Measuring the Extinction Law in Nearby Galaxies via Spectral Synthesis Modeling

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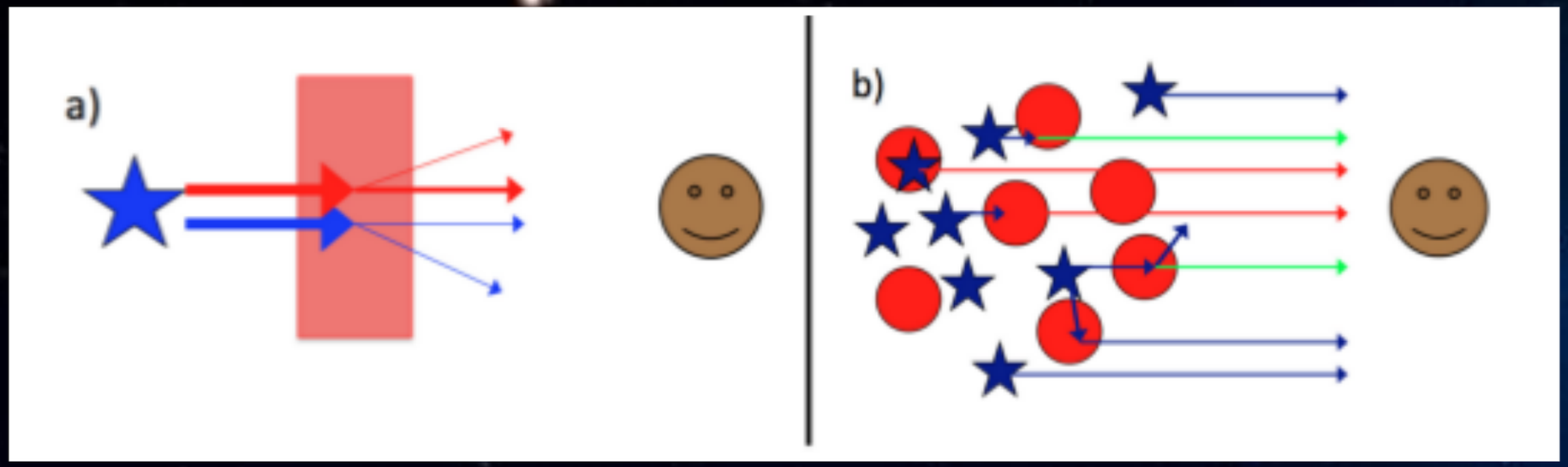
Outline

- Dust attenuation in nearby galaxies toward SNe.
- Data set
- SED fitting with Prospector
- Results from fitting mock data
  - Testing different data configuration
  - Checking biases and goodness of fit

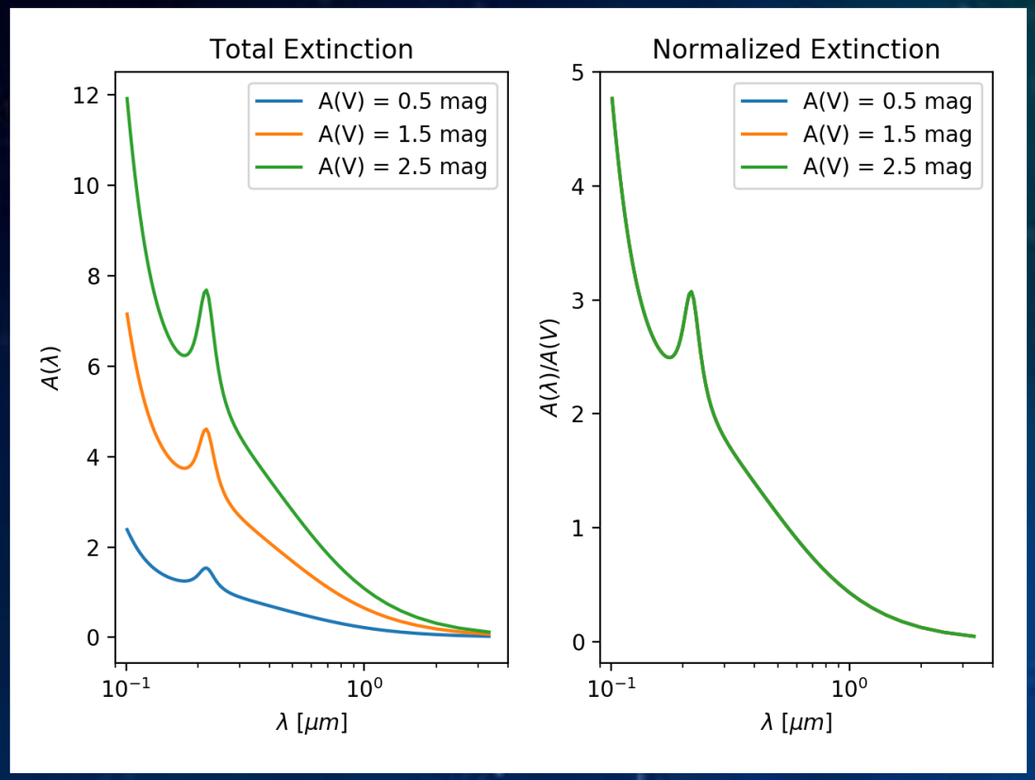
Extinction vs Attenuation



Calzetti (2012)

Extinction assumes a simple foreground screen of dust scattering the light out of the los.

Attenuation refers to a complex geometry between source and dust:



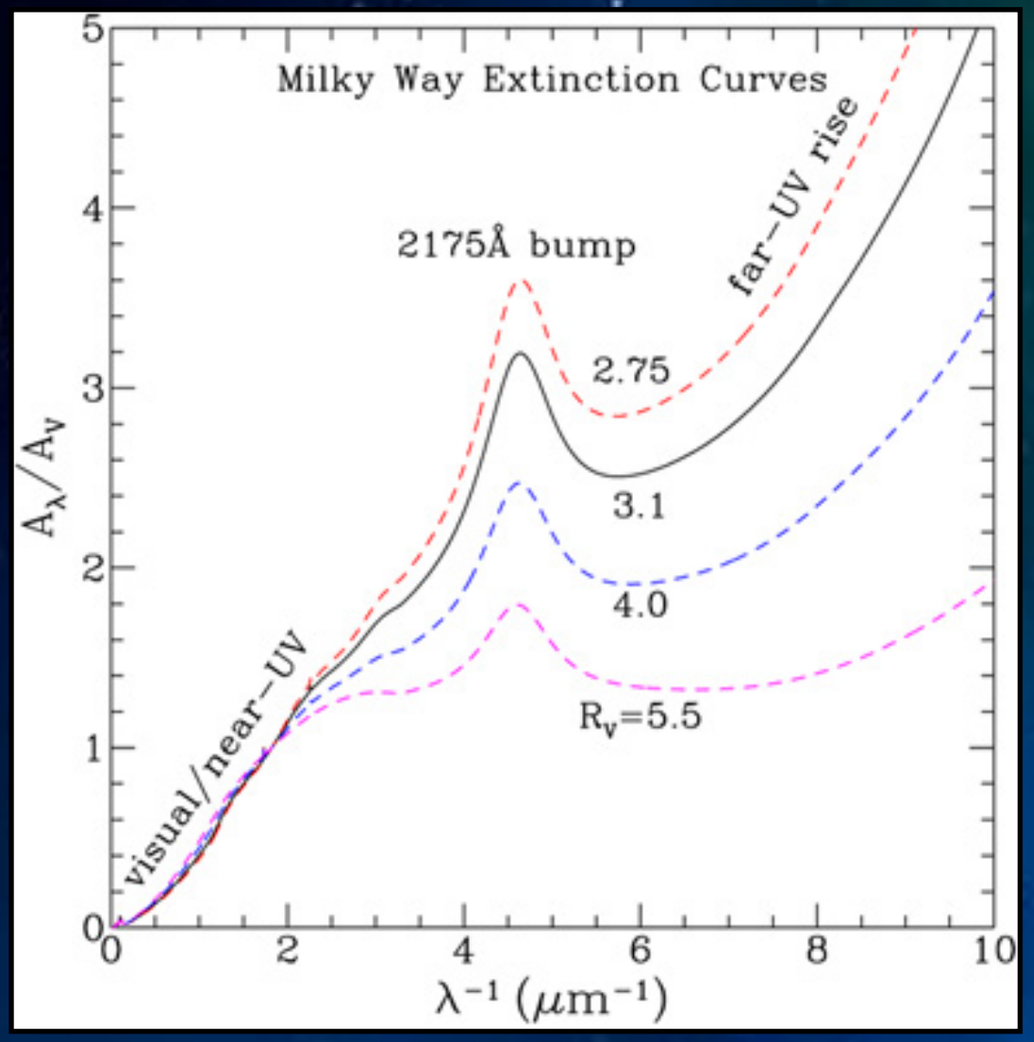
Extinction laws

What is the extinction we measure?

Extinction laws define how the light is absorbed at different wavelengths depending on dust properties.

- $\lambda^{-1.5}$ power law assumed for MW (Cardelli+, 1989).
- $R_V \rightarrow$ dust grain size (Draine, 2011).
- A constant R_V does not account for the local properties of the ISM.

Li (2007)



Extinction towards SNe

Extinction curves with unusual low values of R_V have been found from

Large samples (<2; Tripp 1998; Astier+2006; Nobili & Goobar 2008; Kowalski+2008; Folatelli+2010; Burns+2014)

Individual reddened events: 1999cl (R_V=2.0, Krisciunas+2006); 2002cv (R_V=1.6, Elias-Rosa+2008); 2003cg (R_V=1.8, Elias-Rosa+2008); 2006X (R_V=1.5, Wang+2008); 2014J (R_V=1.4, Amanullah+2014)

Similar low-R_V values are inferred from spectropolarimetric measurements (Patat+2015; Zelaya+2017).

Debate on origins

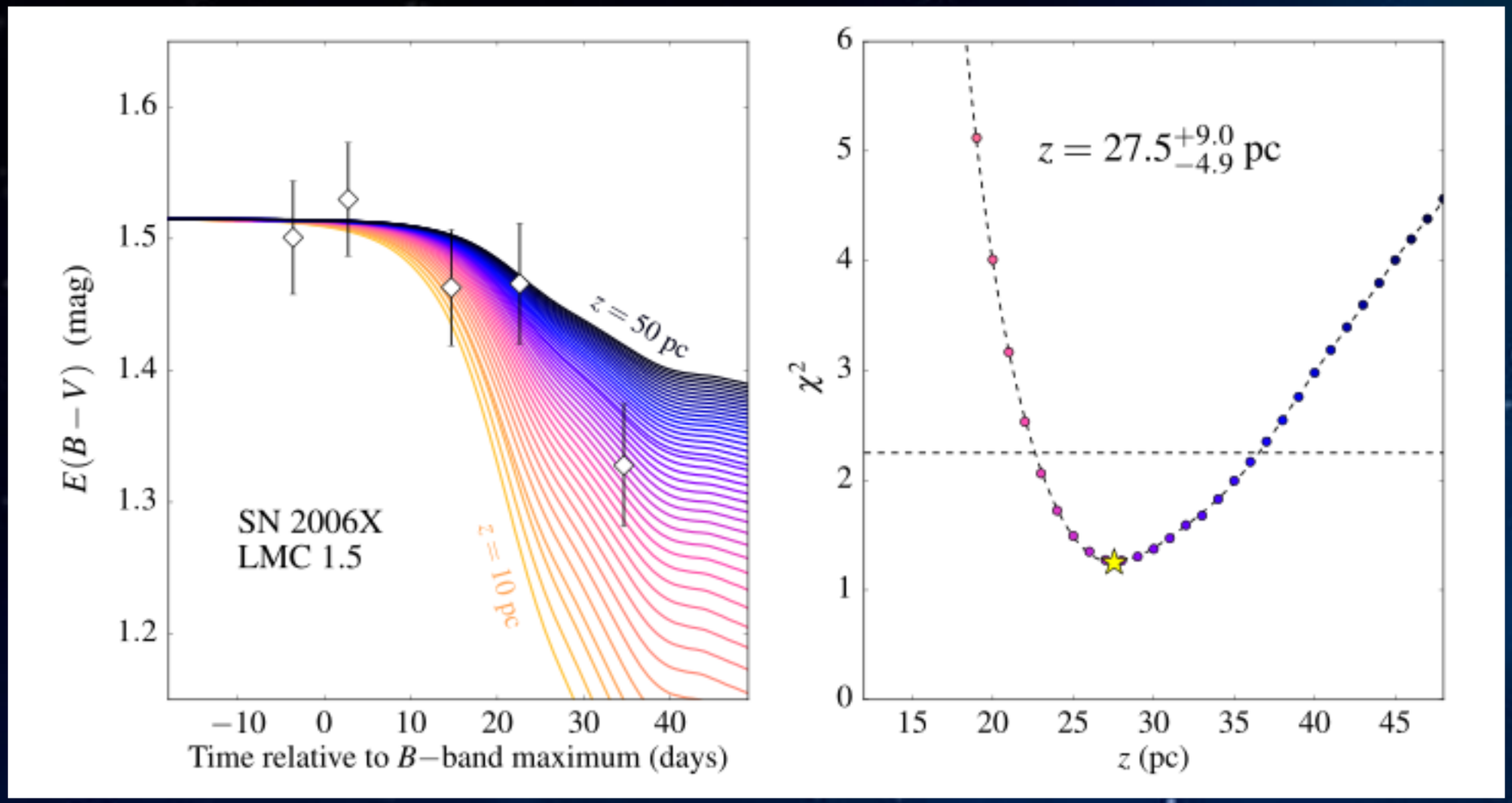
IS medium

- The simplest explanation of smaller grains although the reason is puzzling (e.g. Amanullah+ 2014, but see Hoang 2017).

- Correlation found between highly reddened SNIa and the presence of an interstellar band at 5780 Å (Phillips+ 2013).

- CS origin can be excluded by the lack of infrared thermal emission (Johansson+ 2017).

Puzzle solved?



Bulla+ (2017)

Our plan

We can look at unresolved stellar population in nearby galaxies and fit SEDs from high spatial resolution data.

- Use IFU data from MUSE observations
- Combine photometric data from Carnegie Supernova Project (CSP)
- Start with a nearby SN Ia host galaxy
- Measure the variation of R_V in the environment

Dataset

~250 AMUSING galaxies

→ **SN host galaxies** observed with MUSE

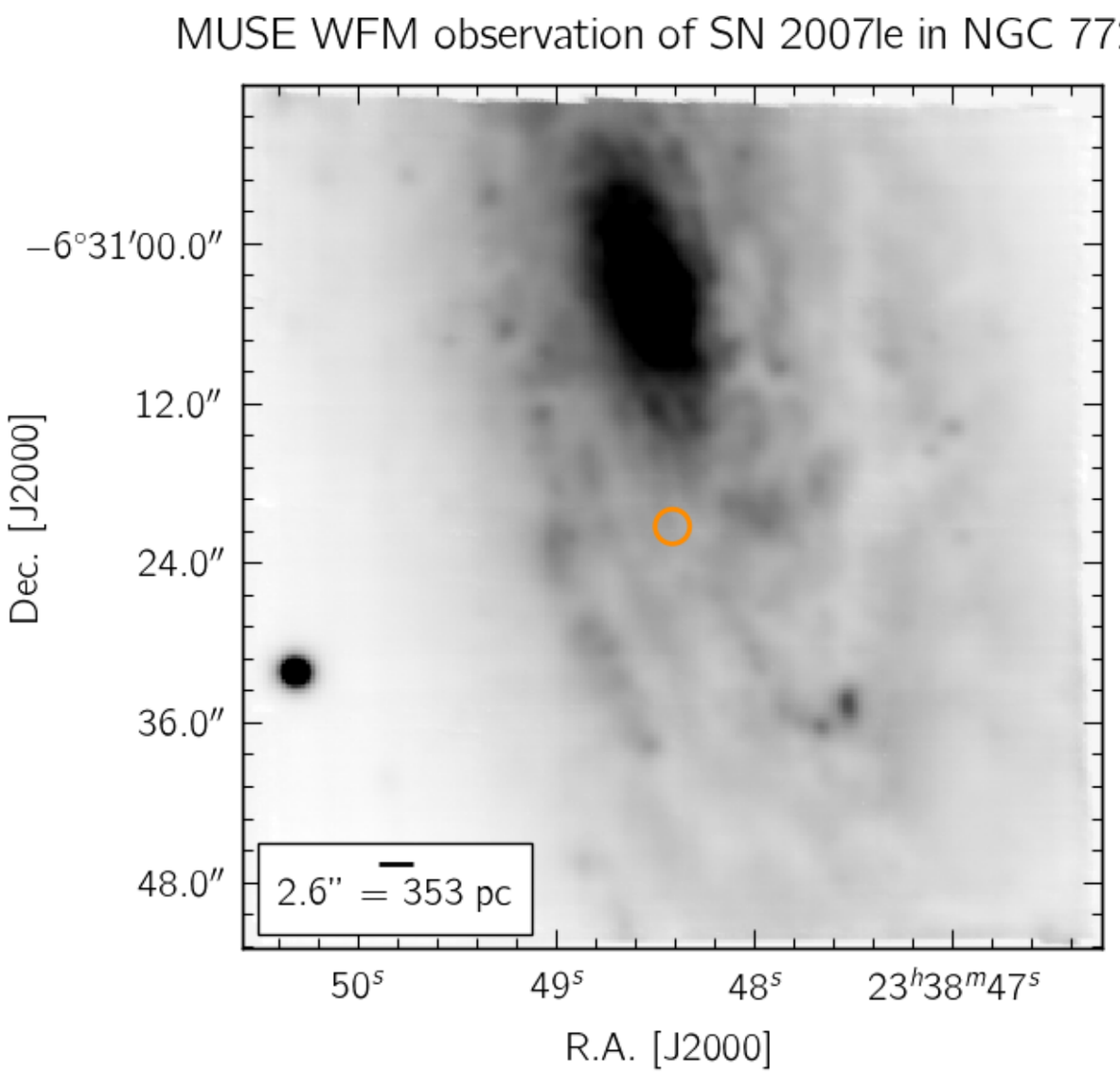
~100 SN host galaxies observed in *ugrizBVYJH* with Du Pont

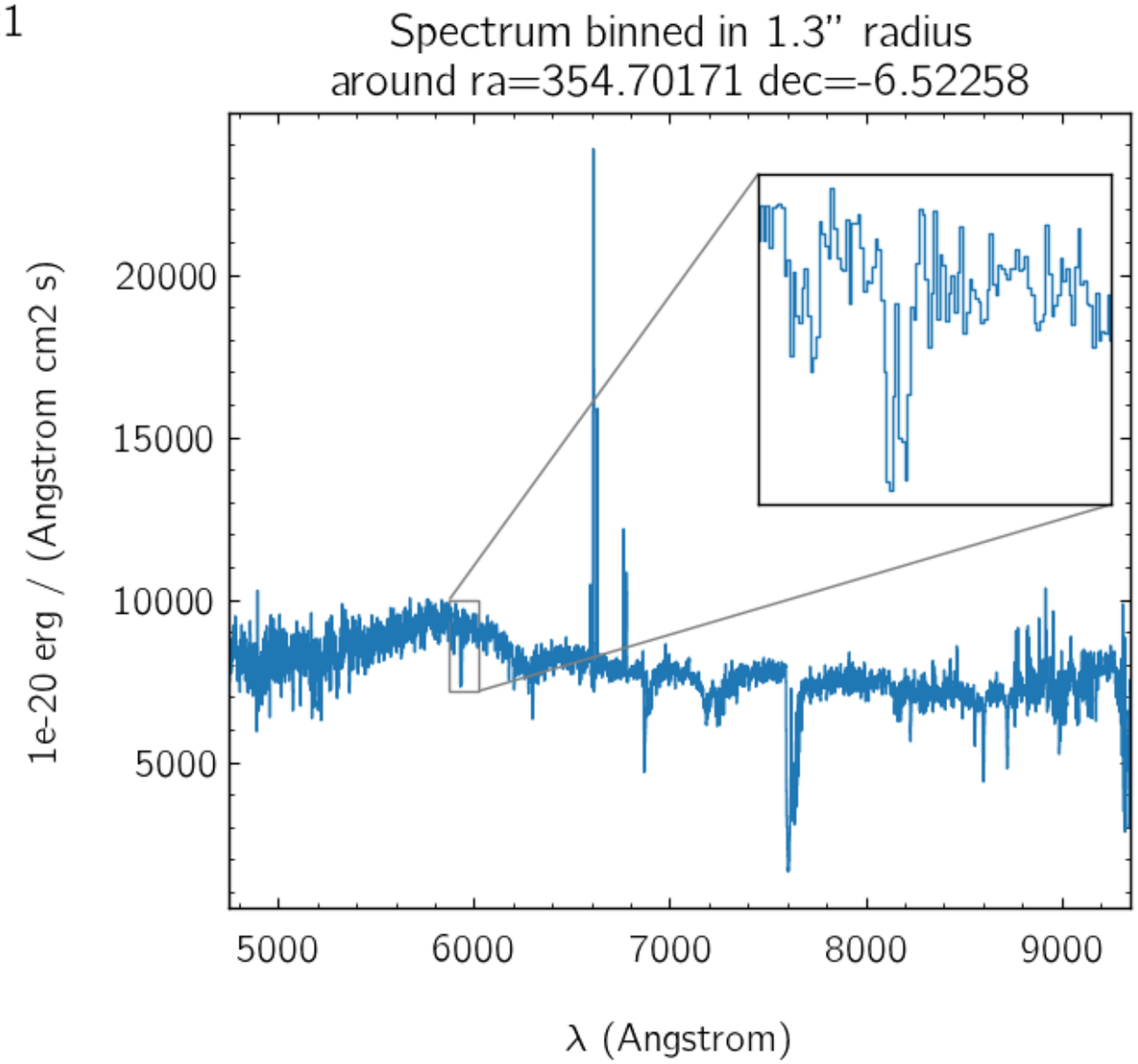
→ deep images of the hosts taken during CSP-I campaign

18 PHANGS galaxies

→ very nearby galaxies observed with several MUSE pointings for more than 70 hours of observation

Dataset


MUSE WFM observation of SN 2007le in NGC 7721
−6°31′00.0″
12.0″
24.0″
36.0″
48.0″
Dec. [J2000]
2.6″ = 353 pc
50^s
49^s
48^s
23^h38^m47^s
R.A. [J2000]


Spectrum binned in 1.3" radius
around ra=354.70171 dec=-6.52258
1e-20 erg / (Angstrom cm2 s)
20000
15000
10000
5000
5000
6000
7000
8000
9000
λ (Angstrom)

The ingredients of galaxies

Massive stars

Dust lanes

Ionized gas

Low mass stars

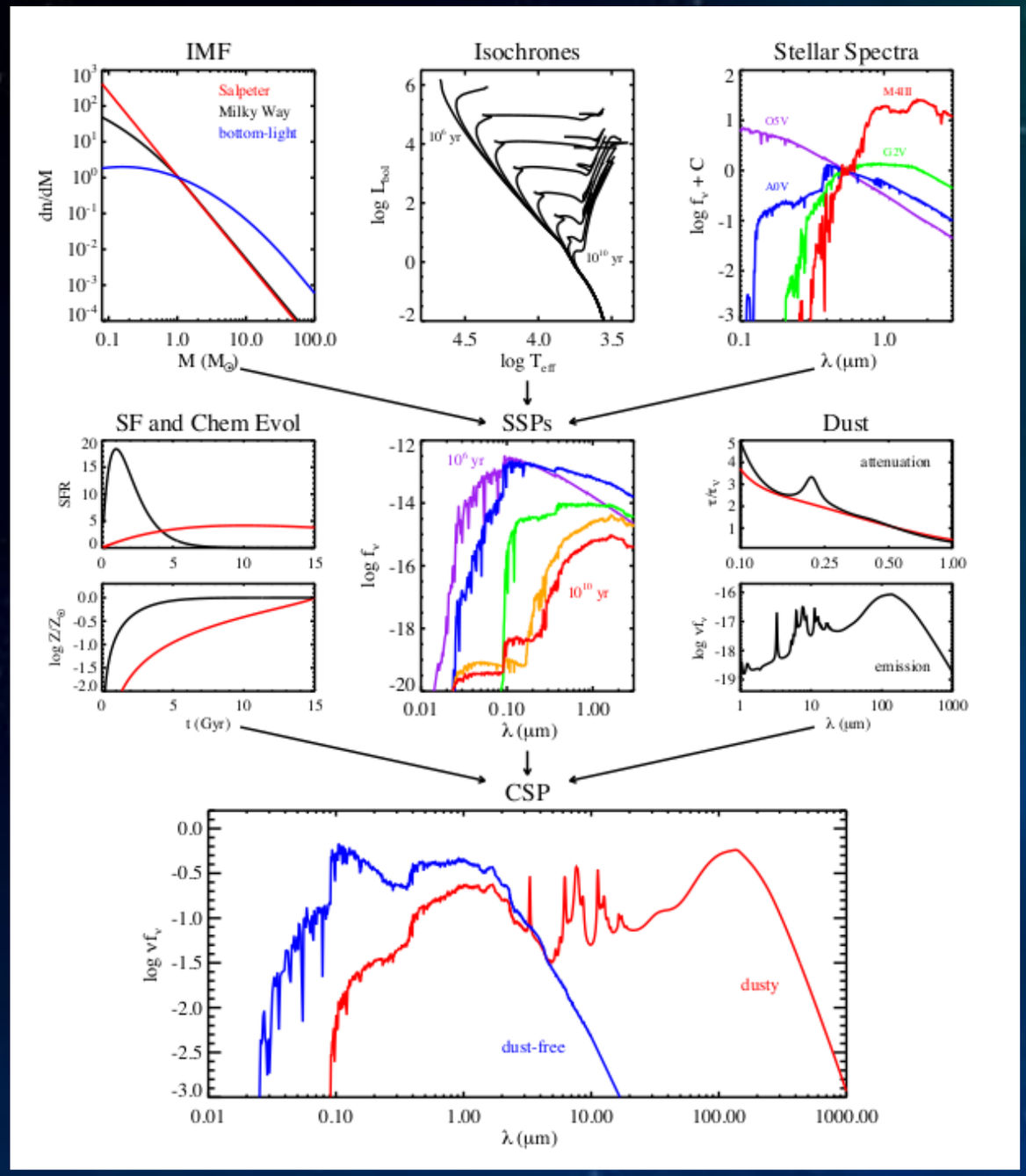
Active nucleus

M51 observed with the HST

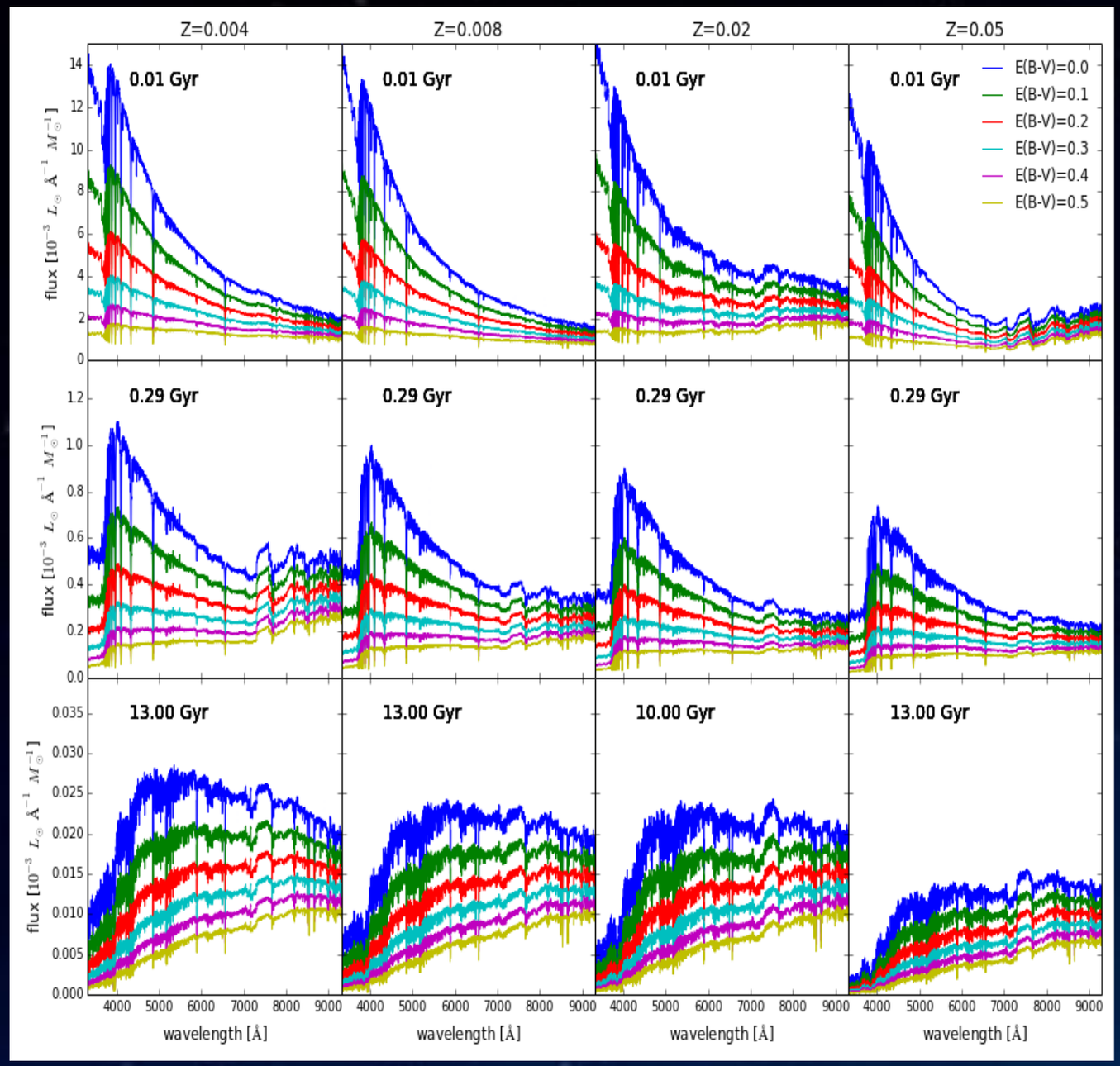
Fitting the SED of galaxies

Simple stellar populations are the building blocks!

Stellar population parameters are encoded in the SED of galaxies.



Synthetic spectra



SPS models show redder spectra for higher extinctions, older ages and lower metallicities

Plotted from Bruzual and Charlot (2003) models

Prospector in a nutshell

- Bayesian SED fitting code (Johnson in preparation, but look at Leja 2017)

- It relies on **FSPS** stellar population synthesis code (Conroy 2009). Models are created on-the-fly.

- Two-step process: optimization and sampling
  - Least square optimization to find the best fit before MCMC sampling
  - Ensamble MCMC sampling

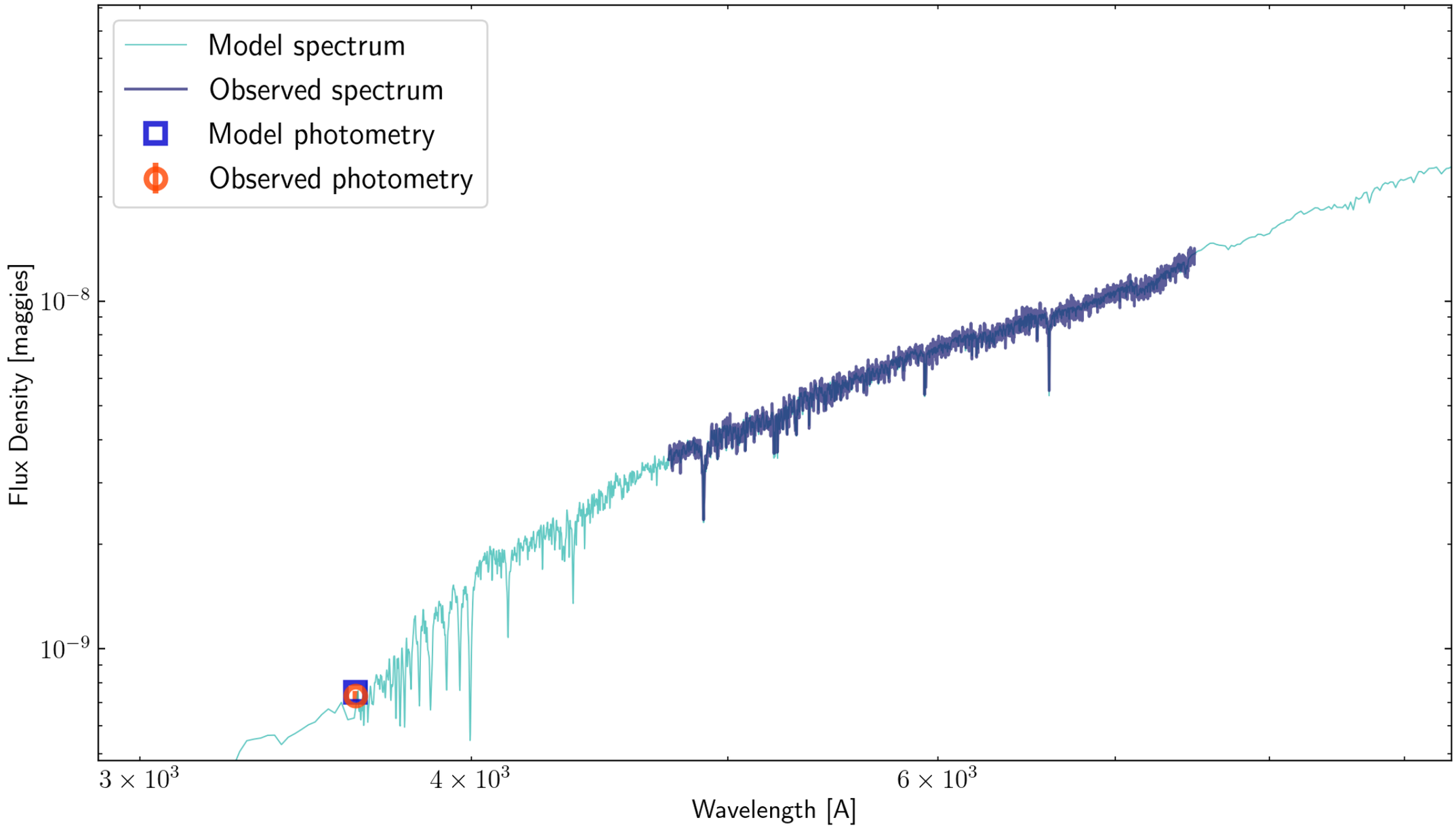
Mock data fitting

It became common practice in SED fitting to test the reliability of the fit with mock data

We devise four combination of mock data set

1. MUSE-like spectrum 4750-7500 Angs (liited by MILES libraries)
2. MUSE-like spectrum + *Iz* → to recover the red part
3. MUSE-like spectrum + *Iz* + *uB*-CSP → to break age-metallicity-extinction degeneracy
4. Full (MILES) spectral range (3525-7500 Angs)+ *Iz*

Mock data fitting



Prospector set up

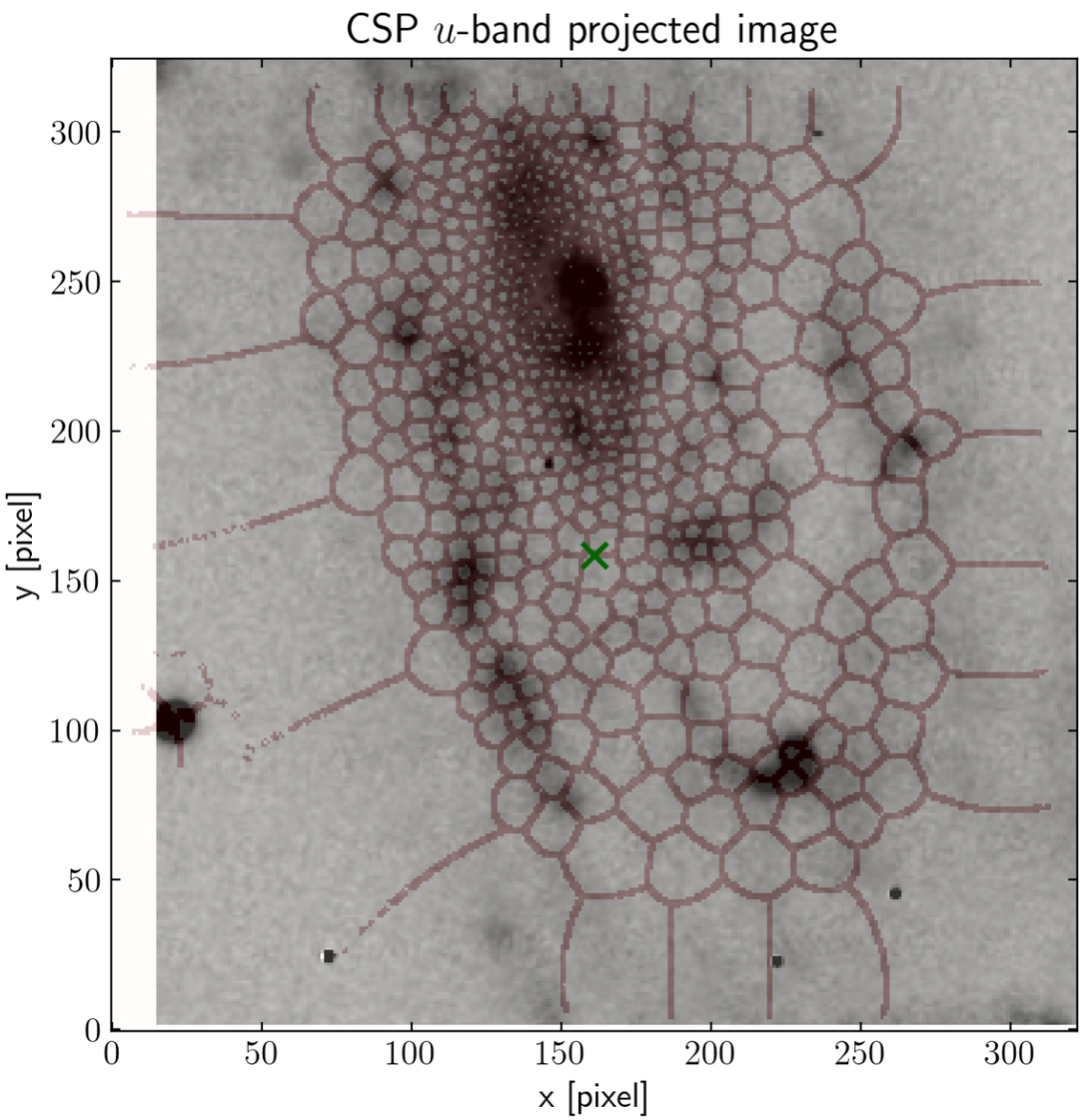
We tested convergence to find the optimal set up:
Number of iteration, number of walkers, initial guess

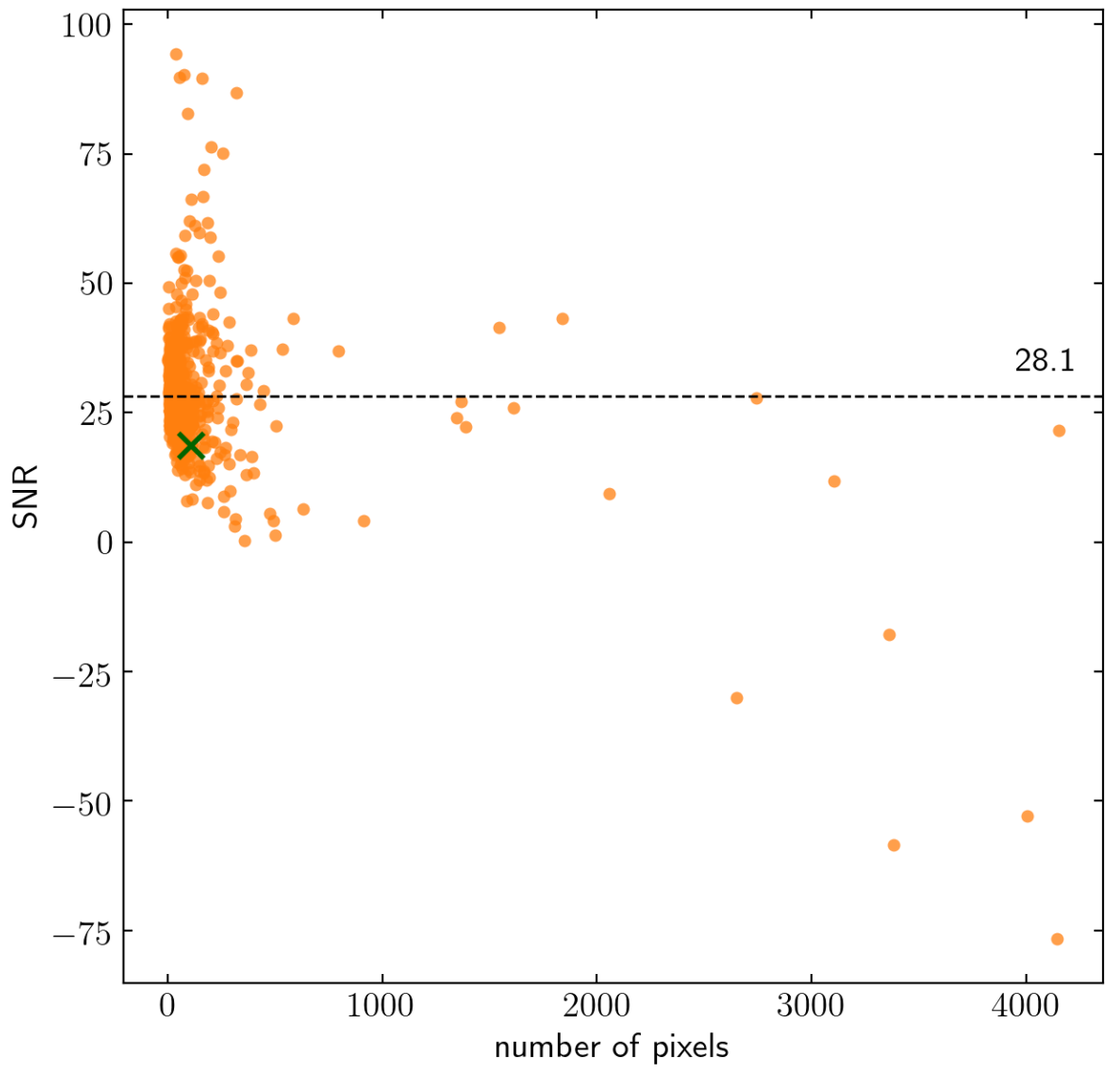
Physically motivated priors are chosen!

Simple dust screen model is assumed for dust attenuation

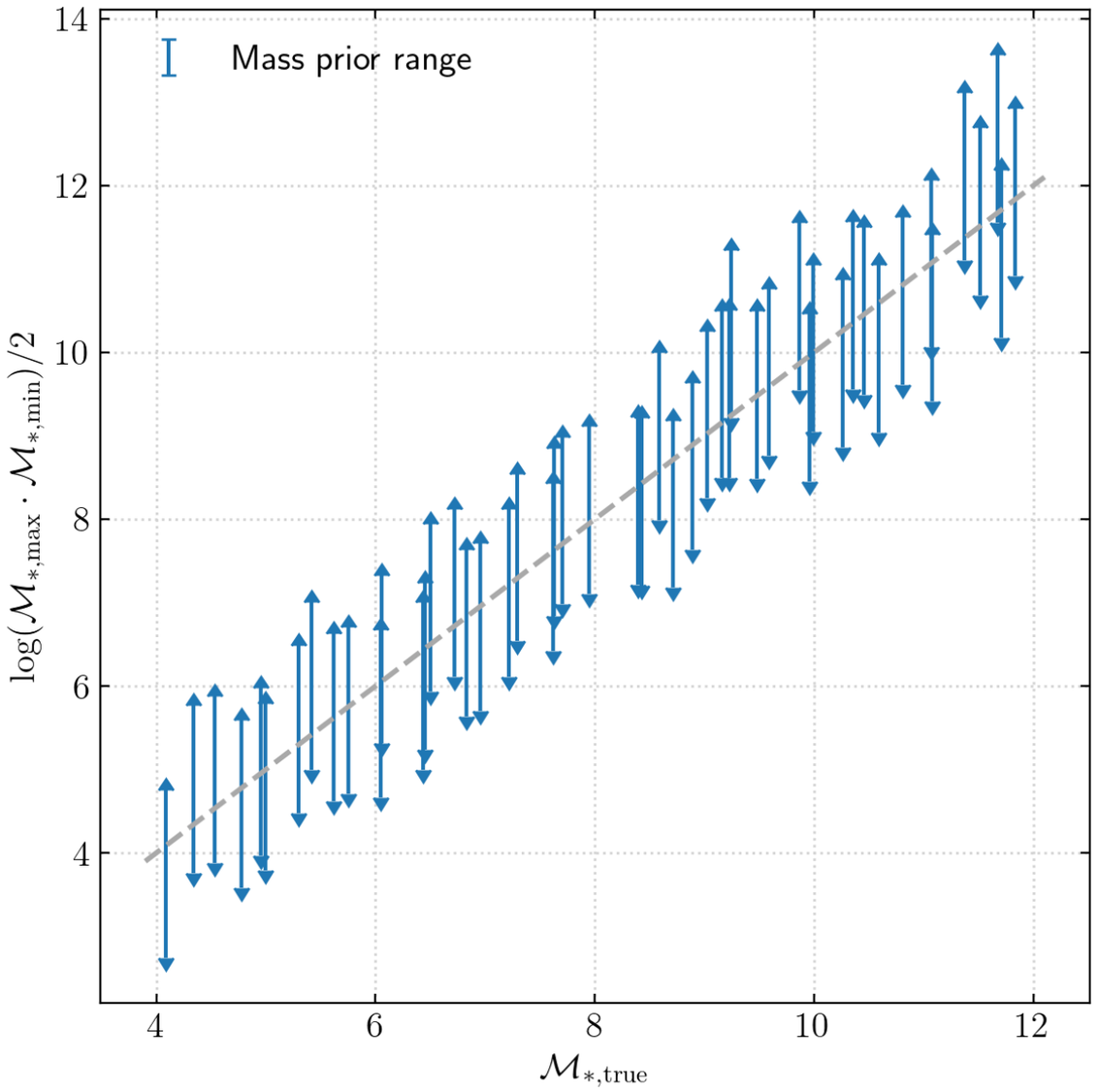
Parametric delayed-SFH is assumed

Prospector set up (SNR)





Prospector set up (Mass)



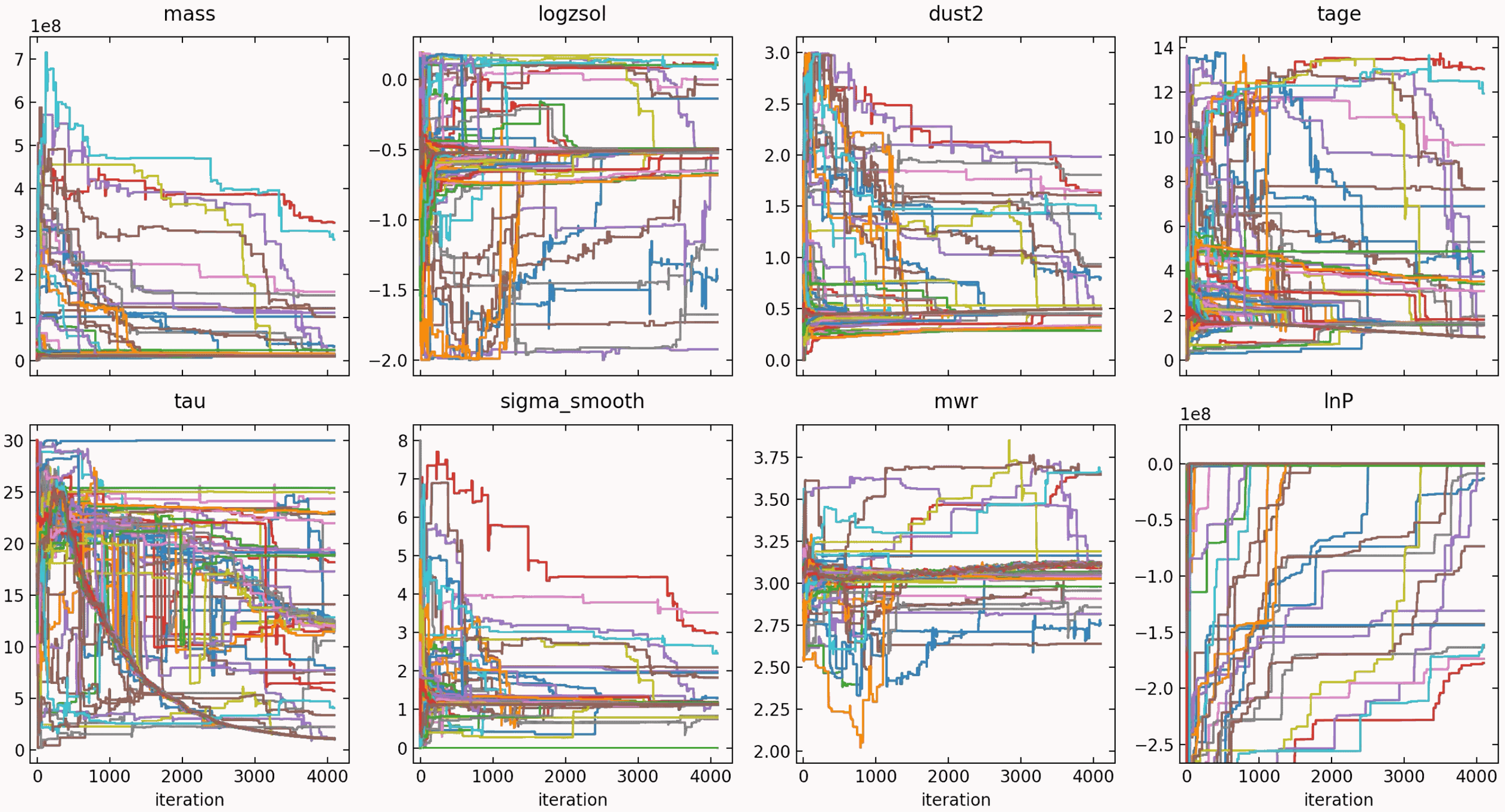
Mass is well-determined by spectral continuum.

But the range of masses is wide when observing nearby galaxies

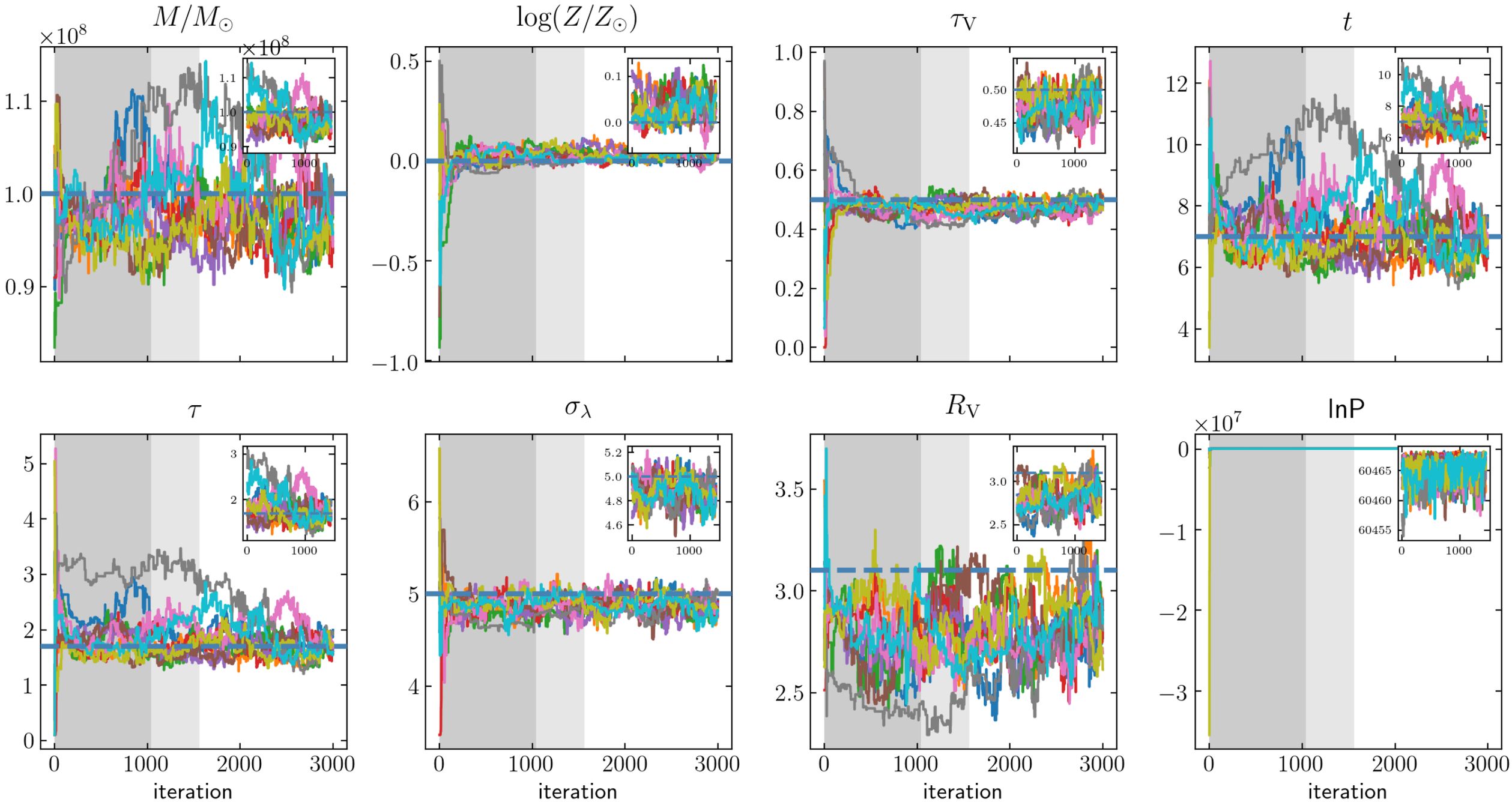
We estimate the mass prior range from assuming a range of M/L and extinctions

We then apply the ranges to the luminosity from MUSE spectrum

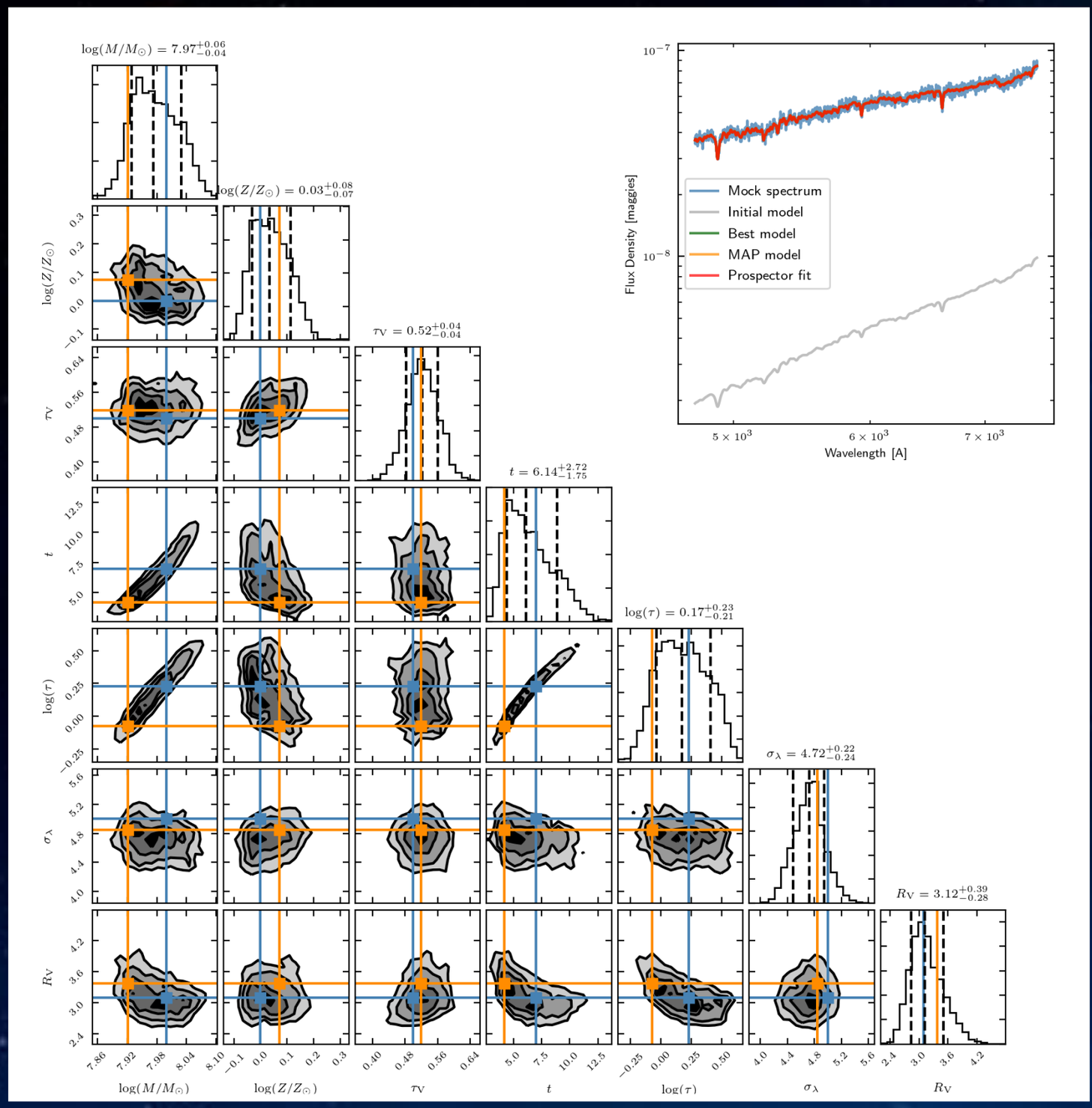
Other refinements



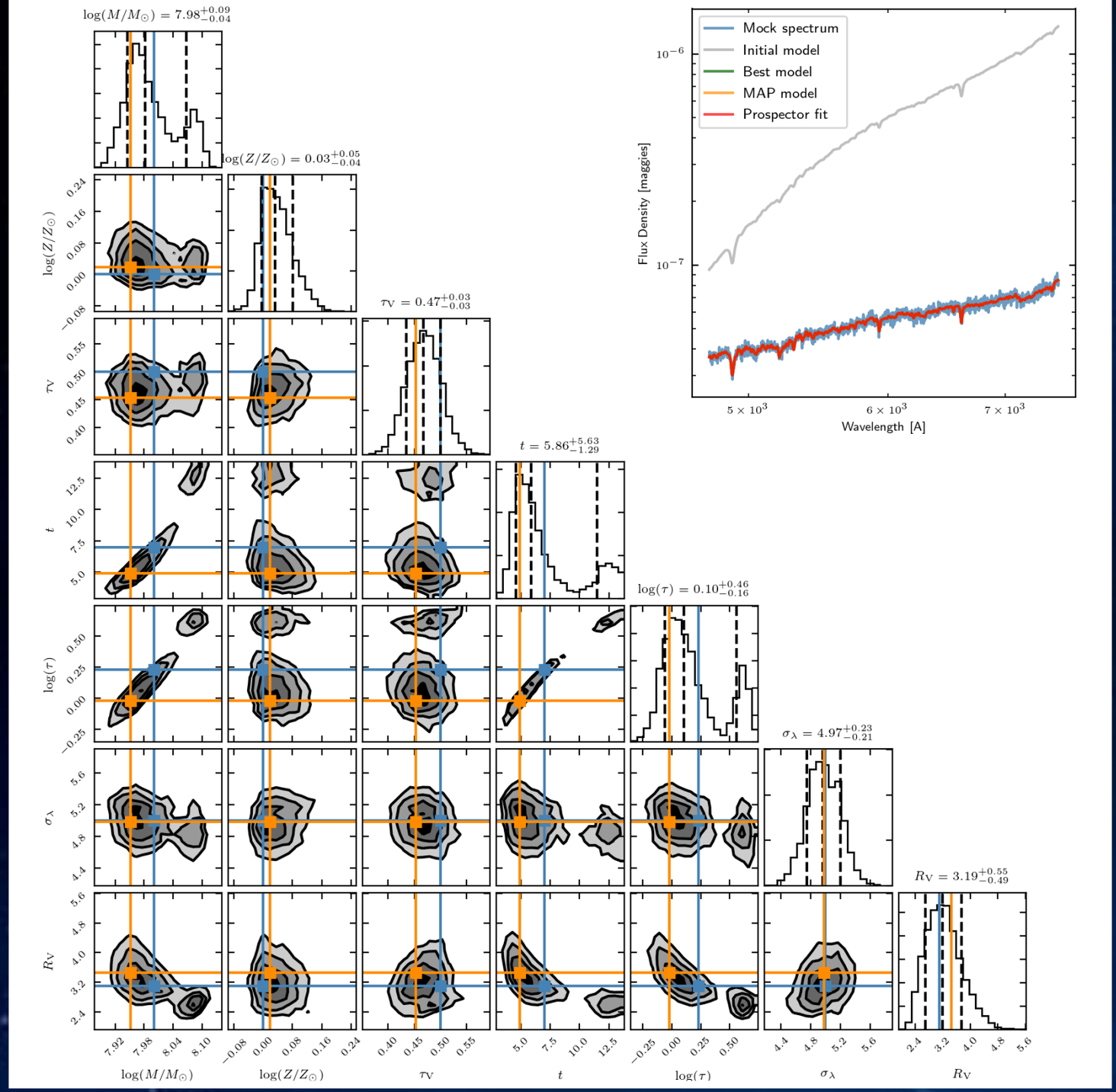
Results (case 4)



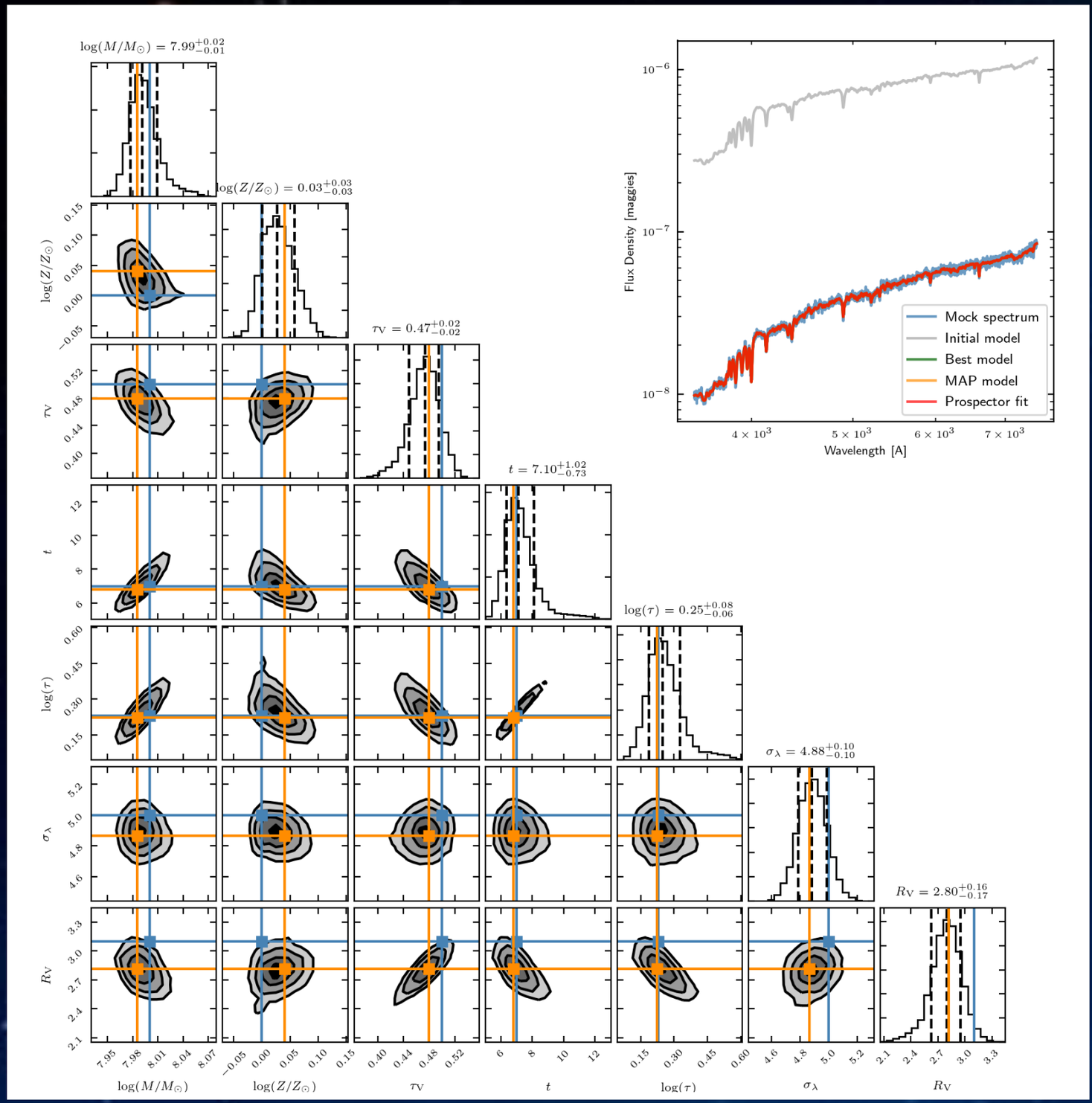
Result (case 2)



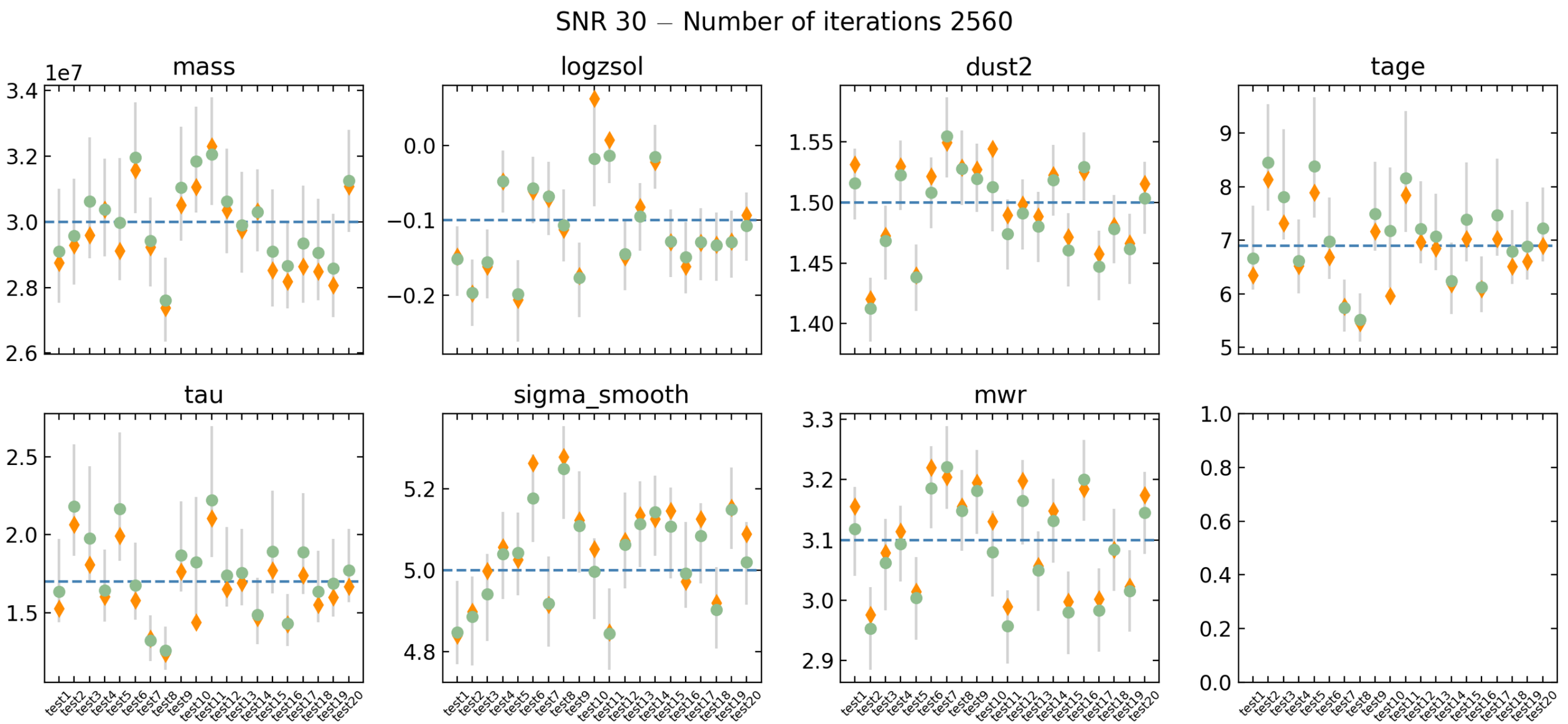
Result (case 3)



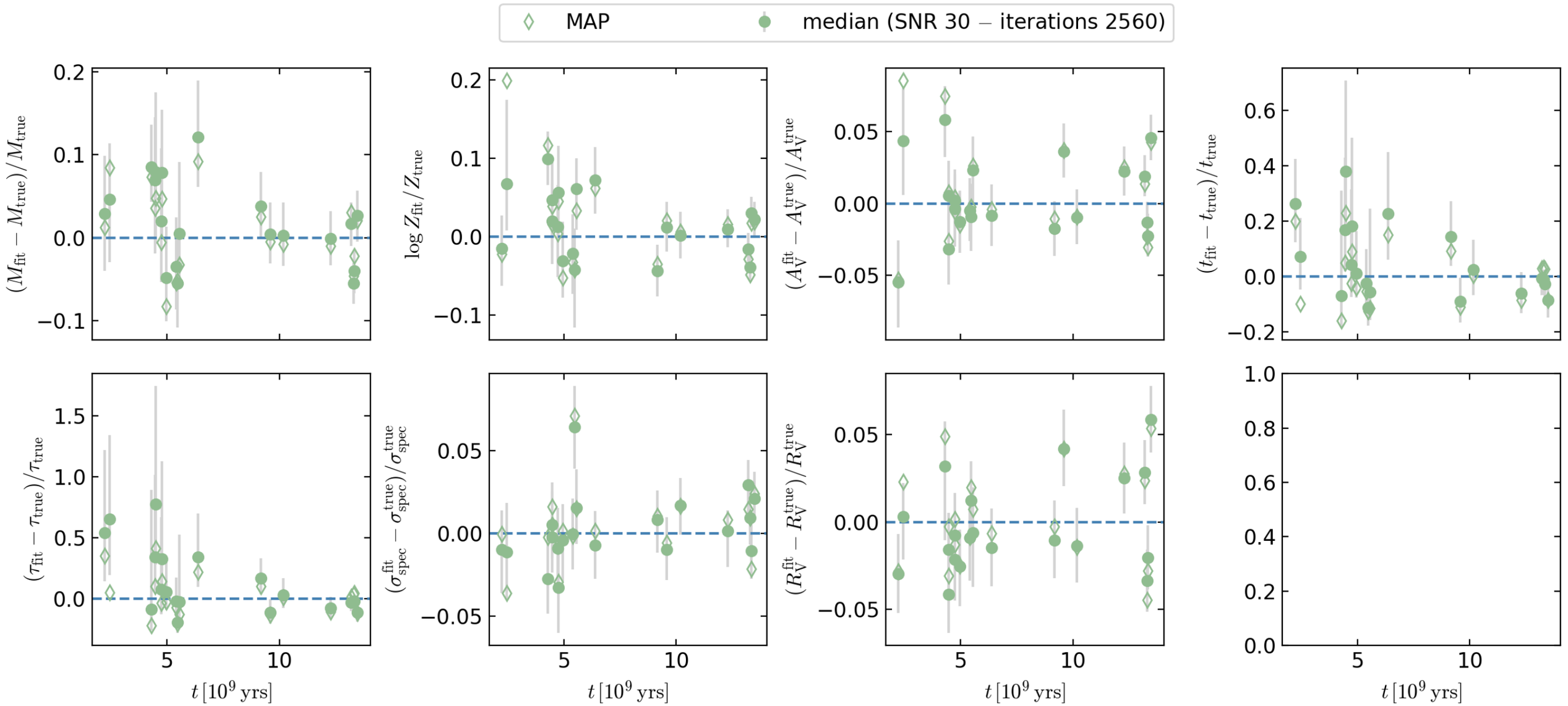
Result (case 4)



Results from larger statistics



Testing biases



Summary

- SED fitting outcome strongly depends on data set and priors

- Other important aspects are the repeatability of the test and checking eventual biases against specific parameters (to be tested with young stellar populations)

- We did not yet test fitting with a different SFH and another model from the simple screen model as the two-component model (coming soon)