Stellar Population synthesis models from the optical to the infrared

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Motivation for extending the models to the IR

- non-existence of reliable and accurate SSP-models in the wavelength range $2.5 - 5\,\mu\mathrm{m}$
- 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
- poorly studied, many open questions concerning the emitted stellar light, absorption features...
- available Spitzer and X-Shooter observations of galaxies

Stellar population modelling

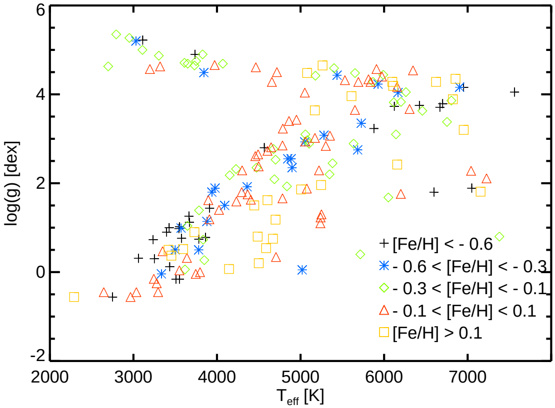
- **general idea:** populate isochrones of various ages and metallicities with stellar spectra according to the prescription given by a chosen IMF
- stars of a particular set of parameters Teff, log(g) and [Fe/H] are reproduced by an interpolation based on an input stellar library of 180 stars
- stellar 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

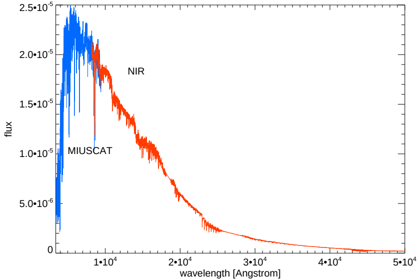
- Determination of stellar atmospheric parameters
- Correcting gaps in the stellar spectra
- Checking the flux calibration
- Characterization of the resolution of the stellar spectra
- Checking for peculiar stars
- Extrapolation of all spectra to $5\,\mu\mathrm{m}$

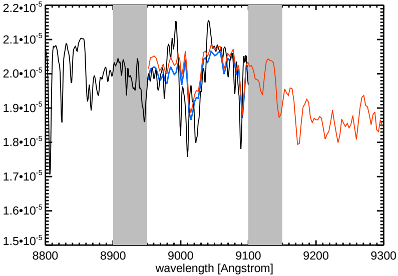
Stellar atmospheric parameters of our 180 stars



satisfying coverage of the stellar atmospheric parameter space, sufficient for modelling (27 AGB stars, 5 carbon stars, 16 M dwarfs among others)

Combining the extended MILES (MIUSCAT) with the IRTF-based models



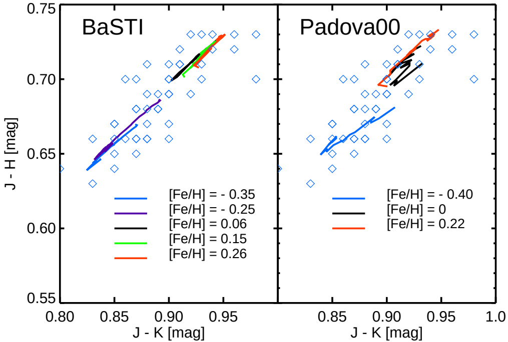


- very well feasible due to excellent flux calibration of the IRTF-library
- combined between 8950 and 9100 Angstrom

Main ingredients and parameter coverage

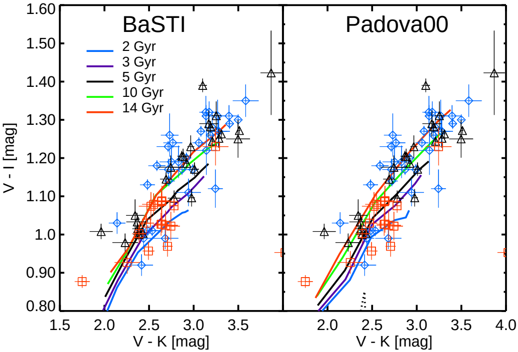
- prepared spectra from the extended MILES and from the IRTF library
- Kroupa-like, uni- and bimodal IMFs of various slopes between 0.3 and 3.3
- BaSTI- (Pietrinferni et al., 2004) and Padova-isochrones (Girardi et al, 2000)
- interpolator (Vazdekis et al., 2003) adopted to the IRTF-library
- metallicities: $[\mathrm{Fe/H}] = -0.35, -0.25, 0.06, 0.15$ (BaSTI), $[\mathrm{Fe/H}] = -0.40, 0, 0.22$ (Padova)
- ages: $> 1\,\mathrm{Gyr}$

Reproducing the NIR colours of early-type galaxies (Frogel et al., 1978)



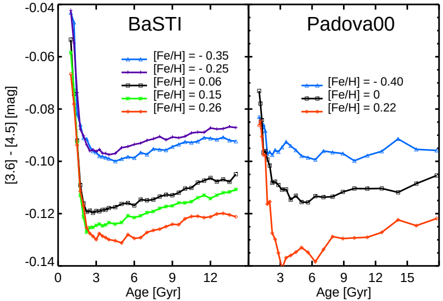
- colours of our models coincide with the mean colours of the observed sample
- colours hampered by age-metallicity degeneracy

Comparison to optical-NIR colours of globular clusters in NGC 4472, NGC 4594 and NGC 5813



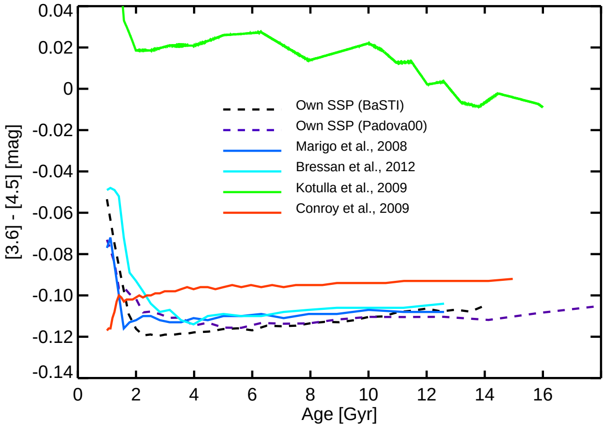
- combination of V- K and V - I breaks in part age-metallicity degeneracy
- models fit observed GCs

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



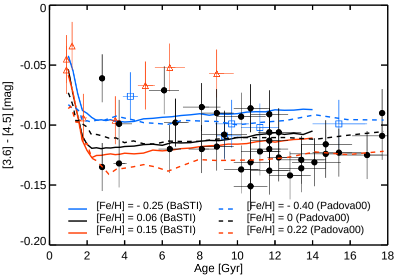
- weak dependence on age and metallicity, for ages $< 2\,\mathrm{Gyr}$ enhanced AGB-star contribution
- solar metallicities result in slightly bluer colours than subsolar ones due to the prominent CO absorption band in the $[4.5]\,\mu\mathrm{m}$ band

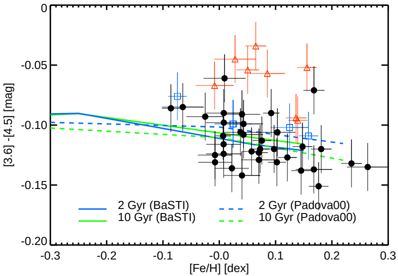
Comparison to models from the literature: ([3.6] - [4.5])



our models coincide well with the ones of Marigo et al.(2008) and the ones of Bressan et al. (2012)

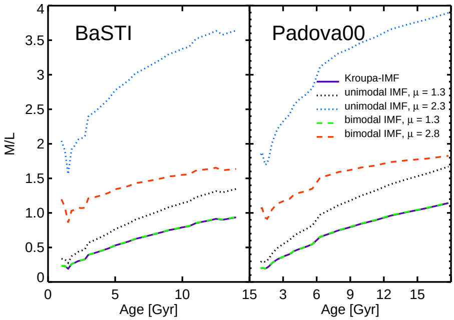
Comparison to nearby elliptical and lenticular galaxies from the SAURON-survey





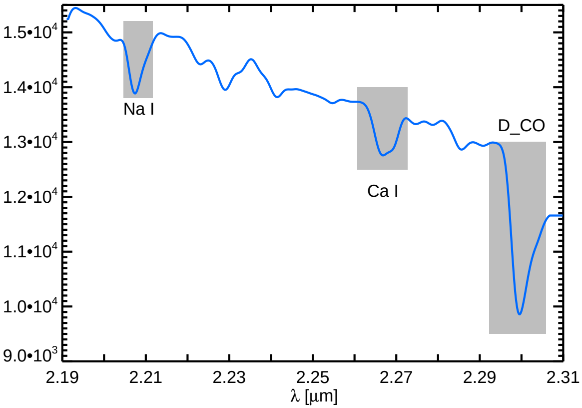
- good agreement between our models and the oldest, most massive, metallic and single-burst like objects
- unable to reproduce the redder colours of younger, lower-mass, star-forming galaxies

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



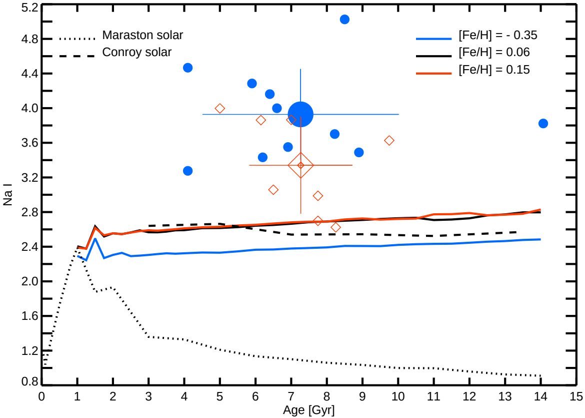
- M/L-ratios less dependent on age and [Fe/H] than in the Optical
- parameter-independent $\mathrm{M/L}_{3.6} = 0.6$ as suggested by Meidt et al. (2014) equal to the mean value from our models
- large differences between the M/L-ratios depending on the used IMF

Studied indices in the K-band



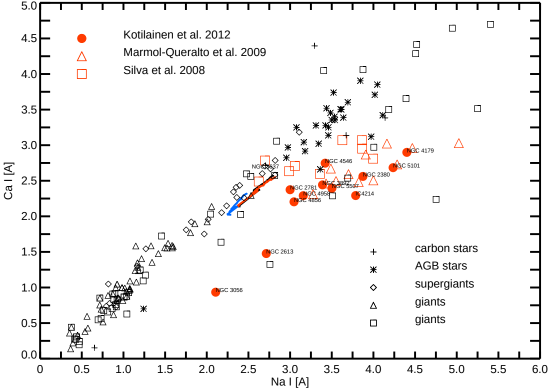
- Mg I and Fe-lines too weak in most observed galaxies
- further indices in H- (and J-) band

Na I at 2.21 μm



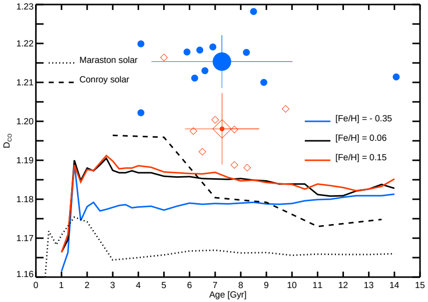
- models are unable to fit most of the observed early-type galaxies
- same problem observed for the NaD in the Optical (see Yi et al., 2014)

Ca I at 2.26 μm versus Na I



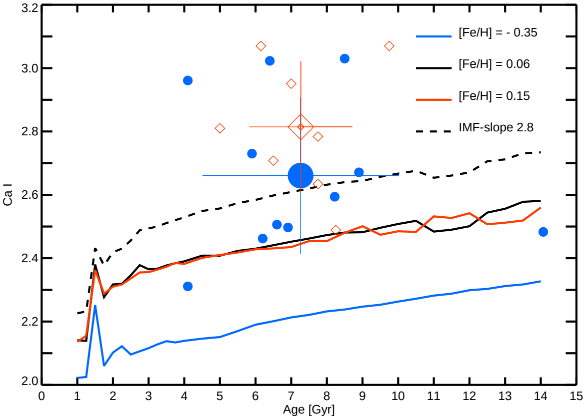
- neither an enhanced contribution of AGB stars nor a more bottom-heavy IMF improve the situation
- possible explanation: supersolar, enhanced [Na/Fe]

First CO bandhead at 2.29 μm



- abundance of CO as compared to Fe higher in field than in Fornax galaxies
- an enhanced contribution of carbon and/or AGB stars to our models could reproduce better the observed CO
- other explanation: significantly shorter star formation timescales in denser environments, compare to Carretero et al., 2004

Ca I at 2.26 μm



model predictions agree better with mean values of observed galaxies

Conclusions

- first models available between 2.5 and 5 μm based on empirical stellar spectra enabling also study of spectral features
- problem due to CO-absorption in the 4.5μm band solved, models behave "as they should do"
- comparisons to observations remain difficult, limited coverage in parameter space...
- understanding and reproducing the behaviour of the NIR line strength indices remains a challenge - work in progress