Stellar Population Models and the Stellar Masses of Galaxies

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"UniMass: Galaxy Evolution across the Hubble time"
Marie Curie Excellence Grant 2007

Unveiling the mass. A celebration of Vera Rubin's career – Kingston 2009

The stellar mass - M* - of galaxies

- **Constrain galaxy formation and evolution (e.g. mass assembly, dark matter, star formation efficiency, etc)**
- M* is obtained with **Stellar Population Models** by:
- * determining the age and the metallicity via some spectral indicators (e.g. line indices) and using tables of M*/L

  mostly at low-redshift, see e.g. M. Hudson/ M. Cappellari's talks and e.g. Gerhard et al. 2000, Bell & de Jong 2001, Kauffmann et al. 2003

  or
- * best-fitting the photometric SED and get M* via normalization mostly done at high-z
- A combination of both Schawinski et al. 2007

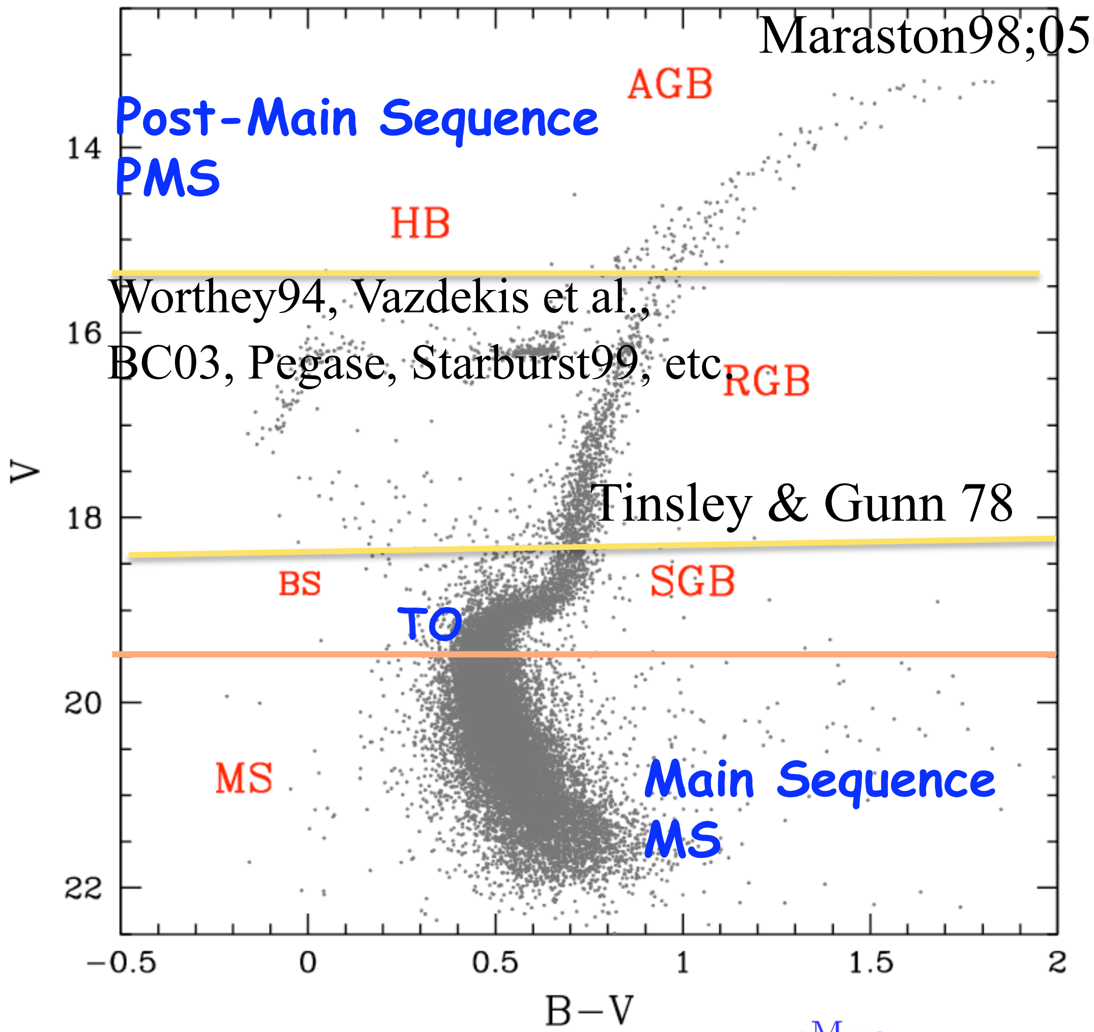
Outline

- Stellar Population modeling of the light & mass

  Light: stellar evolution, stellar atmospheres, element abundance ratios, coding

  Mass: stellar mass losses and remnants
  - Intrinsic ingredients and related uncertainties
- User-dependent assumptions: not related in how good the population model is
  - IMF, star-formation history, wavelength coverage
- Optimal approach and conclusions

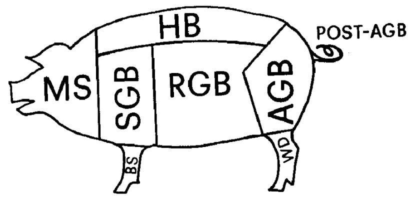
Stellar Population modeling



Two issues:

- **to include all major stellar evolutionary phases**
  - **much improvement over the last few years**

- **to optimally integrate the luminosity contribution**



Renzini 1986

$$L_{\rm SSP}(t;[Y,Z];{\rm IMF}) = {\rm L_{MS}} + {\rm L_{PMS}} = \int_{\rm M_{inf}}^{\rm M_{TO}} {\rm L(M)}\psi({\rm M}){\rm dM} + 9.75\cdot 10^{10}\cdot {\rm b(t)}\cdot\sum_{\rm J}{\rm Fuel_J(M_{TO})}$$

Key Ingredients

Mass-luminosity relation in Main Sequence – stellar model

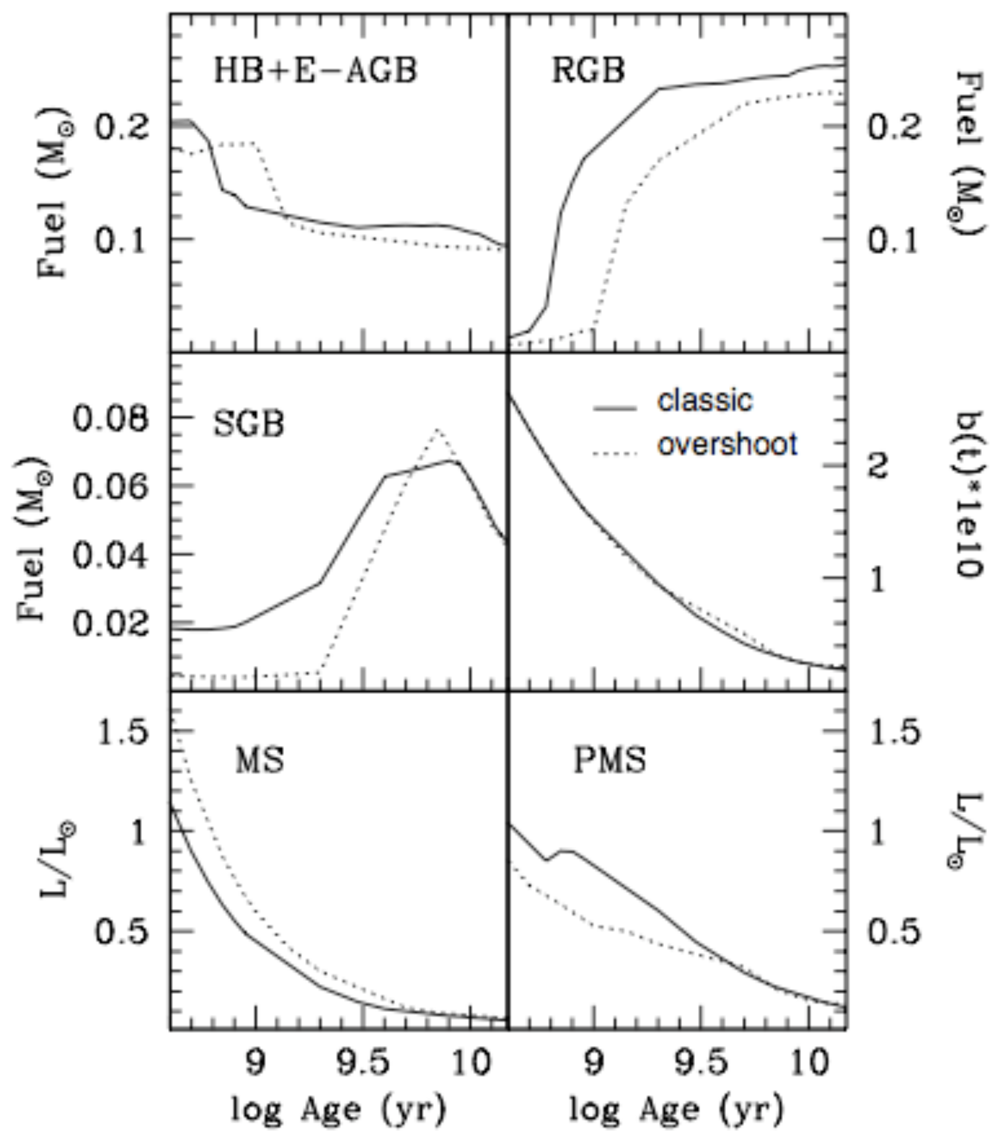
Energetics of post-Main Sequence phases up to the E-AGB – stellar model

Treatment of TP-AGB: empirical calibration

Overshooting: empirical calibration

Temperatures of Red Giant Branch: mixing-length and mass loss

Influence of stellar evolution on bolometric luminosities



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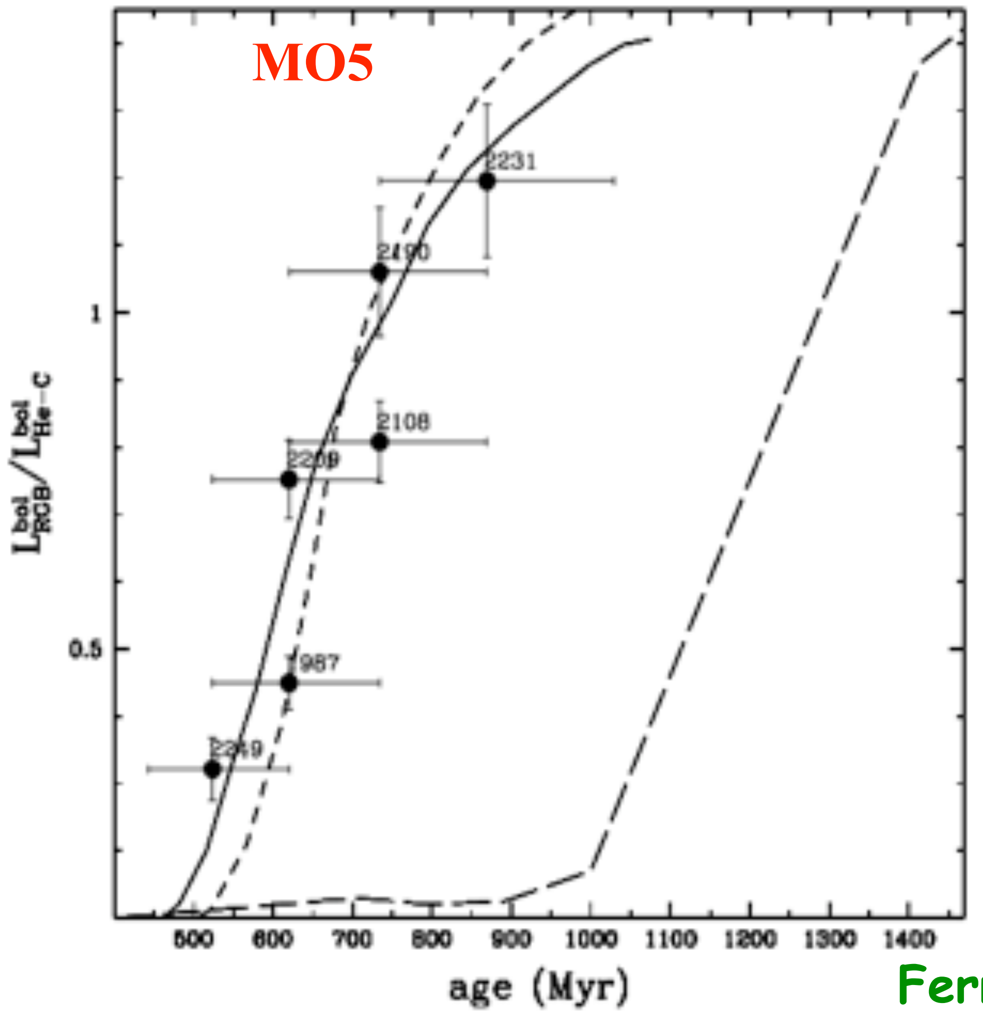
Models based on Padova tracks (BC, Pegase, Vazdekis, Worthey, Conroy) have lower luminosity at ages below some Gyr than M05

---> Higher M*

But overshooting and RGB onset can be calibrated

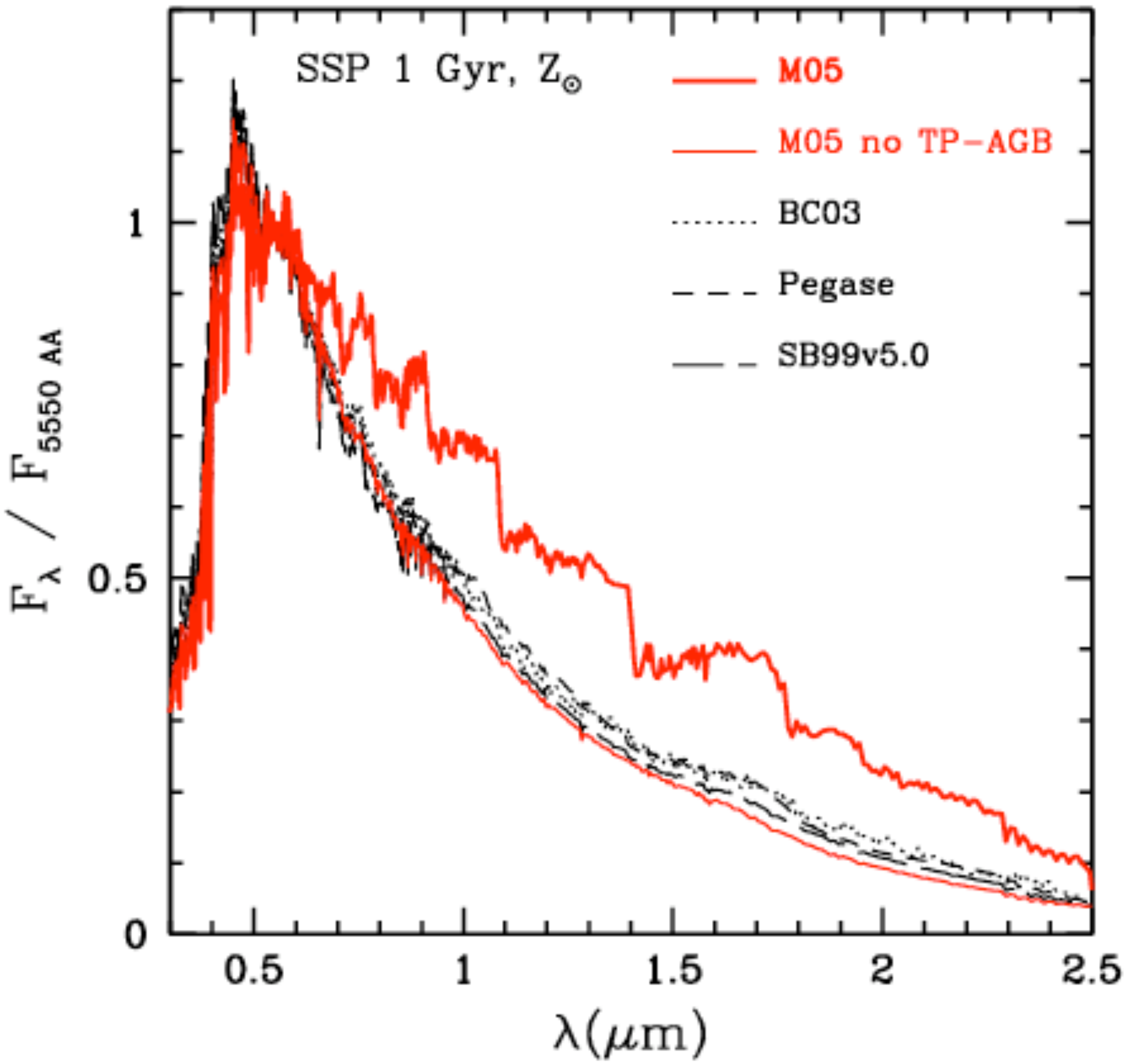
… no uncertainty



Padova tracks
(BC03, Pegase, Starburst99, Vazdekis, Conroy)

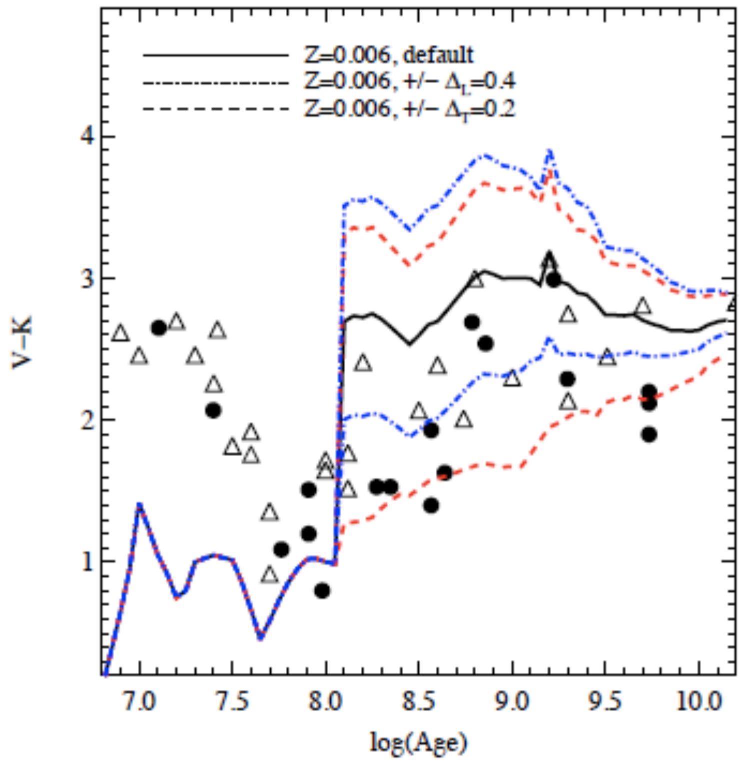
Ferraro et al. 04; 1995

TP-AGB: not much of an uncertainty anymore



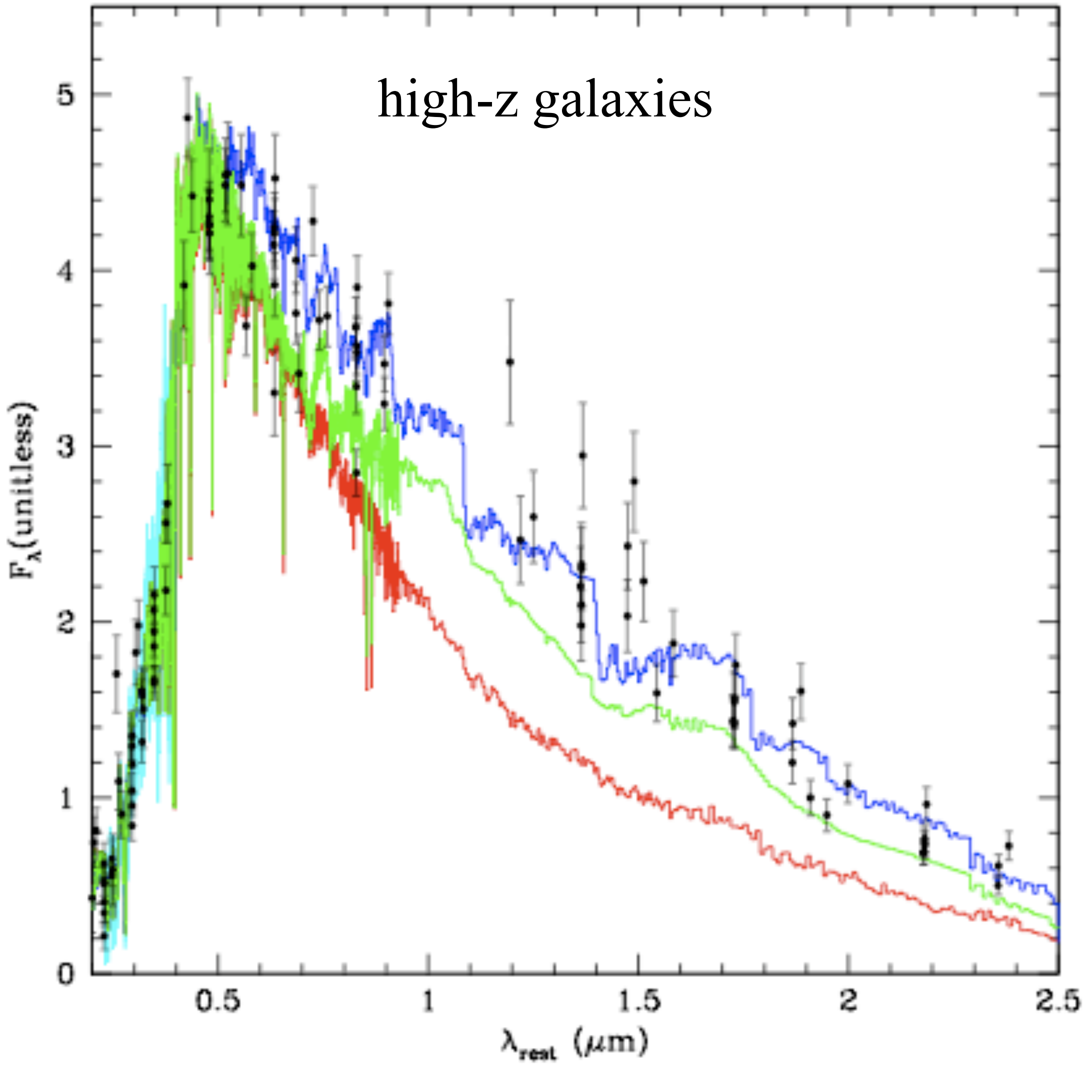
Maraston 2005, MNRAS, 362, 799

Let's not overestimate the uncertainties



Conroy et al. 09

FIG. 2.— $V-K$ colors of LMC star clusters as a function of cluster age. Data are from the compilations of Persson et al. (1983, *filled circles)* and Kyeong et al. (2003, *open triangles)*. Ages for the Persson et al. (1983) sample are adopted from Girardi et al. (1995). The average metallicity of the LMC is $Z \approx 0.006$ (Cioni et al. 2006). These data are compared to our default SPS model (*solid line*), and for a model with variations in the TP-AGB temperatures and luminosities by ± 0.2 dex and ± 0.4 dex (*dashed and dot-dashed lines*, respectively). Note that the standard stellar tracks without modification to the TP-AGB stars (*solid lines*) predict $V-K$ colors redder than the majority of observed clusters.



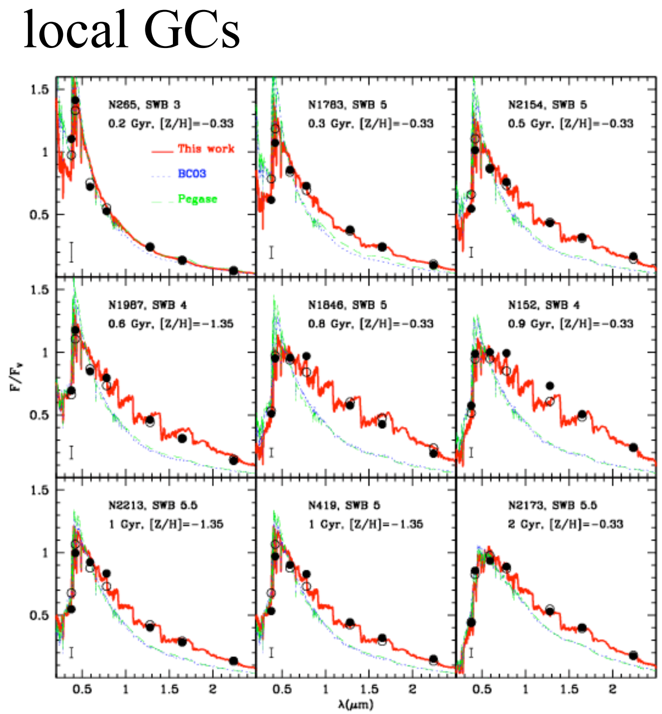
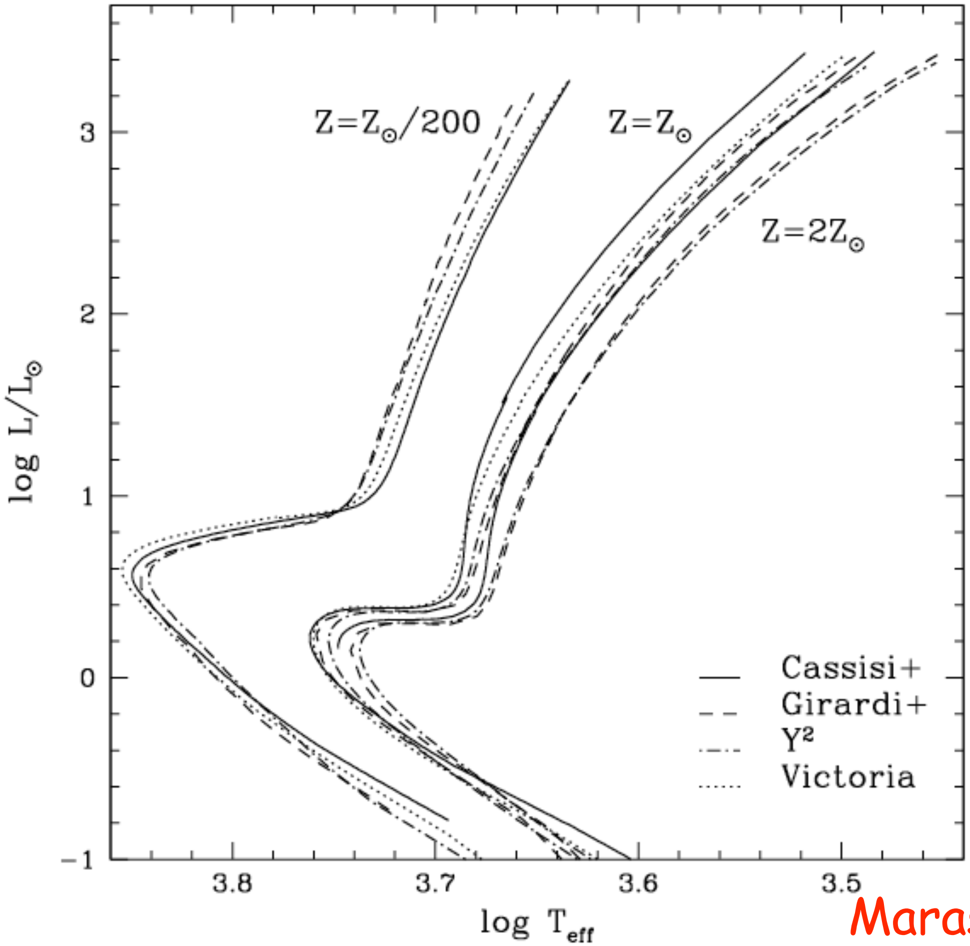


Fig. 5. Same as in Fig. 4, but including also the CB07 best fitting spectrum (green) and showing how the templates differ with each other at longer wavelengths. The observed stacked spectrum is shown in cyan. The black dots are the rest–frame photometry of the galaxies normalized at $\lambda_{rest} = 0.5\mu m$ (see text for more details).

from Cimatti et al. 2008

RGB Temperature distribution uncertainty: yes!

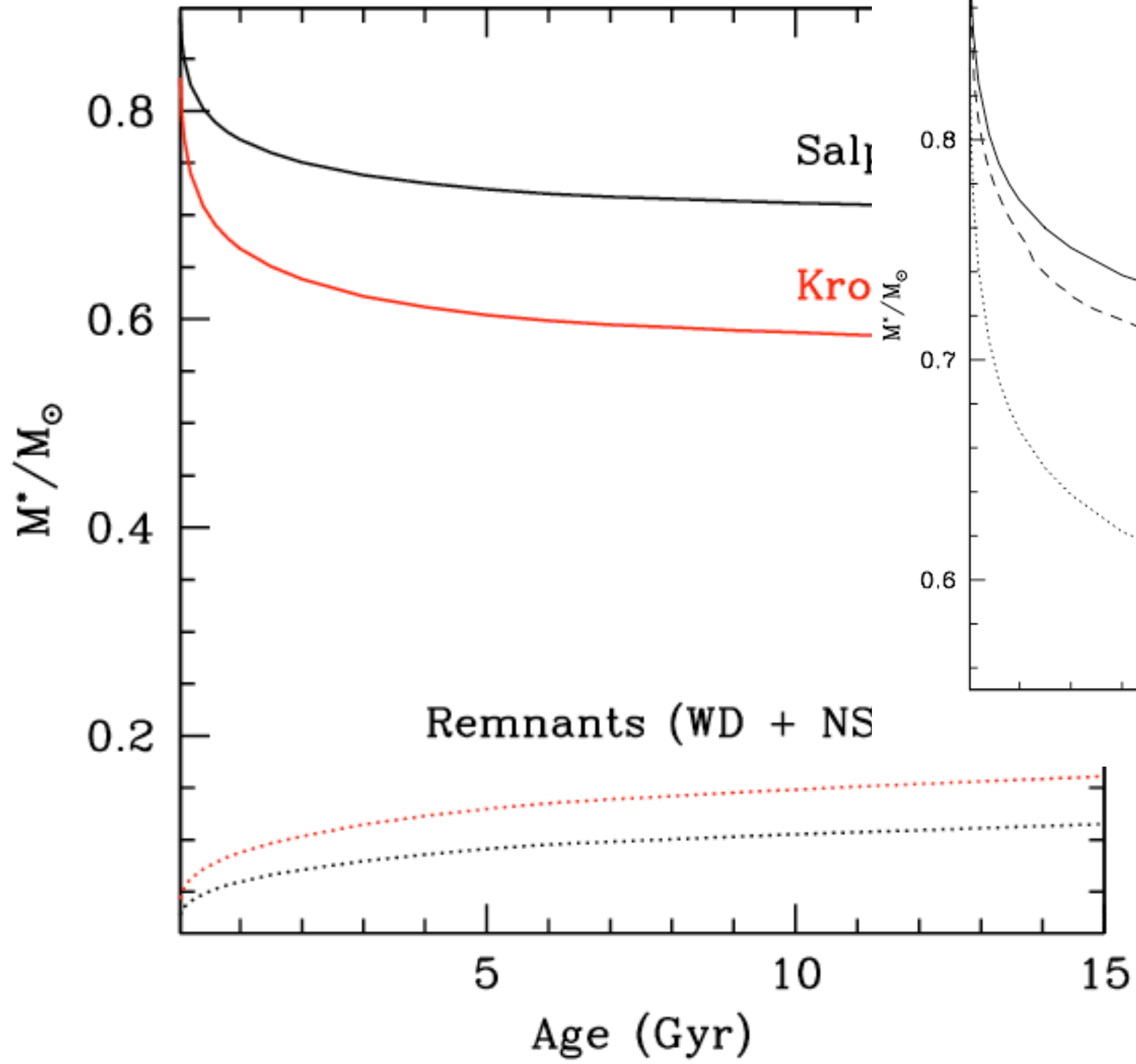


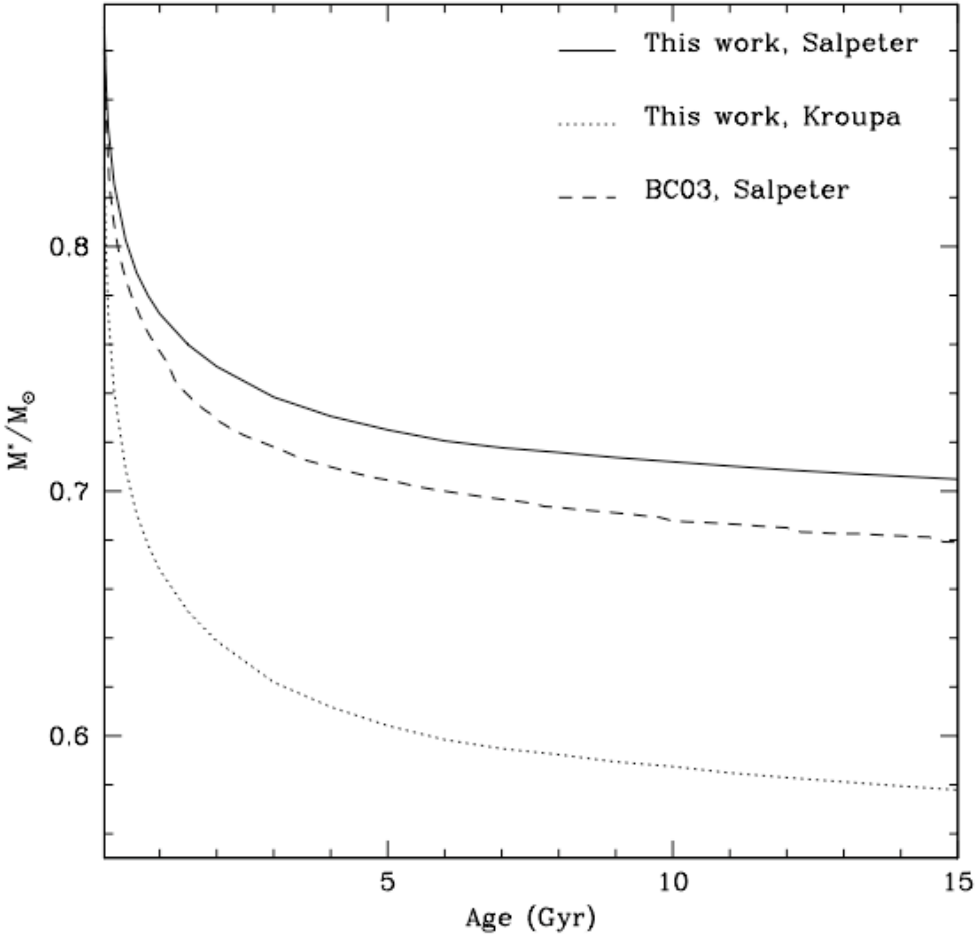
Maraston 2005

Synthetic RGBs have different colours according to different tracks
Hard to calibrate because is high Z
Crucial to understand the SED of Elliptical galaxies

This affects monochromatic luminosities hence M/L for old populations

Modelling the evolution of the stellar mass





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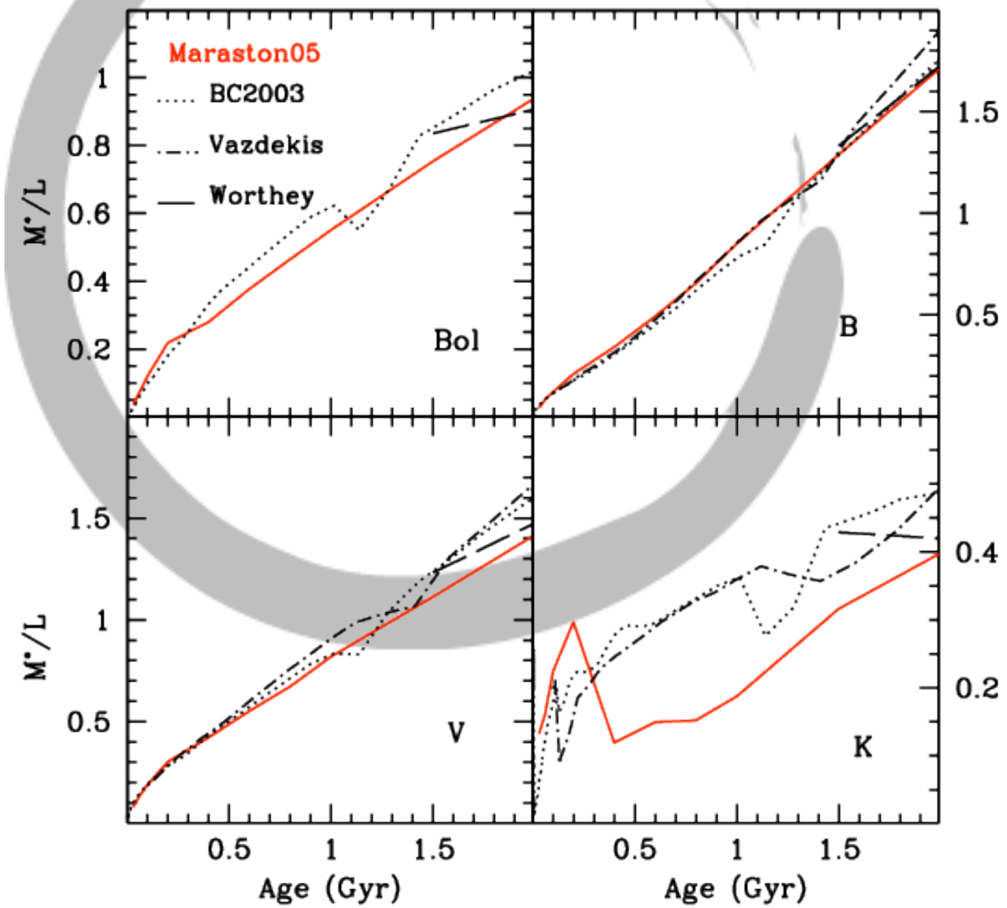
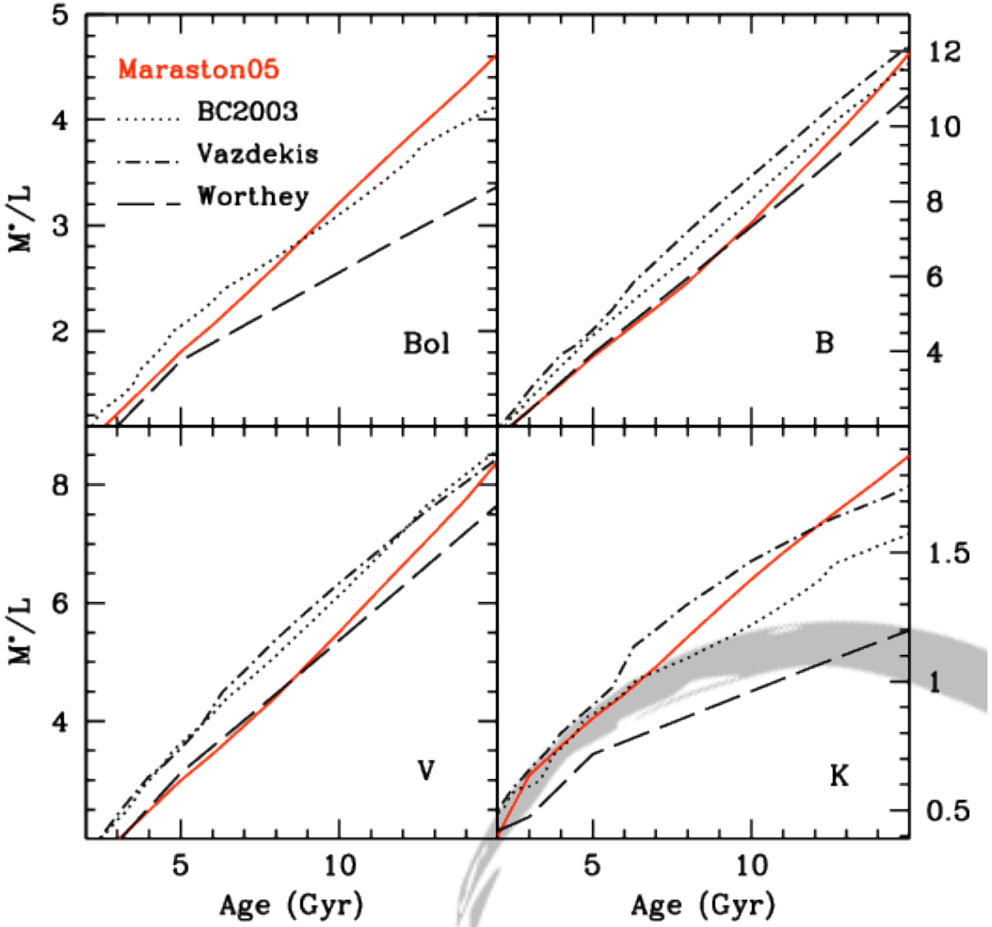
M/L according to different authors





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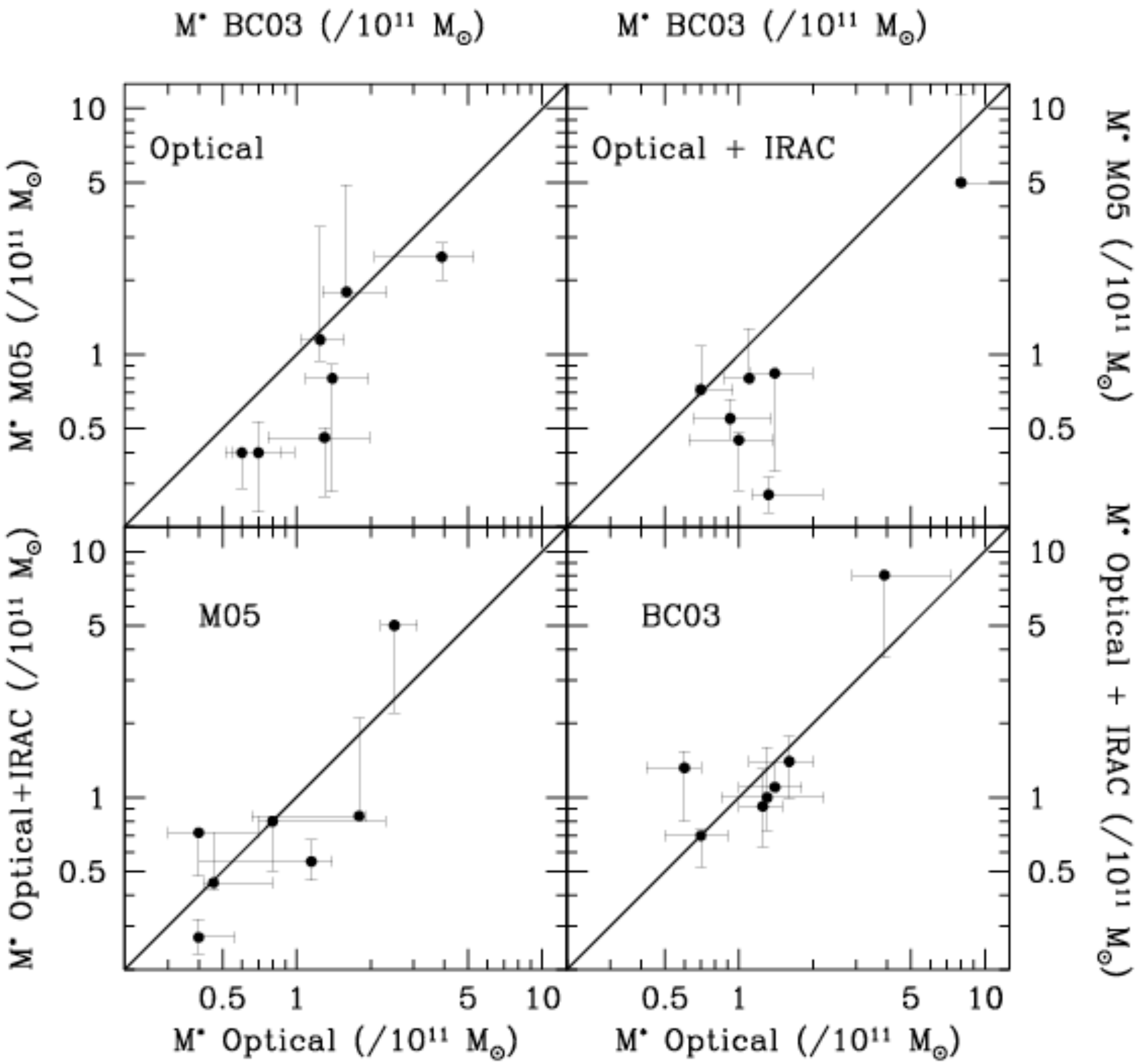
Global effect of stellar population modelling on the derived galaxy stellar masses at high-z



MO5 masses are lower by 60% than BC03 masses (confirmed by a long list of authors including Bruzual 2007)

which does not mean the mass is uncertain by a factor 2 to 3

Maraston et al. 2006

Assessing the impact of individual assumptions

- Star formation histories, reddening laws, wavelength range, etc. are left to the individual choice
- How much do these matter? How well can we recover the masses of galaxies?
- Use mock galaxies from semi-analytic models with well defined properties and fit them as they were observed galaxies

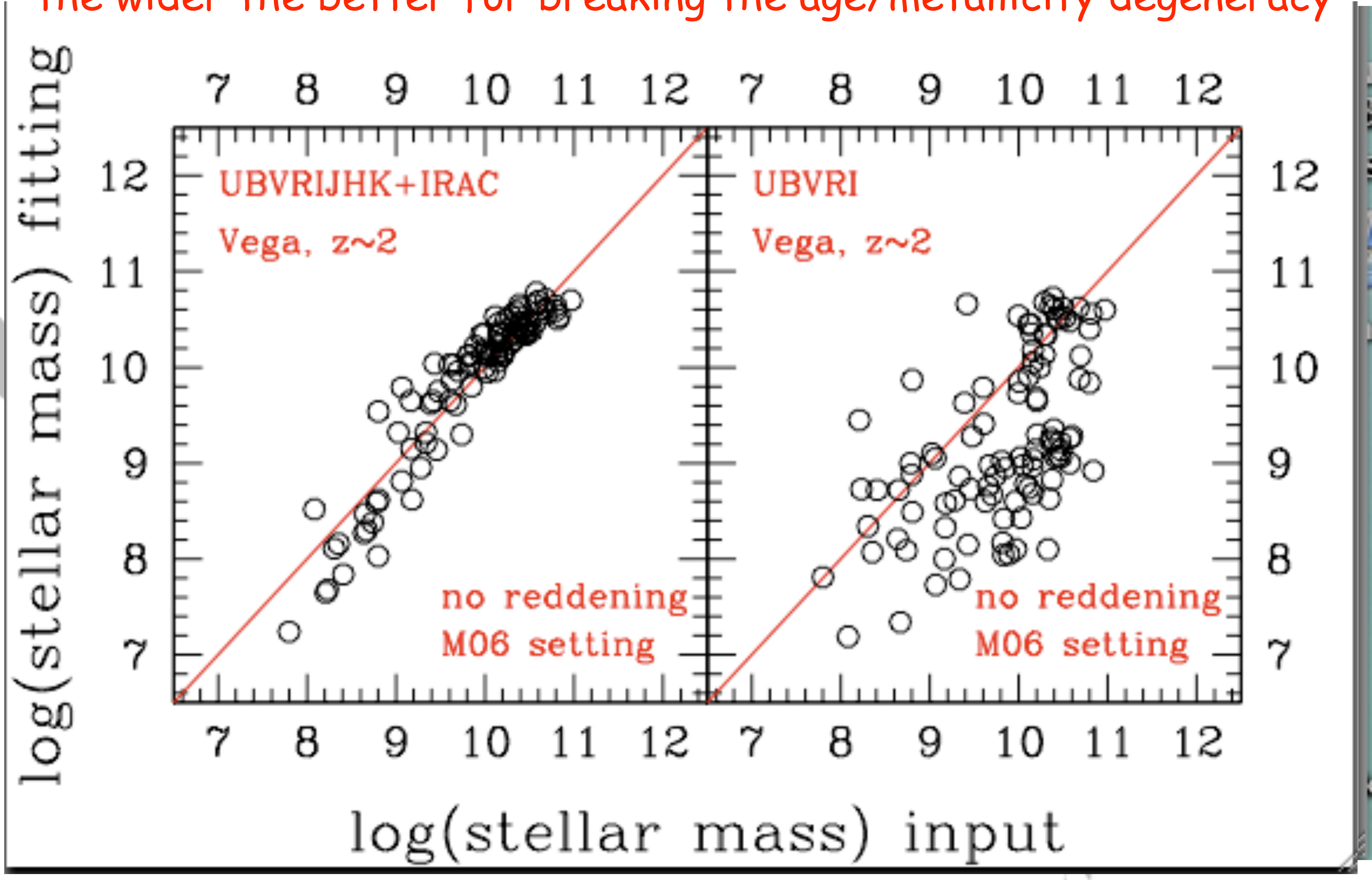
see Wyutts et al. 09 and M. Franx talk;

posters by M. Longhetti and J. Pforr

How well can we recover galaxy masses from data?

1. Wavelength coverage

the wider the better for breaking the age/metallicity degeneracy



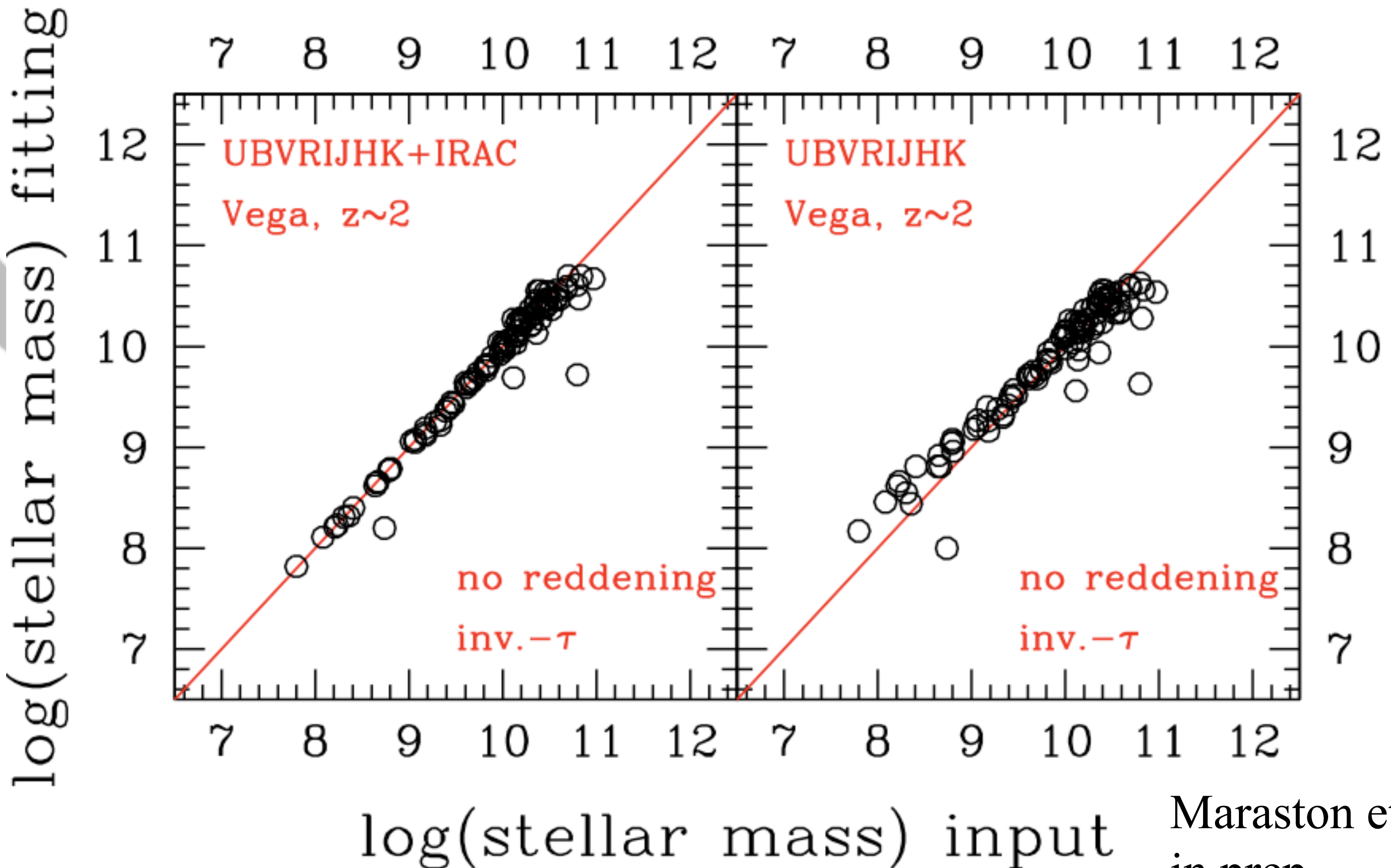
Pforr, CM, Tonini, in prep., see poster by J. Pforr

data.

How well can we recover galaxy masses from data?

2. Star formation history

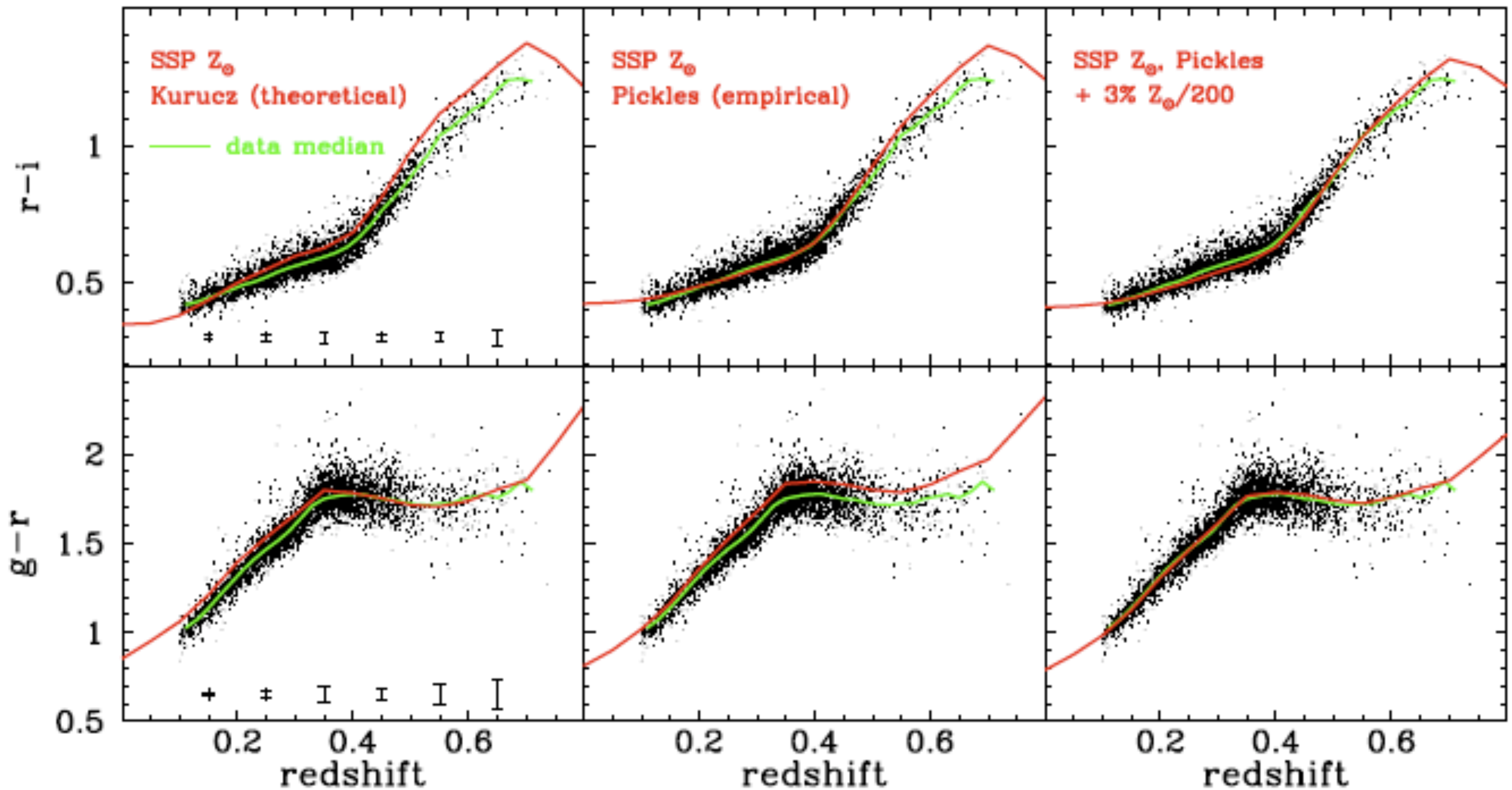
New inverted-tau models



Maraston et al. 09 in prep.

Mature galaxies at low redshift

- Luminous Red Galaxies in SDSS:

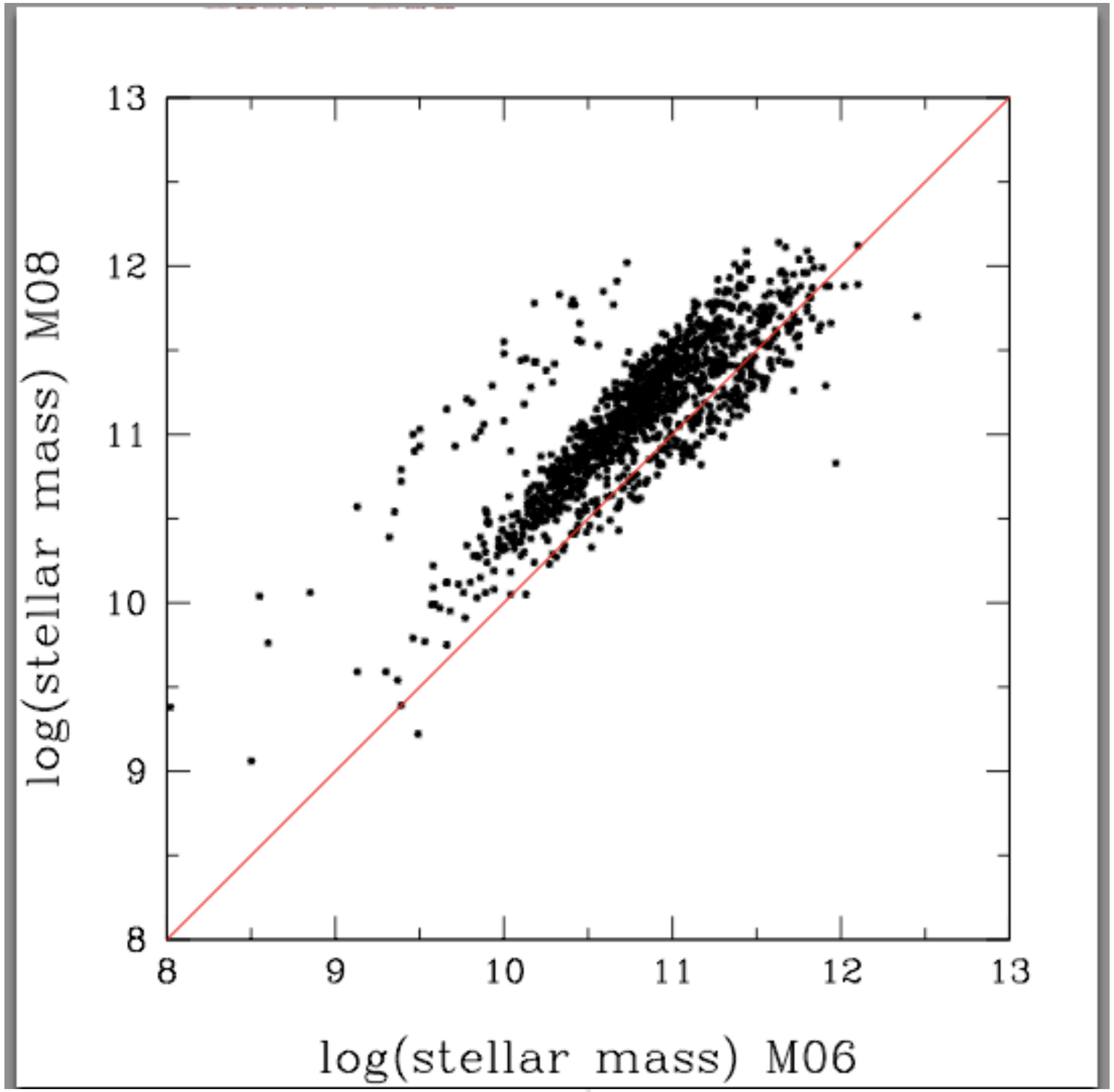


Maraston et al. 2009a, MNRAS-L

Mature galaxies at low redshift: metal-poor stars instead of residual star formation?

- Galaxy mass increases

Ratio between luminous and dark matter and the IMF
-→ less dark matter within 1 Reff in early-type galaxies
(vs. Grillo et al. 0904.3282)



Conclusions

- The relationship between stellar population models and a galaxy stellar mass became clear due to recent improvements
- Classical uncertainties are minimized in modern models: overshooting and TP-AGB high-z galaxies and young galaxies at low-z or spirals
- Real remaining uncertainties mostly affect old galaxies:
  - * RGB Teff of metal-rich populations *use various bands !*
  - * unknown fraction of old but blue stars hot BHB, AGB manque' *consider various templates !*
- External uncertainties: star formation history, wavelength range, IMF (Kroupa's talk), dust content (Conroy's talk)
- Using mock galaxies reveal that Stellar masses can be very well recovered from data provided:

- the stellar evolution in the models is complete
- λ coverage includes rest-frame near-IR
- adequate star formation histories are adopted inverted tau-models are very promising at high-z, old metal-poor component at low-z