

## 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,  $\alpha$  is the power-law slope and  $\lambda_0$  is the median wavelength of the observed wavelength range.

### Code Parameters

- `param1`: power-law slope ( $\alpha_\lambda$ )
- `param2`: power-law normalization ( $F_{\text{PL},0}$ )

### Priors

- $\alpha_\lambda$ : 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  $T_e$ ,  $\tau_{\text{BE}}$  is the optical depth at the Balmer edge, and  $F_{\text{BE}}$  is the normalized flux density at the Balmer edge.

### Code Parameters

- `param1`: electron temperature ( $T_e$ )
- `param2`: optical depth at the Balmer edge ( $\tau_{\text{BE}}$ )
- `param3`: normalized flux density at the Balmer edge ( $F_{\text{BE}}$ )

## Priors

- $T_e$ : flat prior in the [5,000-20,000] Kelvin range.
- $\tau_{BE}$ : 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.

## High order Balmer lines

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  $n=50$ ). Each high order emission line is modeled with a single Gaussian (*Discussion: is it enough? Should we go for a Lorentzian profile?*):

$$F_\lambda = \frac{f_{\text{peak}}}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\lambda-\mu}{\sigma}\right)^2}, \quad (3)$$

## Code Parameters

$\forall$  Gaussian component:

- param1 central wavelength ( $\mu$ )
- param2 width ( $\sigma$ )
- param3 amplitude ( $f_{\text{peak}}$ )

## Priors

- Global priors for emission lines
- Fixed emission line ratios: either from Marianne's list (*under which assumptions are they computed?*), or they can be computed using prescription by Storey & Hummer (1995), case B ( $n_e = 10^8 - 10^9 \text{ cm}^{-3}$ )

## FeII & FeIII

Linear combination of N broadened and scaled iron templates:

$$F_{\lambda,Fe} = \sum_{i=1,..N} F_{Fe,0,i} \text{FeTempl}_{\lambda,i}(\sigma_i) \quad (4)$$

where  $\text{FeTempl}_{\lambda,i}$  is the iron template,  $F_{Fe,0,i}$  is the template normalization, and  $\sigma_i$  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 ( $\sigma_i$ )
- **param4:** template normalization ( $F_{\text{Fe},0,i}$ )

## Priors

- $\sigma_i$ : 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  $\text{H}\beta$ .
- $F_{\text{Fe},0,i}$ : flat prior between 0 and the flux measured at  $\lambda_{\text{Fe},i,\text{max}}$ , where  $\lambda_{\text{Fe},i,\text{max}}$  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:

$$F_{\lambda,\text{Host}} = \sum_{i=1,\dots,N} F_{\text{Host},0,i} \text{HostTempl}_{\lambda,i}(\sigma_*) \quad (5)$$

where  $\text{HostTempl}_{\lambda,i}$  is the host galaxy template,  $\sigma_*$  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 ( $\sigma_*$ ), 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.  $\sigma_*$ : 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

- $\tau_\nu$ : flat between zero and 1.0 *Discussion: do we need higher  $\tau$  values?*

## Nuclear Reddening

### Code Parameters

- param1: Possible reddening laws:
  - Option 1: Small Magellanic Cloud, SMC
  - Option 2: Fit for  $R_v$ ?
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### Priors

- $\tau_\nu$ : flat between zero and 1.0 *Discussion: do we need higher  $\tau$  values?*

## Emission lines

Functional fitting to broad and narrow emission-line components.

- **Broad Emission Line List,  $\lambda_{0,b}$**

- Ly $\alpha$   $\lambda$ 1215 (actual  $\lambda = 1215.670\text{\AA}$ )
- N v  $\lambda$ 1240 (doublet at  $\lambda\lambda$ 1238.808, 1242.796 $\text{\AA}$ )
- “1400 Feature”: Si iv (doublet at  $\lambda\lambda$ 1393.755, 1402.770 $\text{\AA}$ ) plus O iv] blend ( $\lambda\lambda$ 1397.210, 1399.780, 1404.790, 1407.390 $\text{\AA}$ )
- N iv]  $\lambda$ 1486 (actual  $\lambda = 1486.500\text{\AA}$ )
- C iv  $\lambda$ 1549 (unresolved doublet at  $\lambda\lambda$ 1548.188, 1550.762 $\text{\AA}$ )
- He ii  $\lambda$ 1640 (actual  $\lambda = 1640.720\text{\AA}$ )
- O iii]  $\lambda$ 1663 (doublet at  $\lambda\lambda$ 1660.800, 1666.140 $\text{\AA}$ )
- C iii]  $\lambda$ 1909: actually a blend of Al iii  $\lambda\lambda$ 1854.720, 1862.780 $\text{\AA}$ , Si iii]  $\lambda = 1892.030\text{\AA}$ , and C iii]  $\lambda = 1908.734\text{\AA}$ .
- Mg ii  $\lambda$ 2798 (doublet at  $\lambda\lambda$ 2796.350, 2803.530 $\text{\AA}$ )
- H $\delta$   $\lambda = 4101.735\text{\AA}$
- H $\gamma$   $\lambda = 4340.450\text{\AA}$
- He ii  $\lambda$ 4686 (actual  $\lambda = 4685.650\text{\AA}$ )
- H $\beta$   $\lambda = 4861.320\text{\AA}$
- He i  $\lambda$ 4922 (actual  $\lambda = 4921.9\text{\AA}$ )
- He i  $\lambda = 5016\text{\AA}$
- He i  $\lambda$ 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 $\alpha$   $\lambda = 6562.780\text{\AA}$

- **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 $\beta$   $\lambda = 4861.320\text{\AA}$
- [O iii]  $\lambda\lambda$ 4958.920, 5006.850 $\text{\AA}$
- [N ii]  $\lambda\lambda$ 6548.060, 6583.39 $\text{\AA}$
- H $\alpha$   $\lambda = 6562.780\text{\AA}$
- [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:

$$F_\lambda = \frac{f_{\text{peak}}}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\lambda-\mu}{\sigma}\right)^2}, \quad (6)$$

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

- 6th Order Gauss-Hermite Polynomial:

$$F_\lambda = [f_{\text{peak}}\alpha(w)/\sigma] \left( 1 + \sum_{j=3}^6 h_j H_j(w) \right), \quad (7)$$

$$w \equiv (\lambda - \mu)/\sigma, \quad (8)$$

$$\alpha(w) = \frac{1}{2\sqrt{\pi}} e^{-\frac{1}{2}w^2}. \quad (9)$$

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):

$$H_3(w) = \frac{w(2w^2 - 3)}{\sqrt{3}}, \quad (10)$$

$$H_4(w) = \frac{w^2(4w^2 - 12) + 3}{2\sqrt{6}}, \quad (11)$$

$$H_5(w) = \frac{w[w^2(4w^2 - 20) + 15]}{2\sqrt{15}}, \quad (12)$$

$$H_6(w) = \frac{w^2[w^2(8w^2 - 60) + 90] - 15}{12\sqrt{5}}. \quad (13)$$

- Lorentzian

$$F_\lambda = \frac{f_{\text{peak}}}{\pi} \frac{\frac{1}{2}\sigma}{(\lambda - \mu)^2 + (\frac{1}{2}\sigma)^2}, \quad (14)$$

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 ( $\mu$ )
  - `param2` width ( $\sigma$ )
  - `param3` amplitude ( $f_{\text{peak}}$ )
- $\forall$  6th Order Gauss-Hermite Polynomial:
  - `param1` central wavelength ( $\mu$ )
  - `param2` width of the Gaussian component( $\sigma$ )
  - `param3` amplitude of the Gauss-Hermite series ( $f_{\text{peak}}$ )
  - `param4-7` Gauss-Hermite moments  $h_3, h_4, h_5, h_6$
- $\forall$  Lorentzian component:
  - `param1` central wavelength ( $\mu$ )
  - `param2` width ( $\sigma$ )
  - `param3` amplitude ( $f_{\text{peak}}$ )
- $\forall$  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 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*)
    - $f_{\text{peak}}/f_{\text{cont}} = [0, 1.\text{d}4, 1.\text{d}-3]$
    - $\mu = \lambda_{0,n}(1 + z) \pm 1000 \text{ km s}^{-1}; \Delta\mu \sim f(\text{pixscale})$
    - $\sigma = [100, 3.\text{d}4]; \Delta\sigma \sim f(\text{pixscale})$
    - $h_j = [-0.3, 0.3, 1.\text{d}-3]$