anticorrelation

SP1	SP2
↓Na, ↑O	↑ Na, ↓O

Multiple populations in M4. (Lardo et al. 2017)



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- Different He -> mass differences between sub-populations (e.g. MacLean et al., 2018; Jang et al., 2019)

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↓Na, ↑O	↑ Na, ↓O
↓He, ↑ mass	↑ He, ↓ mass

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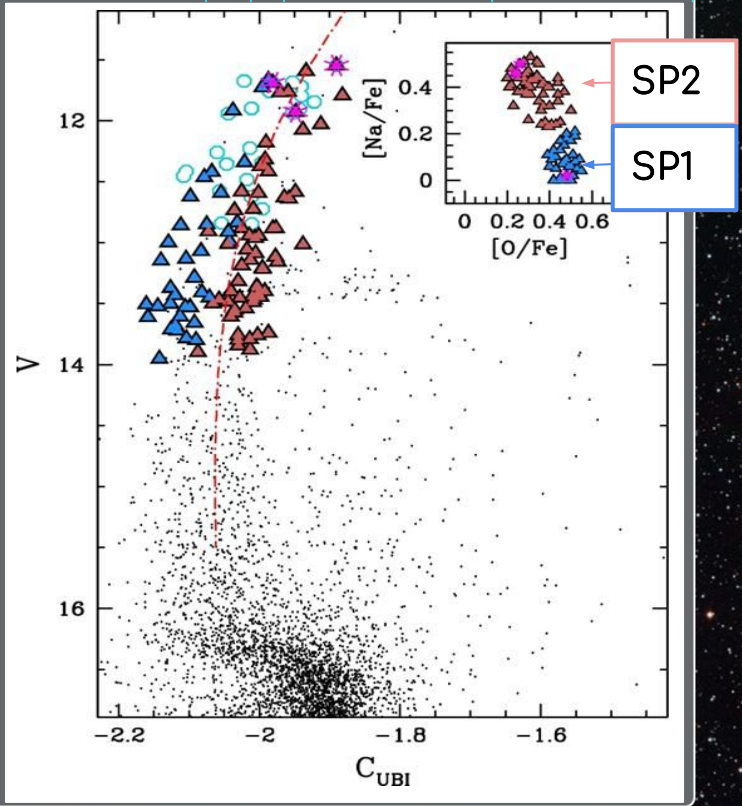

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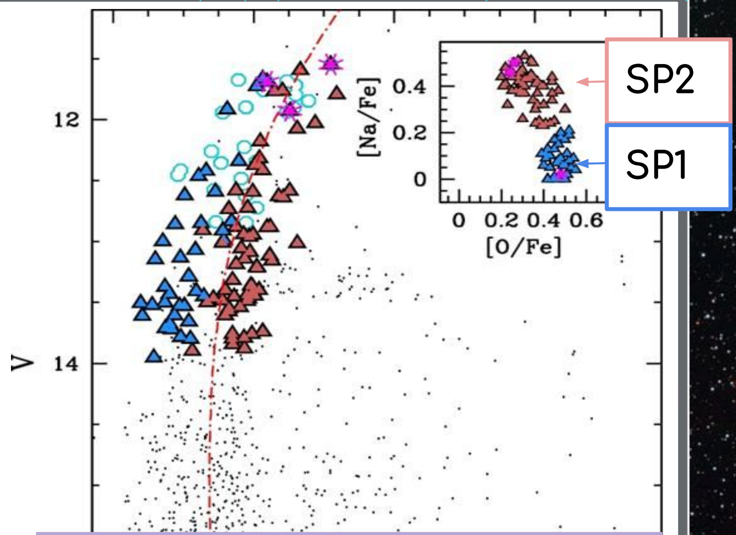

SP1	SP2
↓Na, ↑O ↓He, ↑ mass	↑ Na, ↓O ↑ He, ↓ mass

Bimodal mass distribution

Multiple Populations in GCs

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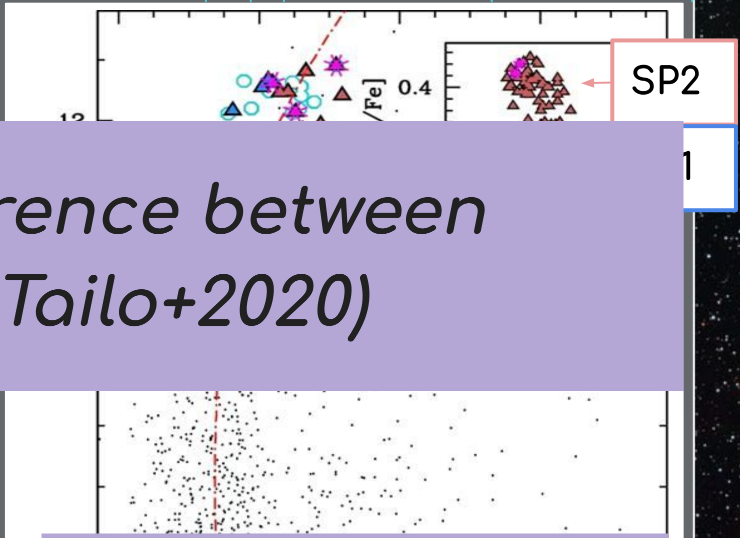


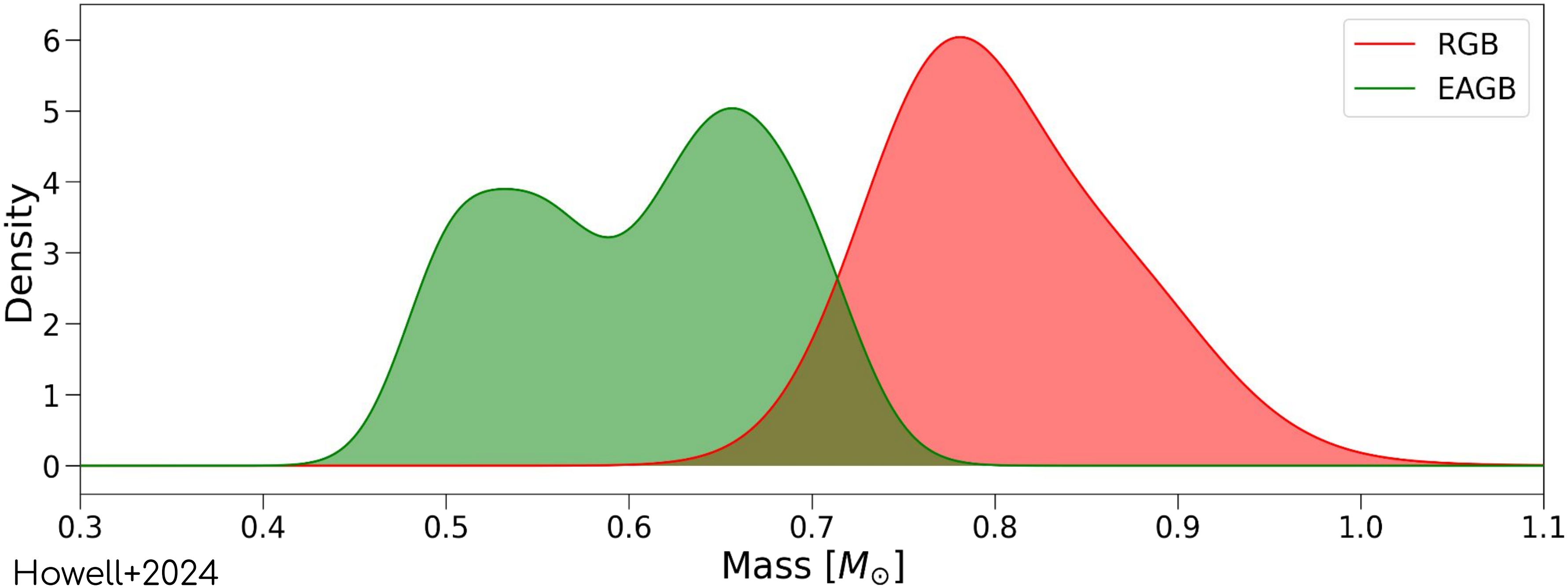
- Sub-populations vary in light elements

Modelled mass loss difference between sub-populations (e.g. Tailo+2020)

SP1	SP2
↓Na, ↑O	↑Na, ↓O
↓He, ↑ mass	↑ He, ↓ mass
↓ mass loss?	↑ mass loss?

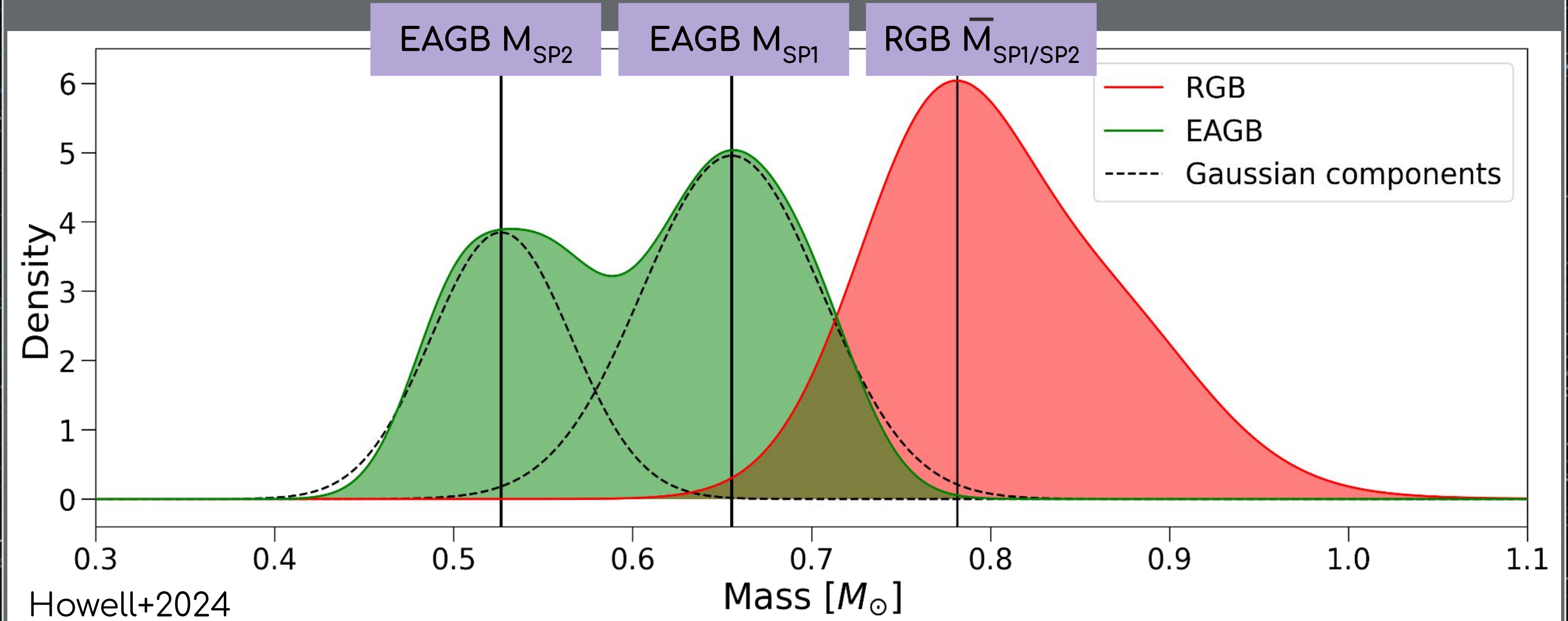
Bimodal mass distribution

Multiple Populations in M80



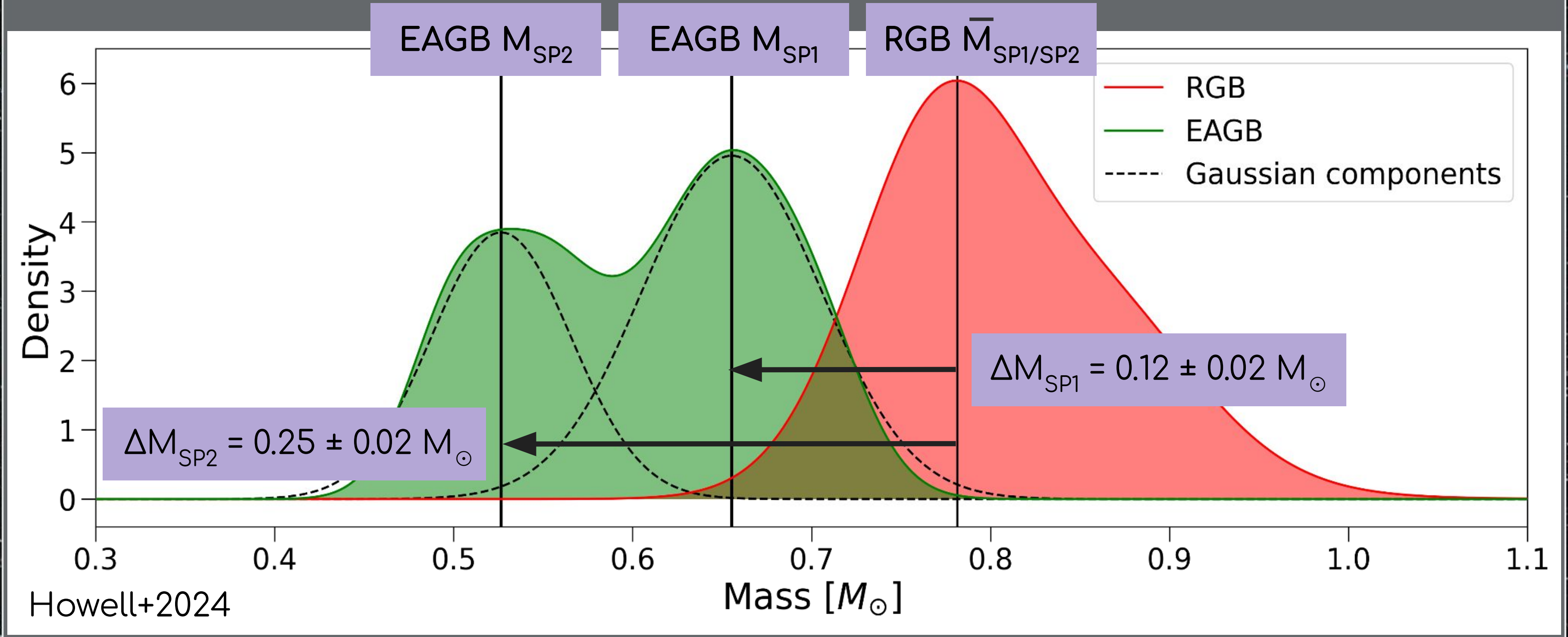
Howell+2024

Multiple Populations in M80

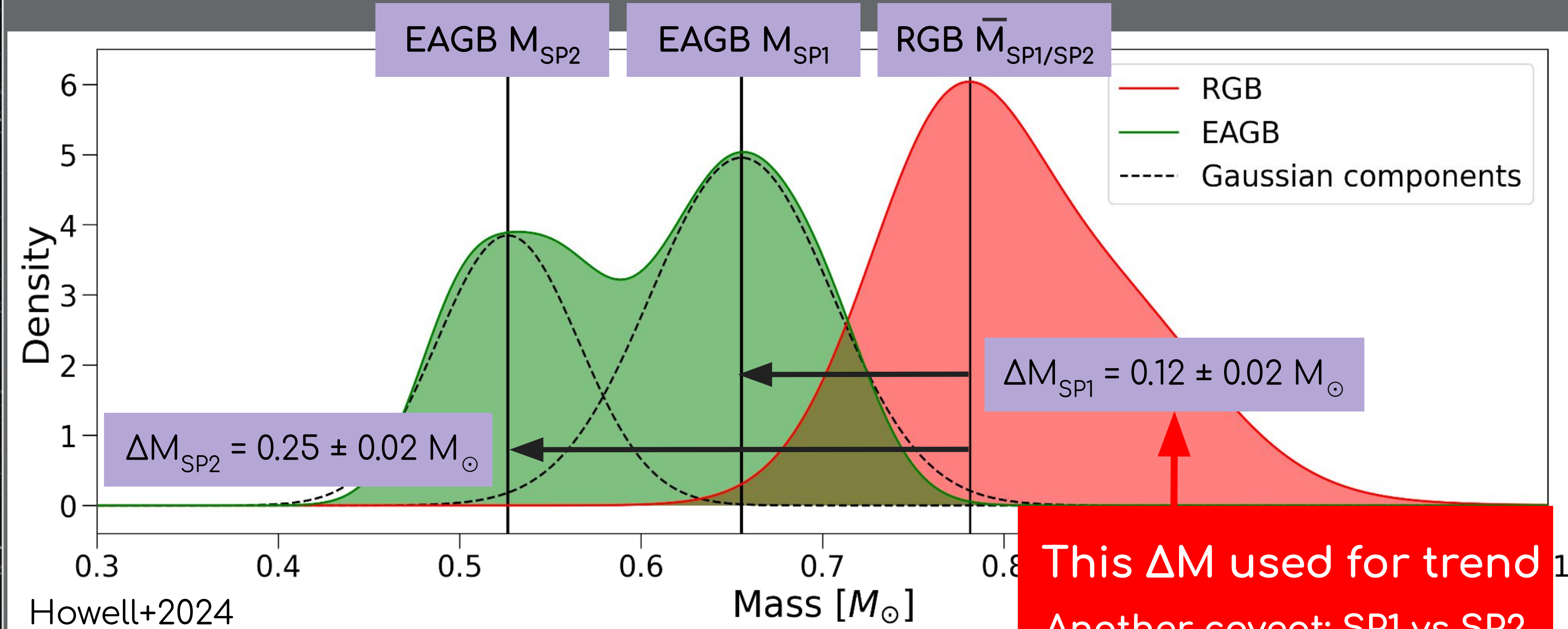


Howell+2024

Multiple Populations in M80



Multiple Populations in M80

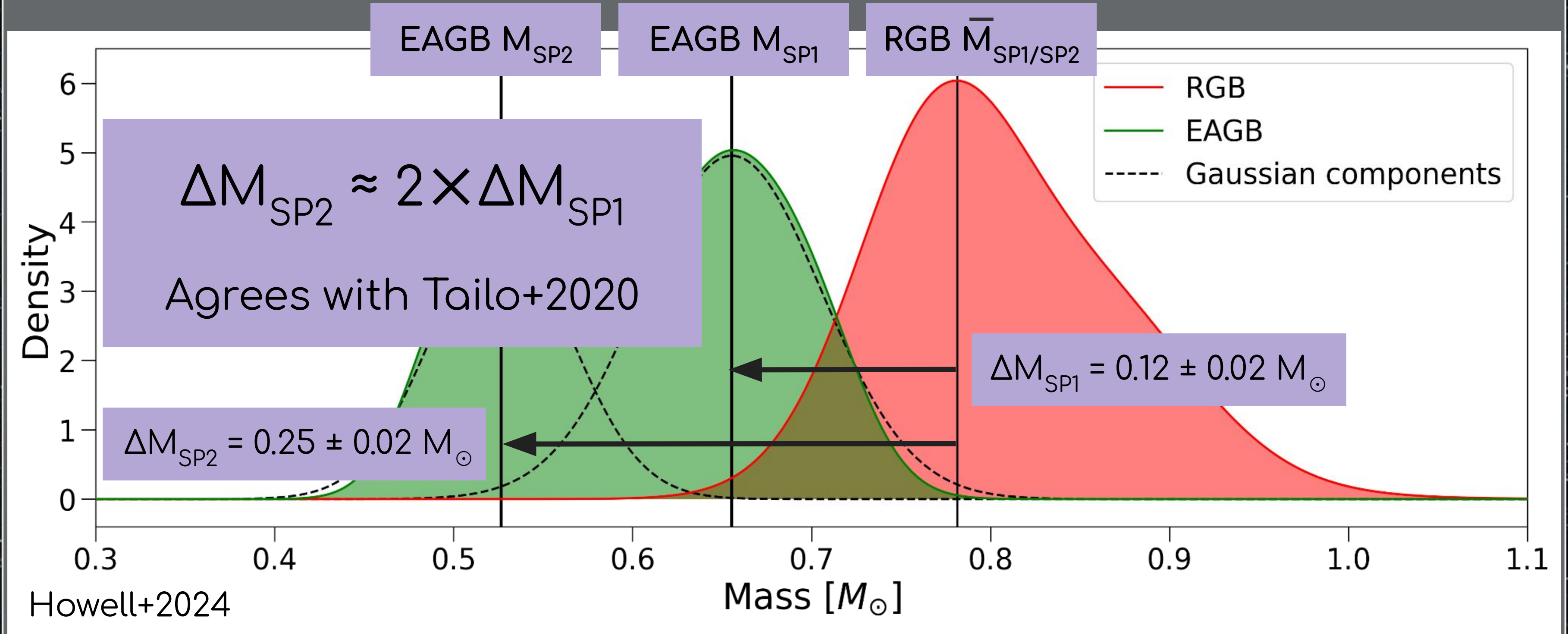


Howell+2024

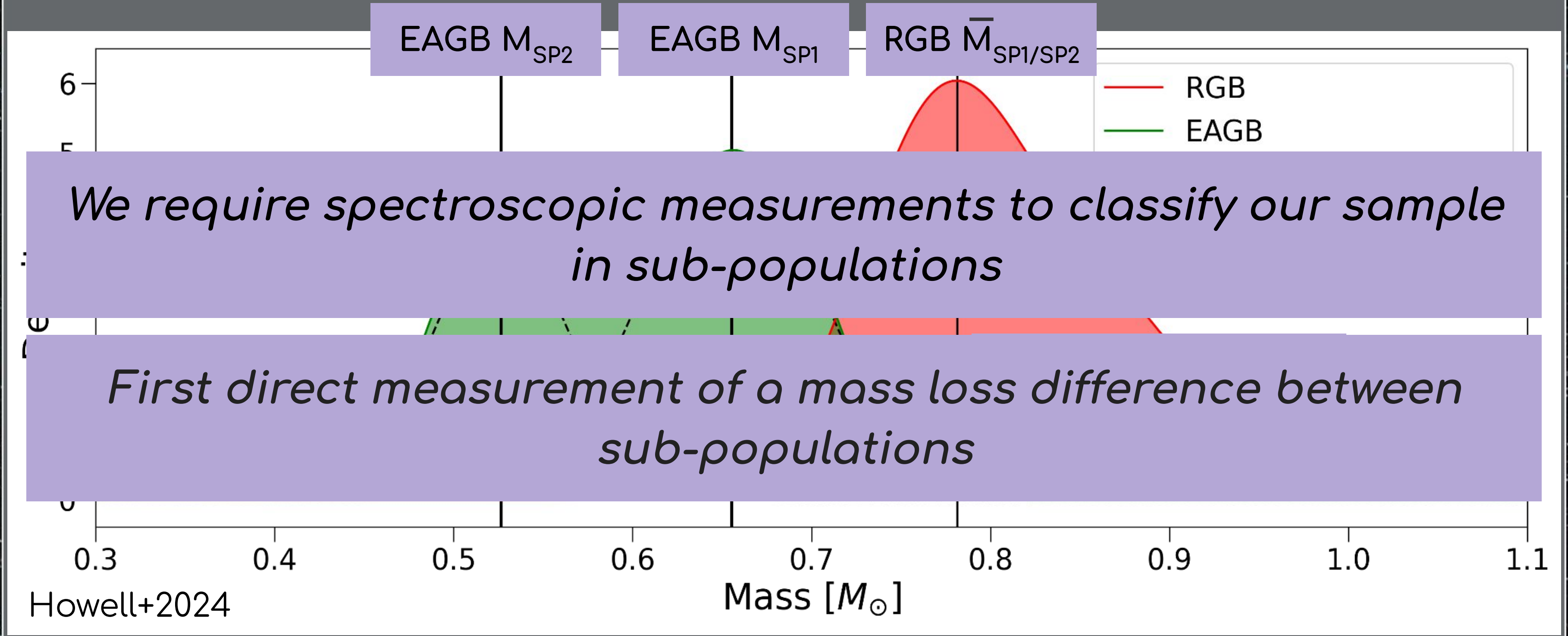
This ΔM used for trend

Another caveat: SP1 vs SP2 mass loss-metallicity trend

Multiple Populations in M80



Multiple Populations in M80



We require spectroscopic measurements to classify our sample in sub-populations

First direct measurement of a mass loss difference between sub-populations

Summary

Measured the asteroseismic masses of red giants in four GCs

Mass loss-metallicity trend

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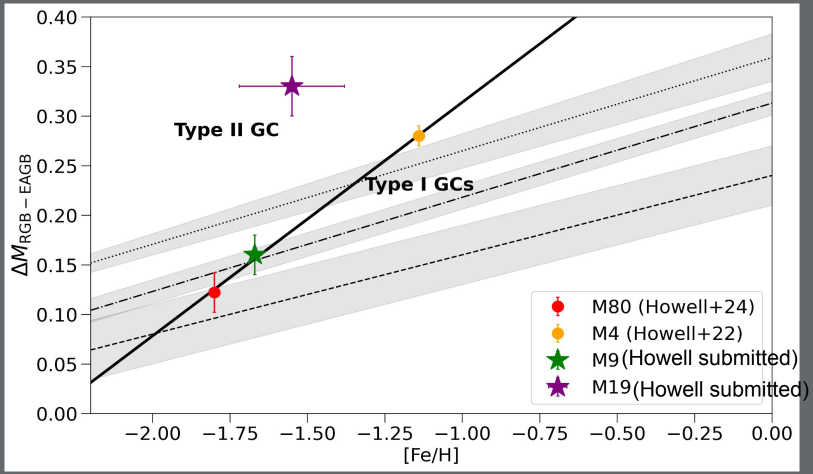
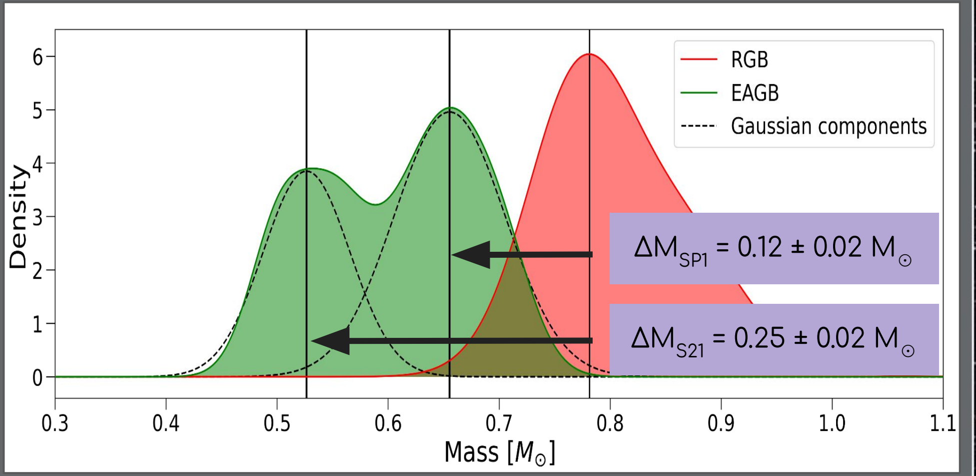
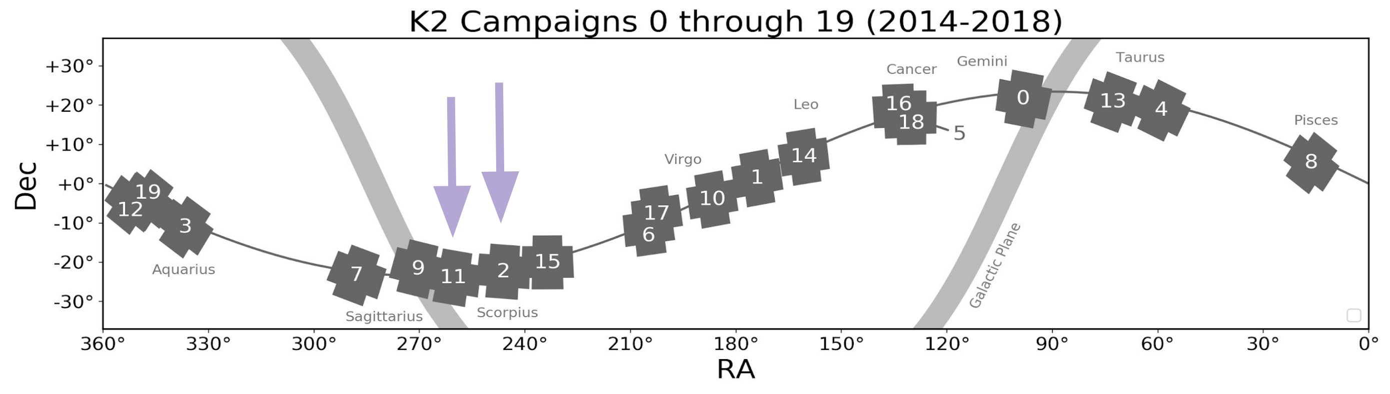


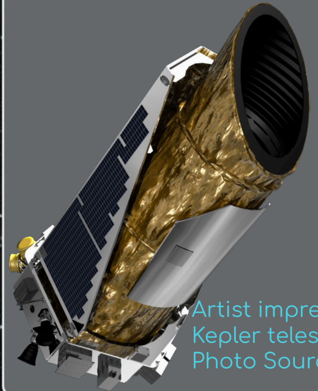
Multiple populations

For M80, SP2 stars have approx. twice more mass loss than SP1



The *K2* Mission





Artist impression of Kepler telescope. Photo Source: NASA

Disadvantages to *K2*

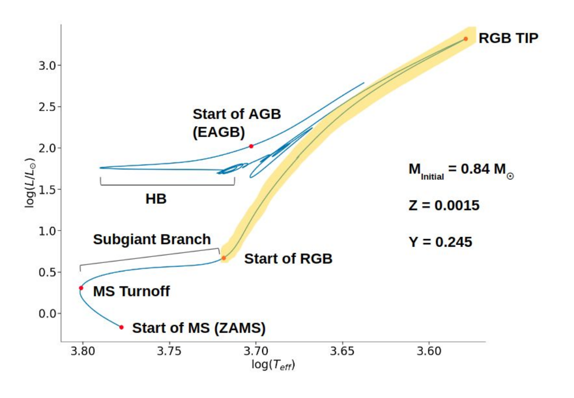
- Large pixels (~4"/pixel) -> increases chance of contamination
- Short observing period approx. 80 days
  - low SNR & frequency resolution = no $\Delta\nu$!!!!

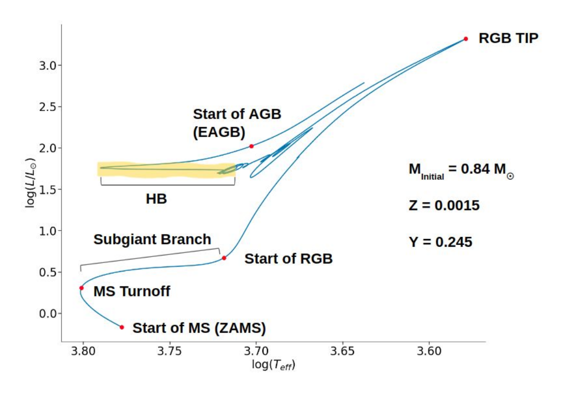
$$\left(\frac{M}{M_\odot}\right) \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{L}{L_\odot}\right)\left(\frac{T_{\mathrm{eff}}}{T_{\mathrm{eff},\odot}}\right)^{-7/2}$$

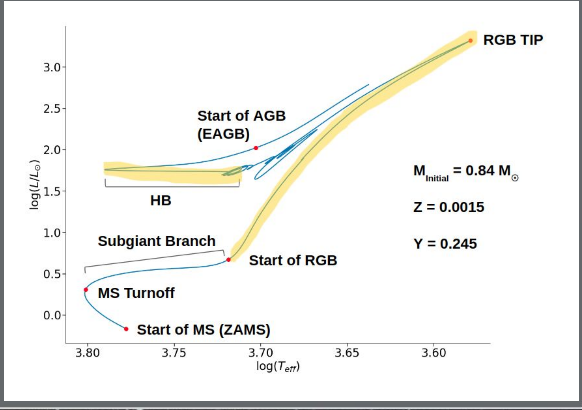
Integrated Mass Loss

Difference between average masses in different evolutionary phases

RGB mass loss	HB mass loss	RGB+HB mass loss
$M_{RGB} - M_{HB}$	$M_{HB} - M_{EAGB}$	$M_{RGB} - M_{EAGB}$







Second Parameter Problem

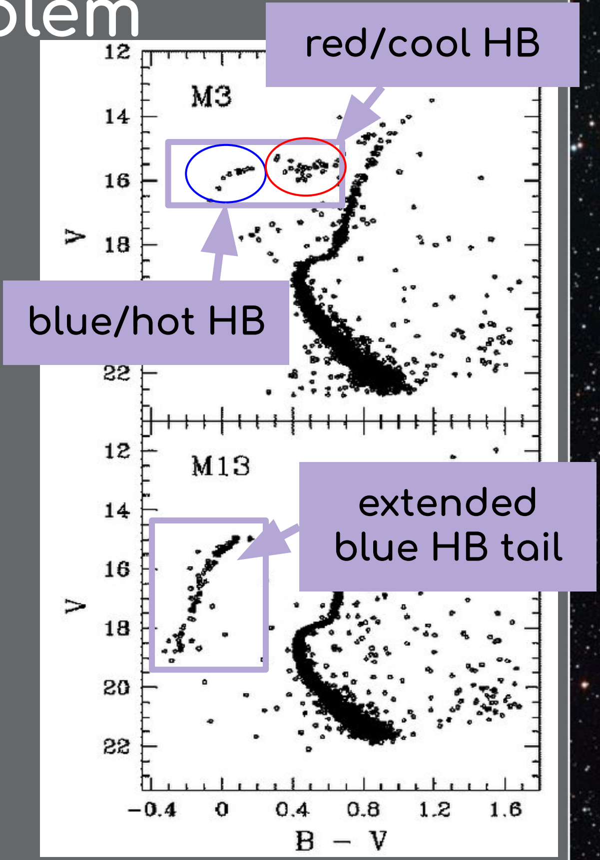
Variation in HB morphologies between globular clusters

... we need second parameter(s) (van den Bergh, 1967; Sandage & Wildey, 1967; Fusi Pecci et al., 1993)

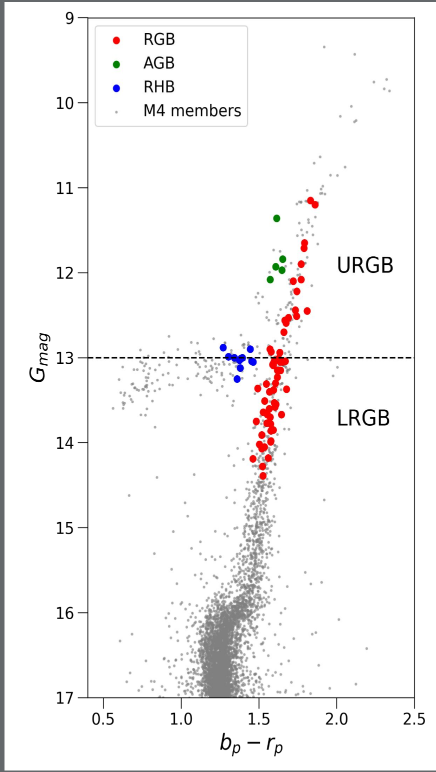
Proposed second parameters (Tailo et al., 2020)

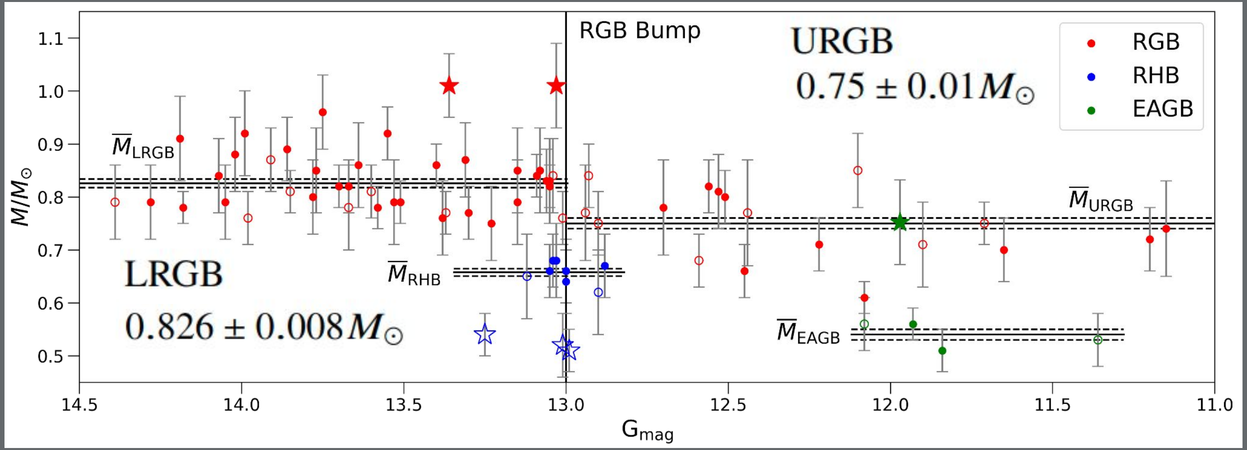
- He abundance variations
- Differing RGB mass loss rates

Difference in the integrated mass loss between sub-populations



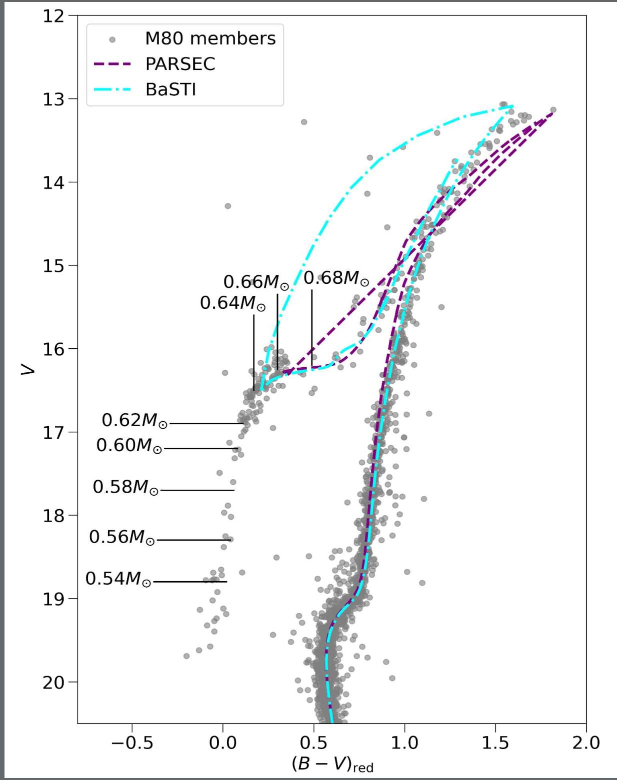
M4: Mass Decline on URGB?

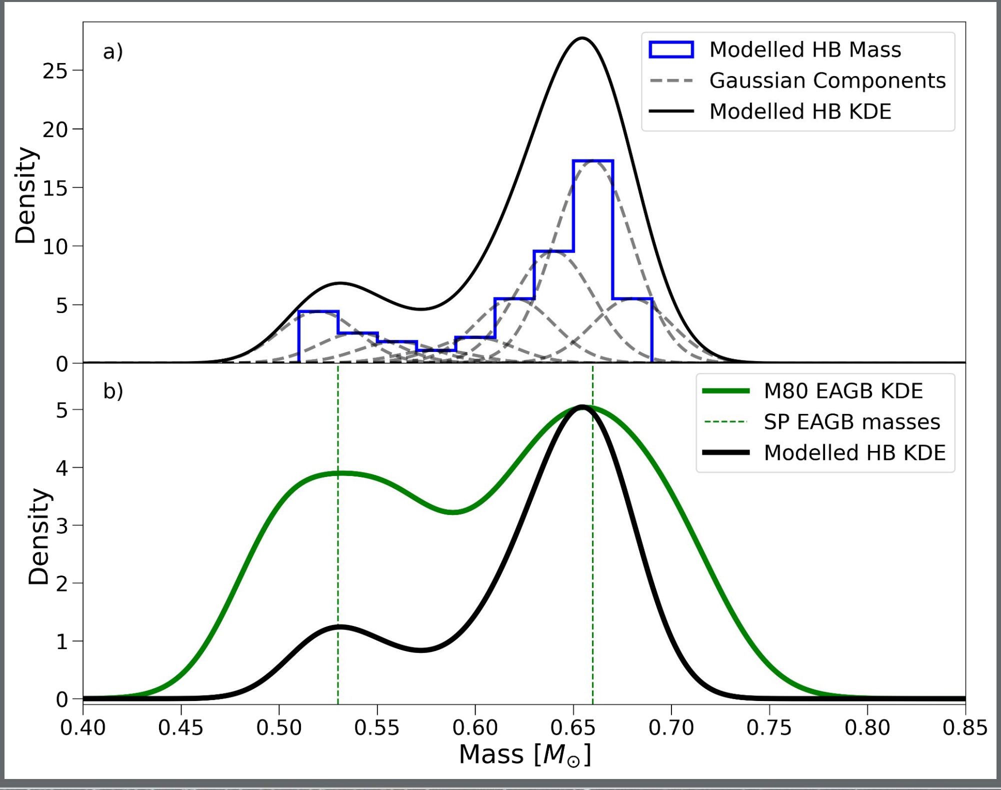




Supports theory that *significant mass loss in low-mass stars does not occur until the RGB bump (Bharat Kumar et al. 2015, Mullan & MacDonald 2003, 2019a)*

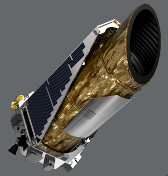
M80: HB vs EAGB mass distribution





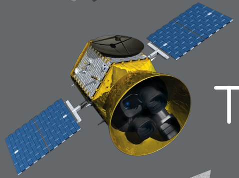
What's Next?

<u>Asteroseismology</u>

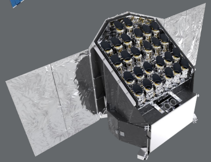


Kepler & the K2 mission (4"/pixel) - retired

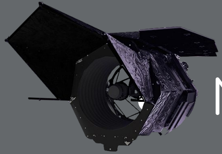
- Other GCs too faint (except NGC 5897; Kalup et al. in prep)



TESS mission (21"/pixel) - current



PLATO mission (15"/pixel) - launch in 2026



Nancy Grace Roman Telescope (0.11"/pixel!!!) - launch in 2027

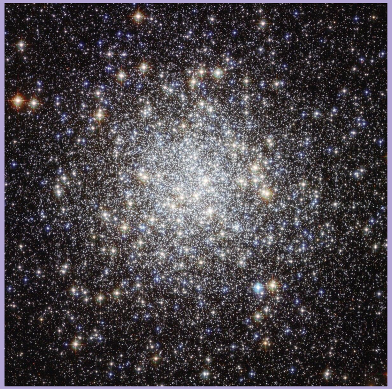
Seismically Studied GCs

M4

- [Fe/H] = -1.1

M80

- [Fe/H] = -1.8



M9

M19

- Metallicity:
    - M9 - [Fe/H] = -1.67
    - M19 - [Fe/H] = -1.55 +/- 0.17 dex
- Sample
    - M9 - 55 red giants
    - M19 - 37 red giants