

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.

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.

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?*):

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

Code Parameters

\forall Gaussian component:

- param1 central wavelength (μ)
- param2 width (σ)
- param3 amplitude (f_{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 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 ($F_{\text{Fe},0,i}$)

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 $\text{H}\beta$.
- $F_{\text{Fe},0,i}$: 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, 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. Each set of “broad” and “narrow” lines will be treated as two separate components in the code because of the relatively different sets of priors associated with each type of line. In addition, there are some priors that are ‘global’ to the type of emission lines, as a class, and some that will be ‘local’ to specific emission lines. Regardless of the priors, the following functional forms will be options for fitting to both narrow and broad emission lines.

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 (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

Narrow Emission lines

Global Priors: for all $i=1, N$ narrow lines

- z : flat prior between 0 and 8 with $z=\text{constant}$ for all i (This is the most general prior; likely, some knowledge of the redshift will be known, so in that case, this should be a Gaussian prior with much narrower width, centered on estimated redshift)
- $\mu/(1+z)$: flat prior between -1200 and 1200 km s⁻¹ with $\mu_i = \text{constant}$ for all i
- σ_i : flat prior between 0 and 1200 km s⁻¹ with $\sigma_i = \text{constant}$ for all i (this is to fit narrow components that are co-spatial/kinematic with the “typical” low density NLR traced by the integrated forbidden line flux; any “intermediate” components will be fit with the broad emission lines. It’s also OK to go down to zero width; if the line is not found)
- $F_\lambda > 0$
- $F_{\text{peak}}/F_{\text{cont}}$: flat prior with range of 0 to 10,000 (i.e, it’s OK for the line not to be found)
- h_j : flat prior between -0.3 and 0.3 (KD: this is just what I used in my code for my Gauss-Hermite polynomial fits and it seemed to work OK).

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

- [Ne V] $\lambda 3425.900\text{\AA}$
- [O II] $\lambda\lambda 3726.000, 3728.800\text{\AA}$
 - **Local Prior:** doublet ratio 1:1 (actually density dependent, but the doublet is too closely spaced to constrain in AGNs; Osterbrock); flat prior in range $1 : 1 \pm 0.3$
- [Ne III] $\lambda 3868.800\text{\AA}$
- He II (actual $\lambda = 4685.650\text{\AA}$)
- H β $\lambda = 4861.320\text{\AA}$
 - **Local Prior:** ratio of narrow H β :[O III] $\lambda 5007$; flat prior in range TBD by BPT diagram results (my experience 0-0.4:1)
- [O III] $\lambda\lambda 4958.920, 5006.850\text{\AA}$
 - **Local Prior:** doublet ratio 1:3 (Osterbrock); flat prior in range $1 : 3 \pm 0.5$
- [O III] $\lambda 5007$ blue component
 - **Local Prior:** set very loose priors on existence, location and strength; if the overall region fits better between 4959 and 5007 with the addition of a blue component, go with it; I’m not sure what’s relevant here for coding... Complicated further because must keep total [O III] $\lambda 5007$ flux ratio with 4959.
- [N II] $\lambda\lambda 6548.060, 6583.39\text{\AA}$

- **Local Prior:** doublet ratio 1:3 (Osterbrock); flat prior in range $1 : 3 \pm 0.5$
- $\text{H}\alpha$ $\lambda = 6562.780\text{\AA}$
 - **Local Prior:** ratio of narrow $\text{H}\alpha$:[N II]; flat prior in range TBD by BPT diagram results.
- [Si II] $\lambda\lambda 6716.420, 6730.780\text{\AA}$
 - **Local Prior:** doublet ratio 1.1:1 (Osterbrock); flat prior in range $1.1 \pm 0.3 : 1$

***Any other specific requirements related to widths or velocity offsets of individual lines should be listed as local priors.*

Additional “Conditions” (not really priors, so I’m not sure how they should be coded)

- As listed above; the potential presence of a blue component to [O III] $\lambda\lambda 4958.920, 5006.850\text{\AA}$.

Broad Emission lines

Global Priors: for all $i=1, N$ Broad lines

- z : solution determined from NELs applied; but broad line centers can be allowed to shift relative to this solution.
- $\mu/(1+z)$: flat prior between -6000 and 4000 km s^{-1} , independent for each broad line component.
- σ_i : flat prior between 0 and 12000 km s^{-1} ; multiple components will account for all “very broad”, broad, and “intermediate” components. It’s also OK to go down to zero width (if the line is not found).
- $F_\lambda > 0$
- $F_{\text{peak}}/F_{\text{cont}}$: flat prior with range of 0 to 10,000 (i.e, it’s OK for the line not to be found)
- h_j : flat prior between -0.3 and 0.3 (KD: this is just what I used in my code for my Gauss-Hermite polynomial fits and it seemed to work OK).

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

- Ly α $\lambda 1215$ (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 $\lambda = 1640.720\text{\AA}$)
- He II $\lambda 1640$ blue component
 - **Local Prior:** set very loose priors on existence, location and strength; if the overall region fits better between He II $\lambda 1640$ and C IV with the addition of a blue component, go with it; I’m not sure what’s relevant here for coding... I can maybe try to come up with some better priors from looking at data I have, but probably best to just leave it loose and see how it does.
- 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 δ $\lambda = 4101.735\text{\AA}$
- H γ $\lambda = 4340.450\text{\AA}$
- He II $\lambda 4686$ (actual $\lambda = 4685.650\text{\AA}$)
- He II $\lambda 4686$ blue component
 - **Local Prior:** set very loose priors on existence, location and strength; if the overall region fits better between He II $\lambda 4686$ and potential presence of Fe II and host with the addition of a blue component, go with it; I’m not sure what’s relevant here for coding... I can maybe try to come up with some better priors from looking at data I have, but probably best to just leave it loose and see how it does.
- H β $\lambda = 4861.320\text{\AA}$
- 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 α $\lambda = 6562.780\text{\AA}$

***Any other specific requirements related to widths or velocity offsets of individual lines should be listed as local priors.*

Additional “Conditions” (not really priors, so I’m not sure how they should be coded)

- He I $\lambda 4922$ and He I $\lambda = 5016\text{\AA}$ are highly blended with H β , [O III], and possibly Fe II, and thereby hard to independently constrain. The condition is therefore that “if” He I $\lambda 5876$ is present in the spectrum, $\sigma_{4922} = \sigma_{5016} = \sigma_{5876}$.
- As listed above; the potential presence of a blue component to He II $\lambda 1640$ and He II $\lambda 4686$. We see this region in reverberation campaigns when no other Fe II is present, so we have evidence to suggest it’s there; it’s just highly blended and somewhat low EW in single spectra.