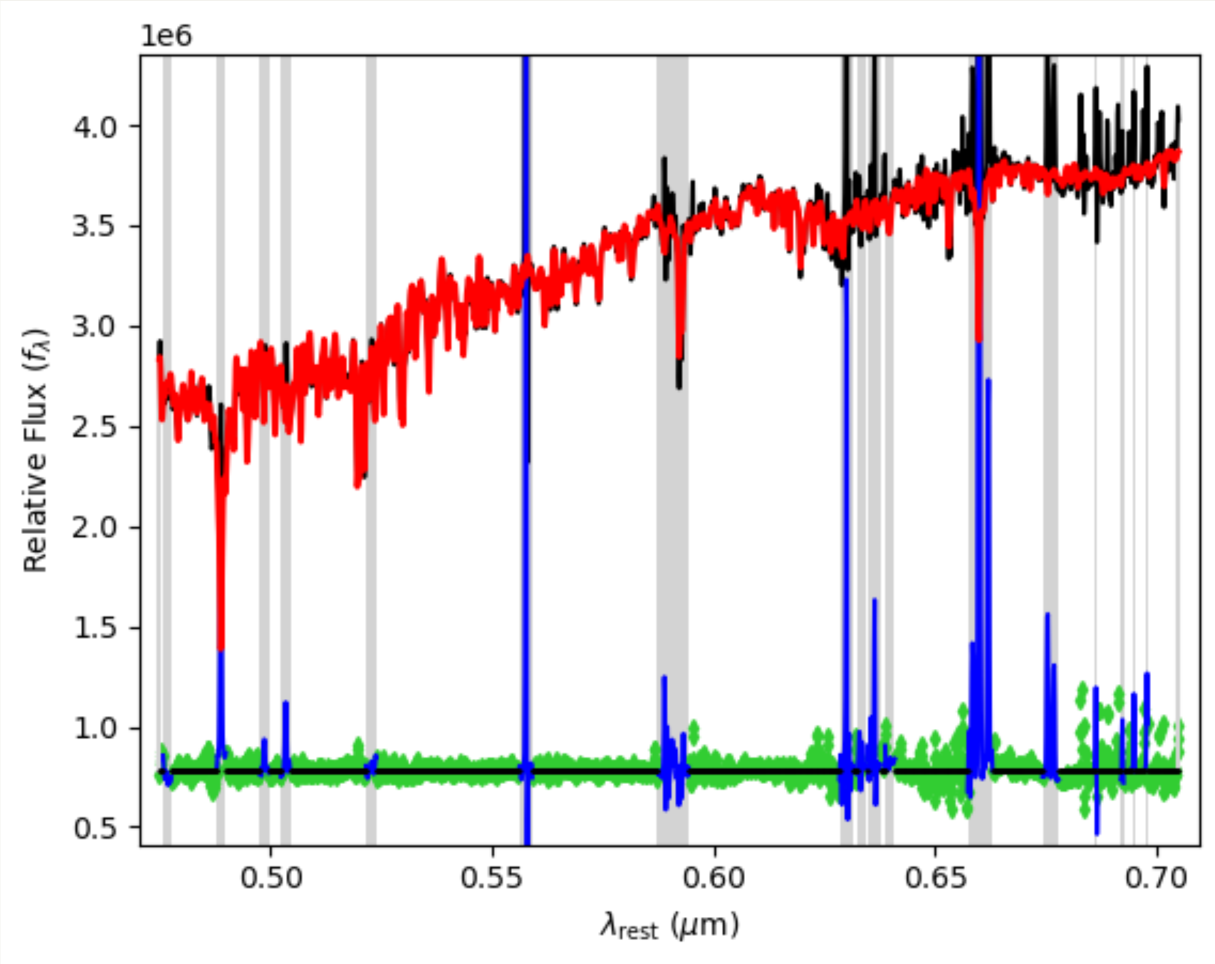
20250514 Mass to Light Ratio

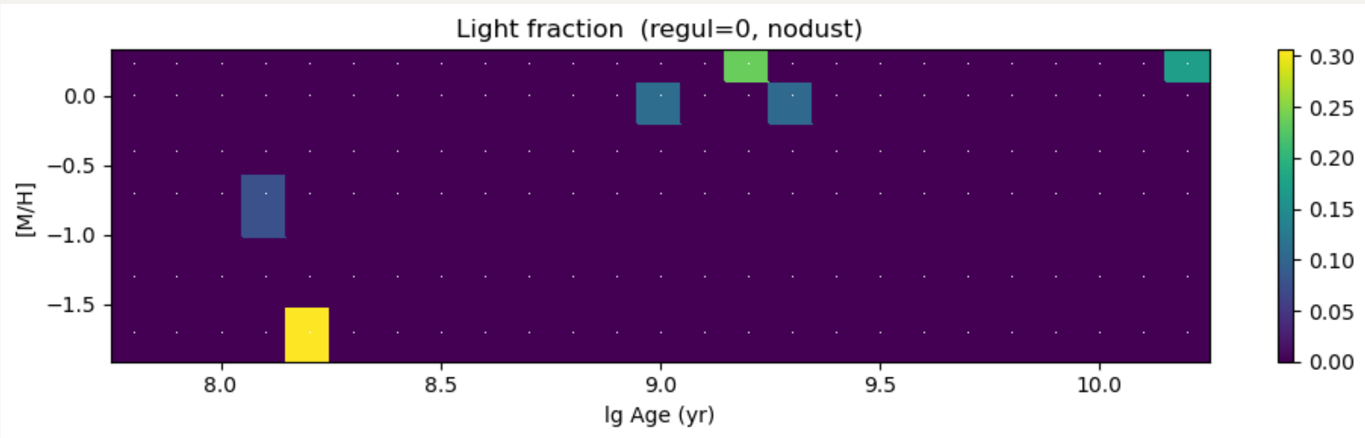
Including Dust Attentuation in `pPXF` fitting

Note that for now, regularization parameter `regul` is turning off. I will discuss it later.

Previously, I end up with r band $M_*/L_* = 2.139 = \log(0.330)$.

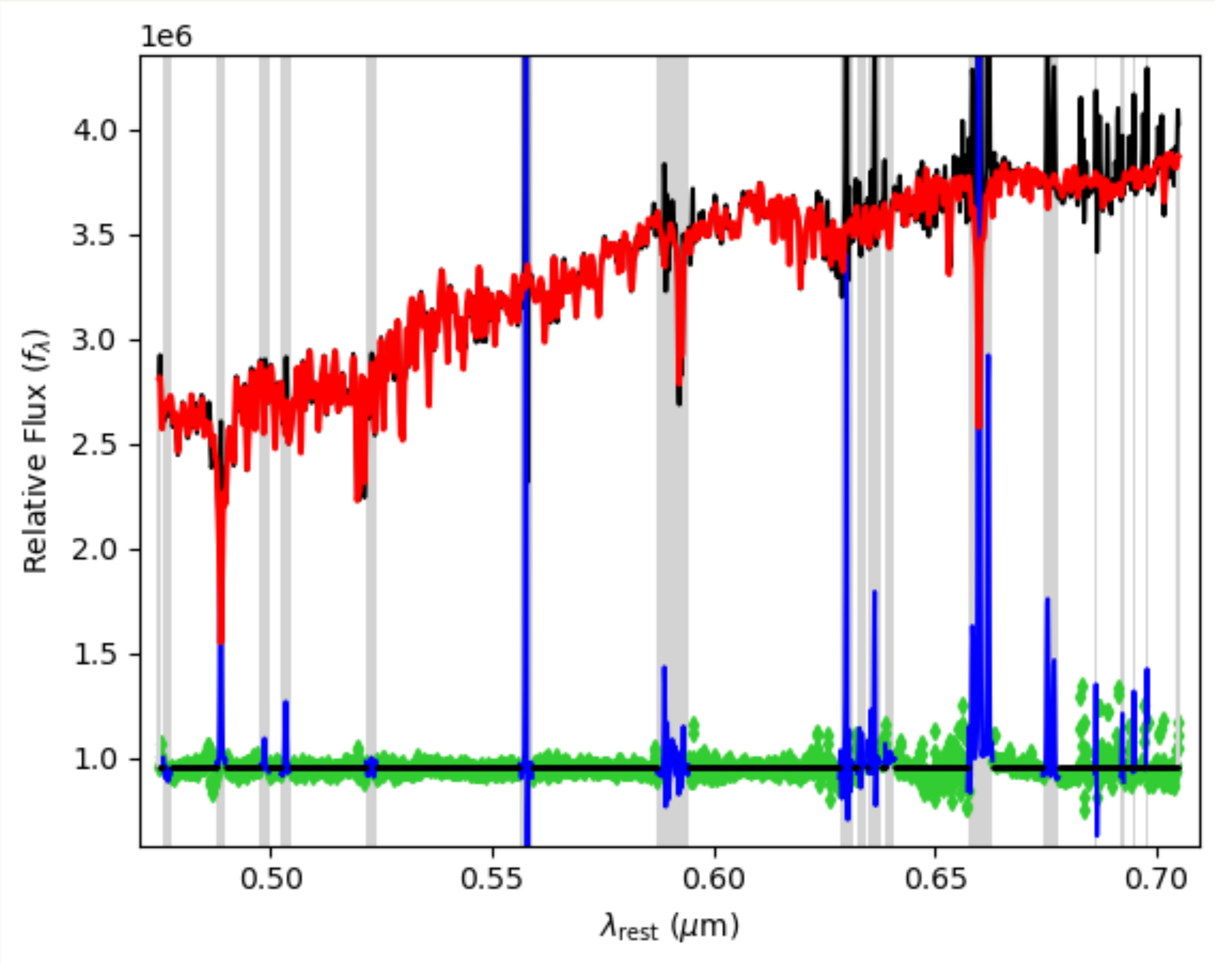
```
 Best Fit:       Vel     sigma
 comp.  0:      1675        59
chi2/DOF: 888.9; DOF: 1833; degree = 12; mdegree = 0
method = capfit; Jac calls: 4; Func calls: 14; Status: 4
linear_method = lsq_box; Nonzero Templates (>0.1%): 6/150
(M*/L)=2.139 (SDSS/r at z=0.0056)
nodust | regul=    0 | χ²/DOF= 888.87 | M/L_r=  2.14 = log(  0.330)
|
```

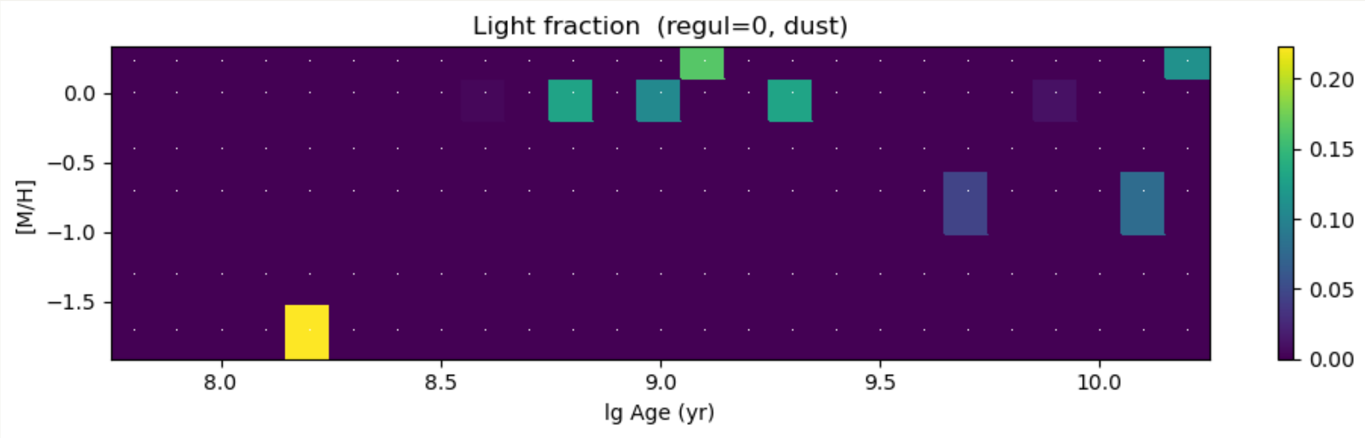




Considering that dust attentuation will largely obscure young stellar population, I turn on the `dust` parameter in `pPXF` fitting to account for this effect. And this gives r band $M_*/L_* = 2.068 = \log(0.316)$.

```
 Best Fit:       Vel     sigma
 comp.  0:      1676        65
Attenuation Parameters 0: 0.935 -1.000
chi2/DOF: 831.2; DOF: 1831; degree = 12; mdegree = 0
method = capfit; Jac calls: 4; Func calls: 22; Status: 4
linear_method = lsq_box; Nonzero Templates (>0.1%): 10/150
(M*/L)=2.068 (SDSS/r at z=0.0056)
dust    | regul=     0 | χ²/DOF= 831.18 | M/L_r=  2.07 = log( 0.316)
|
```





So the dust attenuation parameters here are: $A_V = 0.935$ and $\delta = -1$.

In PPXF, one can adopt a generic function, which can be different for different templates and can have an arbitrary number of parameters. The parameters can have bounds or can be kept fixed. By default, I currently implemented a four-parameters attenuation function in linear units $A(\lambda) = f(A_V, \delta, E_b, f_{\rm nodust})$ defined by

$$D(\lambda) = \frac{E_b\,(\lambda\,\Delta\lambda)^2}{(\lambda^2 - \lambda_0^2)^2 + (\lambda\,\Delta\lambda)^2} \tag{23a}$$

$$k(\lambda) = \frac{A_V}{R_V}\left[k'(\lambda) + D(\lambda)\right]\left(\frac{\lambda}{\lambda_V}\right)^{\delta} \tag{23b}$$

$$A(\lambda) = f_{\rm nodust} + (1 - f_{\rm nodust})\,10^{-0.4\,k(\lambda)}. \tag{23c}$$

Here, equation (23a) is the Lorentzian-like Drude function adopted by Noll et al. (2009) to describe the UV bump around $\lambda_0 = 0.2175\ \mu$m, with width $\Delta\lambda = 0.035\ \mu$m. The equation (23b) is the expression adopted by Kriek & Conroy (2013), which includes the attenuation $k'(\lambda)$ and $R_V = 4.05$ from Calzetti et al. (2000, eqs. 4 and 5) and allows for a variable UV slope δ around the pivot V-band wavelength $\lambda_V = 0.55\ \mu$m. Optionally, one can make E_b a function of δ (Kriek & Conroy 2013, eq. 3)

$$E_b = 0.85 - 1.9 \times \delta. \tag{24}$$

Finally, equation (23c) allows one to specify the fraction $f_{\rm nodust}$ of the stellar population (for the given template) that is unattenuated, as suggested by Lower et al. (2022). The resulting $A(\lambda)$ is the factor to multiply the template at the given wavelength to model the attenuation effect.

So $A_V = 0.935$ looks reasonable for me, but $\delta = -1$ is even steaper than SMC-like galaxies. That means IC3392 is very metal-poor (Shivaei et al. 2020)?

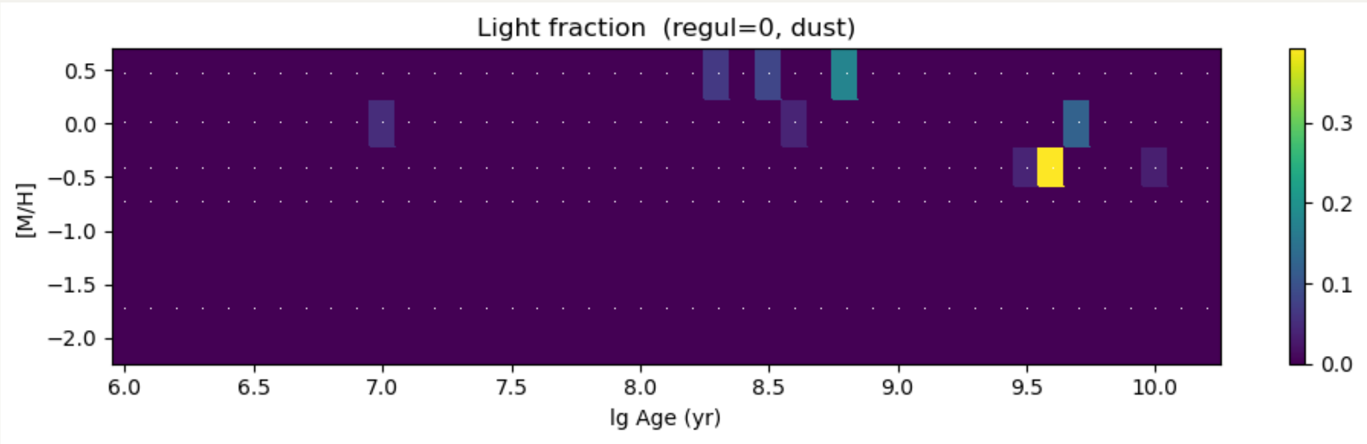
Different M_*/L_*

Recall that using Legacy data and applying Taylor et al. 2011's approach, I get r band $M_*/L_* = 1.35 = \log(0.13)$. Also if take $g - i = 1.008$ and use Zibetti et al. 2009's calibration, it will be r band $M_*/L_* = 1.54 = \log(0.19)$. The former use `BC03` templates while the latter use `CB07` (2007 version of BC03). In contract, in `pPXF` I adopt `E-MILES`, so you can see in general they differs by $0.13 \sim 0.2$ dex.

In Figure E.15 of Pessa et al. 2023, they find stellar mass surface density $\log(\Sigma_*)$ of the star-forming region derived using `E-MILES` is roughly 0.2 dex higher than `CB07`, regardless of adding nebular correction and removing most metal-poor templates. But in general, all templates produce unexpected very metal-poor artefacts ($[Z/H] \lesssim -1.3$) in the star-forming ring.

However, in Lee et al. 2025, they show different resluts by compareing `E-MILES`, `BC03`, `CB19` (2019 version of `CB07`), and `FSPS`. In Figure 1, they show that the M_*/L_* curves are nearly coincident in SDSS r band across different templates; while in $3.6\mu m$, `BC03` and `CB19` lie ≈ 0.25 dex below `E-MILES`/`FSPS` from $\log(8.7 - 10.2)M_\odot$.

I notice that they only compare in the range of $\log(8.7 - 10.2)M_\odot$, but in fact `E-MILES` models lack spectral templates for stellar ages younger than 63 Myr. I think this may `pPXF` tends to estimate the weights (and therefore M_*/L_*) in a higher parameter space of $\log(Age/yr)$. Indeed, if swtich to `GALAXEV` (updated 2016 version of the `BC03` templates), the weight pattern will be lefter than `E-MILES`:



And this gives $M_*/L_* = 1.91 = \log(0.290)$, so it is slightly decrease but still higher than color-color relation. And it seems kind of breaking the age-metallicity degeneracy because of no more young but very metal poor stars.

Switching different templates still not accounts for the gap between them, so I guess the smoking gun is the different approaches I adopted, i.e. colour-color relation tends to underestimate the M_*/L_*. Ge et al. 2021 concluded that we should be careful with using M_*/L_* color relation for those galaxies with young luminosity-weighted stellar ages. My understanding is that color relation will be intrinsically biased by the luminosity and misrepresents older stars with younger populations. Therefore, it should be safer to use `pPXF` if data are eligible.

One more thing, should we customize SPS templates and adopt mass-weighted properties?