

Spectral Components

Nuclear Continuum

$$F_{\lambda, \text{PL}} = F_{\text{PL},0} \left(\frac{\lambda}{\lambda_0} \right)^\alpha \quad (1)$$

where $F_{\text{PL},0}$ is the power-law normalization, α is the power-law slope and λ_0 is the median wavelength of the observed wavelength range.

Code Parameters

- **param1**: power-law slope (α_λ)
- **param2**: power-law normalization ($F_{\text{PL},0}$)

Priors

- α_λ : flat prior in range $[-3,3]$
- $F_{\text{PL},0}$: flat prior between 0 and the maximum of the spectral flux after computing running median

Balmer Continuum

If we assume gas clouds with uniform temperature T_e , that are partially optically thick, for wavelengths bluer than the Balmer edge ($\lambda_{\text{BE}} = 3646 \text{ \AA}$, rest frame), the Balmer spectrum can be parametrized as (Grandi et al., 1982):

$$F_{\lambda, \text{BC}} = F_{\text{BE}} B_\lambda(T_e) \left(1 - e^{-\tau_{\text{BE}} \left(\frac{\lambda}{\lambda_{\text{BE}}} \right)^3} \right), \quad \lambda < \lambda_{\text{BE}} \quad (2)$$

where $B_\lambda(T_e)$ is the Planck function at the electron temperature T_e , τ_{BE} is the optical depth at the Balmer edge, and F_{BE} is the normalized flux density at the Balmer edge. At wavelengths $\lambda > 3646 \text{ \AA}$ high order Balmer lines are merging into a pseudo continuum, yielding a smooth rise to the Balmer edge. Therefore, together with the continuum components, we also model high-order Balmer emission lines (up to $n=50$). *Comment: MV has a long list of Helium and Balmer lines in the optical and UV from $H\alpha$ to the Balmer Jump that goes to high order (#50 in Balmer line series). The list also has relative line ratios and relative amplitude of BaC jump.*

Code Parameters

- **param1**: electron temperature (T_e)
- **param2**: optical depth at the Balmer edge (τ_{BE})
- **param3**: normalized flux density at the Balmer edge (F_{BE})

Priors

- T_e : flat prior in the [5,000-20,000] Kelvin range.
- τ_{BE} : flat prior in the [0.1-2.0] range.
- F_{BE} : flat prior between 0 and the flux measured at $\lambda_{BC,max}$, where $\lambda_{BC,max}$ is the wavelength corresponding to the maximum of the Balmer Continuum in the observed spectral range.

FeII & FeIII

Linear combination of N broadened and scaled iron templates:

$$F_{\lambda,Fe} = \sum_{i=1,..N} F_{Fe,0,i} \text{FeTempl}_{\lambda,i}(\sigma_i) \quad (3)$$

where $\text{FeTempl}_{\lambda,i}$ is the iron template, $F_{Fe,0,i}$ is the template normalization, and σ_i is the width of the broadening kernel.

Code Parameters

- **param1**: iron templates ($\text{FeTempl}_{\lambda,i}$)
 - **UV template**: Vestergaard & Wilkes (2001), (1250-3090) Å
 - **Optical template**: Véron-Cetty et al. (2004), (3535-7530) Å
 - **Gap between UV and Optical template**: Beverly Wills, (3090-3534.4) Å
 - **Optical template**: Kovacevic et al. (2010), (4000-5400) Å – 5 separate templates (4 templates for F,G,S and P groups, 1 template for I ZW1 lines)
- **param2**: broadening kernel (Gaussian, Lorentzian)
- **param3**: width of the broadening kernel (σ_i)
- **param4**: template normalization ($F_{Fe,0,i}$)

Priors

- σ_i : log-normal prior in the [500-20,000] km/s range. The other possibility is to have a Gaussian prior centered on the line width of $H\beta$.
- $F_{Fe,0,i}$: flat prior between 0 and the flux measured at $\lambda_{Fe,i,max}$, where $\lambda_{Fe,i,max}$ is the wavelength corresponding to the maximum of the i-th iron template in the observed spectral range.

Host Galaxy

Linear combination of N smoothed galaxy templates:

$$F_{\lambda, \text{Host}} = \sum_{i=1, \dots, N} F_{\text{Host}, 0, i} \text{HostTempl}_{\lambda, i}(\sigma_*) \quad (4)$$

where $\text{HostTempl}_{\lambda, i}$ is the host galaxy template, σ_* is the stellar dispersion and $F_{\text{Host}, 0, i}$ is the template normalization.

Code Parameters

- **param1:** Host galaxy templates ($\text{HostTempl}_{\lambda, i}$) *The template choice might depend on the observed wavelength range, how do we prefer to implement this? (switch – prior)*
 - **Option 1:** Empirical Templates of Galaxies (e.g. Kinney et al. 1996, ??)
 - **Option 2:** *FUTURE DEVELOPMENT* Evolutionary stellar population synthesis models e.g. [Bruzal & Charlot 2003](#), [PÉGASE](#) (starbursts and evolved galaxies), [Starburst99](#) (star-forming galaxies)
- **param3:** stellar dispersion (σ_*), corresponding to the width of the smoothing kernel (Gaussian?)

Priors

1. $F_{\text{Host}, 0, i}$: flat prior between 0 and the maximum of the spectral flux after computing running median
2. σ_* : flat prior in the [30-600] km/s range.
3. **Age:** *FUTURE DEVELOPMENT, only in case of evolutionary stellar population synthesis models*
4. **Metallicity:** *FUTURE DEVELOPMENT, only in case of evolutionary stellar population synthesis models*

Possible useful codes for inspection:

Code	Paper	Comments
STARLIGHT	Cid Fernandes, R. et al. 2005, MNRAS, 358, 363	One spectrum at a time
GANDALF	Sarzi et al. 2006, MNRAS, 366, 1151	Deals with 2D data

Host Galaxy Reddening

Code Parameters

- **param1:** Possible reddening laws:
 - **Option 1:** Milky Way
 - **Option 2:** Large Magellanic Cloud, LMC

- Option 3: Small Magellanic Cloud, SMC
- Option 4: Fit for R_v ?
- param2: Dust_geometry: foreground screen or mixed media.

Priors

- τ_ν : flat between zero and 1.0 *Discussion: do we need higher τ values?*

Nuclear Reddening

Code Parameters

- param1: Possible reddening laws:
 - Option 1: Small Magellanic Cloud, SMC
 - Option 2: Fit for R_v ?
- param2: Dust_geometry: foreground screen or mixed media.

Priors

- τ_ν : flat between zero and 1.0 *Discussion: do we need higher τ values?*

Emission lines

Functional fitting to broad and narrow emission-line components.

- **Broad Emission Line List, $\lambda_{0,b}$**
 - Ly α λ 1215 (actual $\lambda = 1215.670\text{\AA}$)
 - N V λ 1240 (doublet at $\lambda\lambda$ 1238.808, 1242.796 \AA)
 - “1400 Feature”: Si IV (doublet at $\lambda\lambda$ 1393.755, 1402.770 \AA) plus O IV] blend ($\lambda\lambda$ 1397.210, 1399.780, 1404.790, 1407.390 \AA)
 - N IV] λ 1486 (actual $\lambda = 1486.500\text{\AA}$)
 - C IV λ 1549 (unresolved doublet at $\lambda\lambda$ 1548.188, 1550.762 \AA)
 - He II λ 1640 (actual $\lambda = 1640.720\text{\AA}$)
 - O III] λ 1663 (doublet at $\lambda\lambda$ 1660.800, 1666.140 \AA)
 - C III] λ 1909: actually a blend of Al III $\lambda\lambda$ 1854.720, 1862.780 \AA , Si III] $\lambda = 1892.030\text{\AA}$, and C III] $\lambda = 1908.734\text{\AA}$.
 - Mg II λ 2798 (doublet at $\lambda\lambda$ 2796.350, 2803.530 \AA)
 - H δ $\lambda = 4101.735\text{\AA}$
 - H γ $\lambda = 4340.450\text{\AA}$
 - He II λ 4686 (actual $\lambda = 4685.650\text{\AA}$)
 - H β $\lambda = 4861.320\text{\AA}$
 - He I λ 4922 (actual $\lambda = 4921.9\text{\AA}$)
 - He I $\lambda = 5016\text{\AA}$
 - He I λ 5876 (actual $\lambda = 5875.680\text{\AA}$)

- He I $\lambda 6678$ (actual $\lambda = 6678.000\text{\AA}$)
- He I $\lambda 7065$ (actual $\lambda = 7065.300\text{\AA}$)
- H α $\lambda = 6562.780\text{\AA}$

• **Narrow Emission Line List, $\lambda_{0,n}$**

- [Ne V] $\lambda 3425.900\text{\AA}$
- [O II] $\lambda\lambda 3726.000, 3728.800\text{\AA}$
- [Ne III] $\lambda 3868.800\text{\AA}$
- He II (actual $\lambda = 4685.650\text{\AA}$)
- H β $\lambda = 4861.320\text{\AA}$
- [O III] $\lambda\lambda 4958.920, 5006.850\text{\AA}$
- [N II] $\lambda\lambda 6548.060, 6583.39\text{\AA}$
- H α $\lambda = 6562.780\text{\AA}$
- [Si II] $\lambda\lambda 6716.420, 6730.780\text{\AA}$

Fitting Function Possibilities

- Narrow Lines
 - Single Gaussian with Prior (1)
 - Double Gaussian with Prior (1)
 - Option (automatically test) for additional (broader) Gaussian to [O III] $\lambda\lambda 4959, 5007$ base.
- Broad Lines
 - Multiple Gaussians
 - Multiple Gauss-Hermite polynomials
 - Gaussian (very broad) plus Gauss-Hermite (broad)
 - Multiple Lorentzians
 - Mix of Gaussian and Lorentzian(s) (i.e., Voigt profile)
 - Powerlaw profiles + 1-2 Gaussians

Functional Forms

- Gaussian:

$$F_\lambda = \frac{f_{\text{peak}}}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\lambda-\mu}{\sigma}\right)^2}, \quad (5)$$

where the Gaussian FWHM = $2\sqrt{2\ln 2}\sigma$ and $\mu = \lambda_0$ (broad, narrow).

- 6th Order Gauss-Hermite Polynomial:

$$F_\lambda = [f_{\text{peak}}\alpha(w)/\sigma] \left(1 + \sum_{j=3}^6 h_j H_j(w) \right), \quad (6)$$

$$w \equiv (\lambda - \mu)/\sigma, \quad (7)$$

$$\alpha(w) = \frac{1}{2\sqrt{\pi}} e^{-\frac{1}{2}w^2}. \quad (8)$$

where this follows the normalization of van der Marel & Franx (1993, ApJ, 407, 525; first equation). The H_j coefficients can be found in Cappellari et al. (2002, ApJ, 578, 787):

$$H_3(w) = \frac{w(2w^2 - 3)}{\sqrt{3}}, \quad (9)$$

$$H_4(w) = \frac{w^2(4w^2 - 12) + 3}{2\sqrt{6}}, \quad (10)$$

$$H_5(w) = \frac{w[w^2(4w^2 - 20) + 15]}{2\sqrt{15}}, \quad (11)$$

$$H_6(w) = \frac{w^2[w^2(8w^2 - 60) + 90] - 15}{12\sqrt{5}}. \quad (12)$$

- Lorentzian

$$F_\lambda = \frac{f_{\text{peak}}}{\pi} \frac{\frac{1}{2}\sigma}{(\lambda - \mu)^2 + (\frac{1}{2}\sigma)^2}, \quad (13)$$

where $\mu = \lambda_0(\text{b,n})$ and the Lorentzian FWHM = $\sigma = 2f_{\text{peak}}/(\pi F(\mu))$.

- Powerlaw profile:

Code Parameters

- \forall Gaussian component:
 - param1 central wavelength (μ)
 - param2 width (σ)
 - param3 amplitude (f_{peak})
- \forall 6th Order Gauss-Hermite Polynomial:
 - param1 central wavelength (μ)
 - param2 width of the Gaussian component(σ)
 - param3 amplitude of the Gauss-Hermite series (f_{peak})
 - param4-7 Gauss-Hermite moments h_3, h_4, h_5, h_6
- \forall Lorentzian component:
 - param1 central wavelength (μ)
 - param2 width (σ)
 - param3 amplitude (f_{peak})
- \forall Power-law profile:
 - param1

Priors

1. Limit all component positions (i.e., velocity offset from laboratory wavelengths) to within a given velocity range to prevent the components to wander.
2. For multiple Gaussian components, the amplitudes can be tied relative to one another (i.e. to the amplitude of the first component).
3. Width and velocity shifts of each of the Gaussian components of narrow forbidden lines tied together and $\text{FWHM} < 1200 \text{ km s}^{-1}$
4. Ranges of widths and velocity shifts to be included. I.e., profile limits to be specified - either one for each emission line, or for each type of line (broad, narrow, weak, strong, etc.) *Comment: MV has a separate long list - don't want to list here in case it needs to be coded differently.*
5. Narrow emission line redshift solution, i.e., $\mu = \lambda_{0,n}(1+z) \pm \Delta\mu$ is constant.
6. Narrow line doublet ratios fixed:
 - [O II] $\lambda\lambda 3726.000, 3728.800\text{\AA}$; ??? (This is density dependent)
 - [O III] $\lambda\lambda 4958.920, 5006.850\text{\AA}$; 1:3
 - [Si II] $\lambda\lambda 6716.420, 6730.780\text{\AA}$; ???
 - [N II] $\lambda\lambda 6548.060, 6583.39\text{\AA}$; ???
7. Fluxes must be non-negative (BLR and NLR emission)
8. Tie together the widths and velocity shifts of broad line components of identical species, e.g., He II $\lambda 1640$ and He II $\lambda 4686$? (*To be tested*).
9. assumptions about CIV redshelf?? Additional HeII component? He II, Fe II, Al III, O II].
10. Suggested Parameter Space to search (*to be discussed*)
 - $f_{\text{peak}}/f_{\text{cont}} = [0, 1.\text{d}4, 1.\text{d}-3]$
 - $\mu = \lambda_{0,n}(1+z) \pm 1000 \text{ km s}^{-1}; \Delta\mu \sim f(\text{pixscale})$
 - $\sigma = [100, 3.\text{d}4]; \Delta\sigma \sim f(\text{pixscale})$
 - $h_j = [-0.3, 0.3, 1.\text{d}-3]$