Stellar Population synthesis models beyond the K-band

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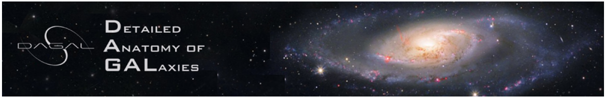

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Motivation for extending the models to the spectral range $2.5 - 5\,\mu\text{m}$

- **in general:** non-existence of reliable and accurate SSP-models in the wavelength range $2.5 - 5\,\mu\text{m}$, e.g.:
  - **GALEV (Kotulla et al., 2009), FSPS (Conroy et al., 2009, 2010):** SSP-models in this wavelength range based on low resolution theoretical BaSeL-stellar library (Westera et al., 2002)
  - **Padova-models (Marigo et al., 2008):** also based on theoretcial stellar atmosphere models, do not provide spectra
  - **Maraston & Strömbäck (2009, 2011):** SSP-models based on empirical spectra and MARCS theoretical stellar library extend only up to $2.5\,\mu\text{m}$
- **advantages**:
  - IR-wavelengths less affected by dust extinction than optical wavelengths
  - good tracers of old stars dominating the baryonic mass in galaxies
  - mid-IR-wavelengths very suitable to quantify the AGB-contribution

Stellar population modelling

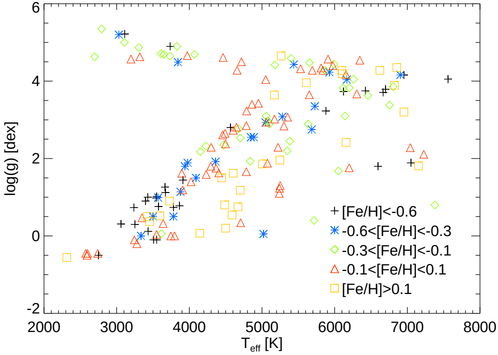
- **general idea:** populate isochrones of various ages and metallicities with stellar spectra according to the prescription given by a chosen IMF
- stars of a particular set of parameters Teff, log(g) and [Fe/H] are reproduced by an interpolation based on an input stellar library of 184 stars
- stellar spectra are integrated along the isochrones in order to mimic different stellar populations
- transformation of theoretical parameters to observational plane is carried out based on empirical photometric libraries and relations
- summarized mathematically:

$$\mathrm{S}_\lambda(\mathrm{t}, [\mathsf{FeH}]) = \int_{\mathrm{m}_1}^{\mathrm{m}_\mathrm{t}} \mathrm{S}_\lambda(\mathrm{m}, \mathrm{t}, [\mathsf{FeH}]) \cdot \mathrm{N}(\mathsf{IMF}, \mathrm{m}, \mathrm{t}) \cdot \mathrm{F}_\mathrm{K}(\mathrm{m}, \mathrm{t}, [\mathsf{FeH}]) \mathrm{dm}$$

Full characterization of the stellar library

- Determination of stellar atmospheric parameters
- Correcting gaps in the stellar spectra
- Checking the flux calibration
- Characterization of the resolution of the stellar spectra
- Checking for peculiar stars
- Extrapolation of all spectra to $5\,\mu\mathrm{m}$

Stellar atmospheric parameters of our 184 stars

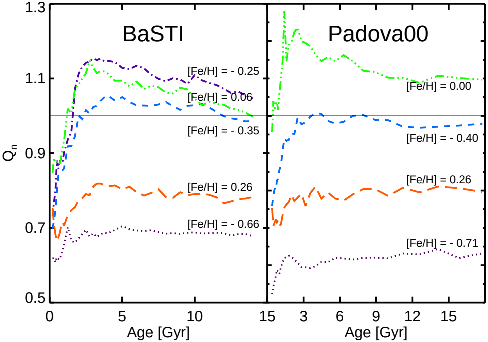


satisfying coverage of the stellar atmospheric parameter space, sufficient for modelling

Main ingredients and parameter coverage

- prepared spectra from the IRTF-library
- Kroupa-like, uni- and bimodal IMFs of various slopes between 0.3 and 3.3
- Teramo- (Pietrinferni et al., 2004) and Padova-isochrones (Girardi et al, 2000)
- conversion to the observational plane based on extensive empirical photometric libraries (e.g. Alonso et al., 1996, 1999)
- interpolator (Vazdekis et al., 2003) adopted to the IRTF-library
- metallicities: $[\mathrm{Fe/H}] = -0.35, -0.25, 0.06$ (Teramo), $[\mathrm{Fe/H}] = -0.40, 0$ (Padova)
- ages: $> 1\,\mathrm{Gyr}$

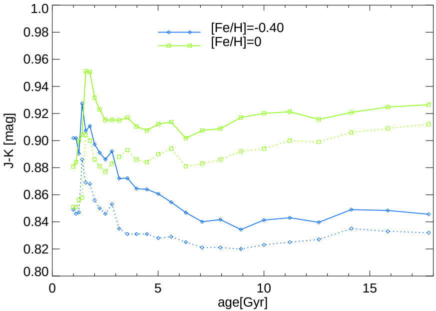
Quality parameter Q



The quality parameter Q depends on the density in the stellar atmospheric parameter space, i.e. the number of stars used by the interpolator in order to calculate one SSP-model

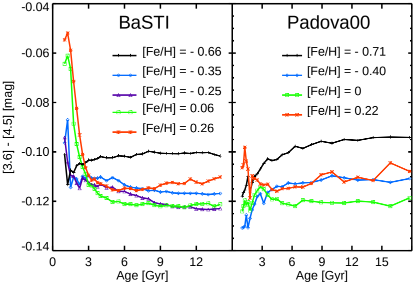
the limits in the parameter coverage were set by postulating the quality parameter Q being at least 1

Comparison: Photometric predictions from MILES versus colours from our new models



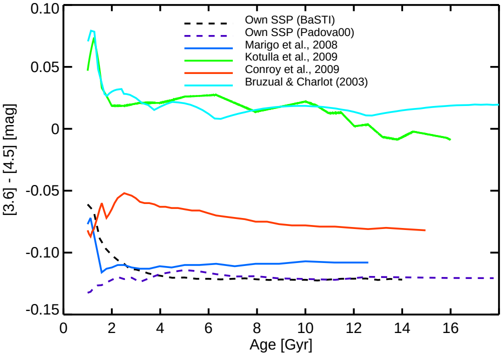
- very good agreement between predicted NIR-colours based on MILES and extracted ones from our new models
- joining of our new models with the MILES-based ones in the Optical very well feasible

Behaviour of the Spitzer [3.6-4.5]-colour as a function of age and metallicity



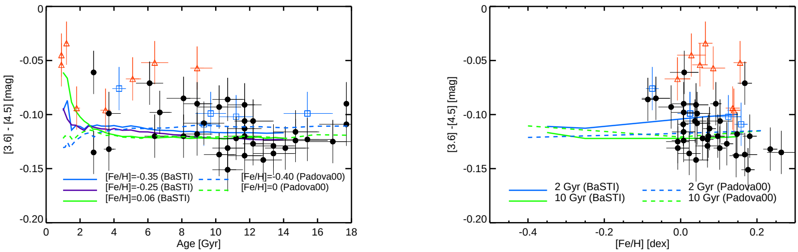
- weak dependence on age and metallicity
- solar metallicities result in slightly bluer colours than subsolar ones due to the prominent CO absorption band in the $[4.5]\,\mu\mathrm{m}$-band
- for ages $< 2\,\mathrm{Gyr}$ enhanced AGB-star contribution

Comparison to model predictions from the literature

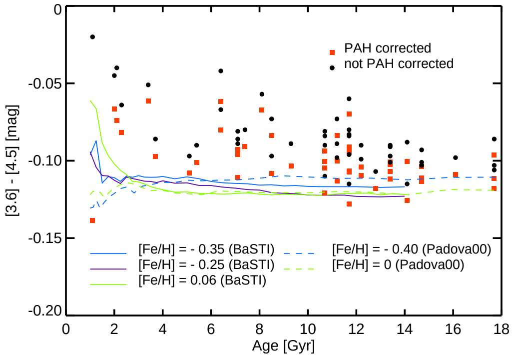


our models coincide well with the ones of Marigo et al.(2008) and the ones of Conroy et al. (2009)

Comparison to nearby elliptical and lenticular galaxies from the SAURON-survey



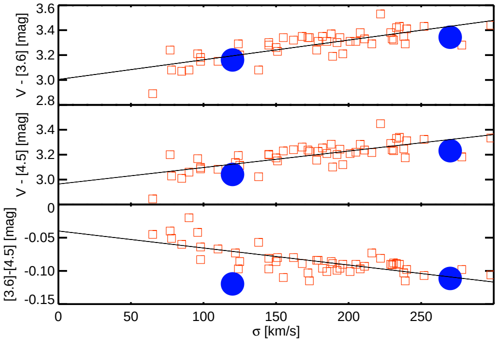
- good agreement between our models and the oldest, most massive, metallic and single-burst like objects
- unable to reproduce the redder colours of younger, lower-mass, star-forming galaxies with more extended SFHs including also younger populations



- SAURON-galaxies corrected for PAH-emission corresponding to recent star formation activity
- much better fit, so SF indeed to blame

Colour-velocity dispersion relations for galaxies

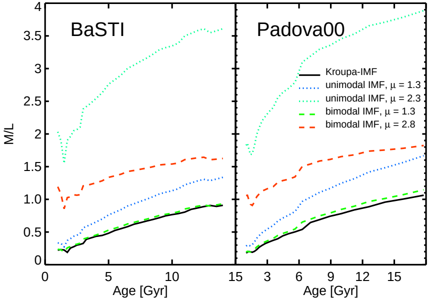
- clear evidence for relation between IMF and central velocity dispersion σ (La Barbera et al., 2013, Ferreras et al., 2013, Spiniello et al., 2014)
- Falcon-Barroso et al. (2011): tight relations between the $(\mathrm{V} - [3.6])$ colour and the central stellar velocity dispersion σ for SAURON galaxies



Colour-velocity dispersion relations for galaxies

- for $(\mathrm{V}-[3.6])$ and $(\mathrm{V}-[4.5])$: model galaxies in good agreement with observed data
- for $([3.6]-[4.5])$: reddening of galaxy colours with decreasing σ not well reproduced by our SSP models
- **impossible to reproduce these types of galaxies by a single-burst SSP-model in the IR**
- this wavelength range might enable us to disentangle the various stellar populations present in young, low-mass, metal-poor galaxies as well as to estimate the contribution of the non-stellar PAH emission

Mass-to-light (M/L) ratios measured in the 3.6μm-band

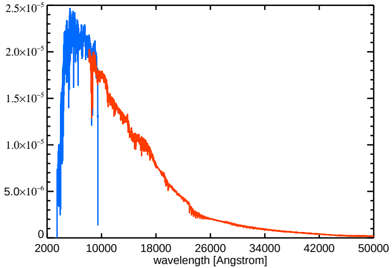


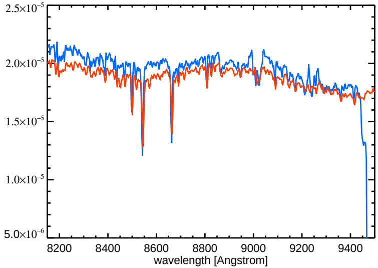
- M/L-ratios less dependent on age and [Fe/H] than in the Optical
- parameter-independent $\mathrm{M/L_{3.6}} = 0.6$ as suggested by Meidt et al. (2014) equal to the mean value from our models
- large differences between the M/L-ratios depending on the used IMF

Conclusions

- first models available in this wavelength range based on empirical stellar spectra
- only models available to date which permit to study spectral features between 2.5 and 5 microns
- problem due to CO-absorption in the 4.5μm-band solved, models behave "as they should do"
- however: comparisons to observations remain difficult, limited coverage in parameter space...

Outlook: Combining the MIUSCAT- with the IRTF-based models





- very well feasible due to excellent flux calibration of the IRTF-library
- combined at around 9000 Angstrom