SPAMM – Spectral Properties of AGN Modeled through MCMC

Spectral Components

Nuclear Continuum

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

where $F_{\mathrm{PL},0}$ 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 ($F_{\mathrm{PL},0}$)

Priors

- α_λ: flat prior in range [-3,3]
- $F_{\mathrm{PL},0}$: 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 $\mathrm{T_e}$, that are partially optically thick, for wavelengths bluer than the Balmer edge ($\lambda_{\mathrm{BE}} = 3646$ Å, rest frame), the Balmer spectrum can be parametrized as (Grandi et al., 1982):

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

where $\mathrm{B}_\lambda(\mathrm{T_e})$ is the Planck function at the electron temperature $\mathrm{T_e}$, τ_{BE} is the optical depth at the Balmer edge, and $\mathrm{F_{BE}}$ is the normalized flux density at the Balmer edge.

Code Parameters

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

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 λ >3646 Å 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?)*:

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

Code Parameters

$\forall$ Gaussian component:

- `param1` central wavelength (μ)
- `param2` width (σ)
- `param3` amplitude ($f_{\rm peak}$)

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 ($n_e = 10^8 - 10^9\ cm^{-3}$)

FeII & FeIII

Linear combination of N broadened and scaled iron templates:

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

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

Code Parameters

- `param1`: iron templates ($\mathrm{FeTempl}_{\lambda,\mathrm{i}}$)
  - `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 ($F_{\mathrm{Fe,0,i}}$)

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 Hβ.
- $F_{\mathrm{Fe,0,i}}$: flat prior between 0 and the flux measured at $\lambda_{\mathrm{Fe,i,max}}$, where $\lambda_{\mathrm{Fe,i,max}}$ 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:

$$F_{\lambda,\mathrm{Host}} = \sum_{\mathrm{i}=1,..\mathrm{N}} F_{\mathrm{Host,0,i}} \; \mathrm{HostTempl}_{\lambda,\mathrm{i}}(\sigma_*) \tag{5}$$

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

The stellar dispersion is currently applied according to the following method. For a given template, increasing the velocity dispersion implies convolving it with a broadening function. For simplicity, we assume that this function is a Gaussian of width $\sigma_{*,\mathrm{use}} = (\sigma_*^2 - \sigma_{*,\mathrm{int}}^2)^{1/2}$. For the moment we will assume that $\sigma_{*,\mathrm{int}} = 0$, as we do not know the intrinsic values for the current templates. Now, since we need to apply it in wavelength space we can note that $P(v)\; dv = P(\lambda)\; d\lambda$ and that

$$P(v;\sigma_*) \;=\; \frac{1}{\sqrt{2\pi}\sigma_*} \;\exp\frac{-1}{2}\left(\frac{v}{\sigma_*}\right)^2, \tag{6}$$

which implies that our convolution function in wavelength space will be

$$P(\lambda;\sigma_\lambda,\lambda_0) \;=\; \frac{1}{\sqrt{2\pi}\sigma_\lambda} \;\exp\frac{-1}{2}\left(\frac{\lambda-\lambda_0}{\sigma_\lambda}\right)^2, \tag{7}$$

where $\sigma_\lambda = \sigma_* \lambda_0 / c$. So, the broadened template can be written as

$$\mathrm{HostTempl}_{\lambda_0,\mathrm{i}}(\sigma_\lambda) \;=\; \int \mathrm{HostTempl}_{\lambda,\mathrm{i}}(\sigma_\lambda = 0)\ \mathrm{P}(\lambda; \lambda_0, \sigma_\lambda)\mathrm{d}\lambda. \tag{8}$$

Now, since our template is discrete, we can write this equation as

$$\mathrm{HostTempl}_{\lambda_0,\mathrm{i}}(\sigma_\lambda) = \sum_\lambda \mathrm{HostTempl}_{\lambda,\mathrm{i}}(\sigma_\lambda = 0) \int_{\lambda_{\mathrm{Min}}}^{\lambda_{\mathrm{Max}}} \mathrm{P}(\lambda; \lambda_0, \sigma_\lambda)\mathrm{d}\lambda, \tag{9}$$

where λ_{Min} and λ_{Max} are the minimum and maximum wavelength of the bin. This can also be written as

$$\mathrm{HostTe\vec{m}pl}_{\mathrm{i}}(\sigma_\lambda) = \mathbf{K}\ \cdot\ \mathrm{HostTe\vec{m}pl}_{\mathrm{i}}(\sigma_\lambda = 0), \tag{10}$$

where the matrix $\mathbf{K}$ is independent of the template and holds all the terms of the convolution. For the moment the convolution kernel is assumed to be a Gaussian, and the matrix $\mathbf{K}$ only considers terms within 5σ of λ_0 to speed up the calculations.

Code Parameters

- `param1`: Host galaxy templates ($\mathrm{HostTempl}_{\lambda,\mathrm{i}}$) *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. $F_{\mathrm{Host},0,\mathrm{i}}$: 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

Simple parameterization of reddening law between 0.12 – 2.2 μm (Calzetti et al. 2000):

$$F_o(\lambda) = F_i(\lambda)10^{-0.4A'(\lambda)} = F_i(\lambda)10^{-0.4E_s(B-V)k'(\lambda)}, \tag{11}$$

$$E_s(B-V) = (0.44 \pm 0.03)E_g(B-V), \tag{12}$$

$$k' = \begin{cases} 2.659(-1.857 + 1.040/\lambda) + 4.05 & : \; 0.63\mu m \leq \lambda \leq 2.2\mu m \\ 2.659(-2.156 + 1.509/\lambda - 0.198/\lambda^2 + 0.011/\lambda^3) + 4.05 & : \; 0.12\mu m \leq \lambda \leq 0.63\mu m, \end{cases}$$

$F_o(\lambda)$ and $F_i(\lambda)$ are the dust-obscured and intrinsic continuum flux densities, respectivly; $A'(\lambda)$ is the dust obscuration, $E_s(B-V)$ and $E_g(B-V)$ are the color excess of the stellar continuum and of the nebular emission lines.

$$\beta = 1.9E_g(B-V) + \beta_o. \tag{13}$$

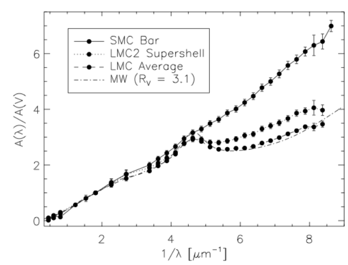

FIG. 10.—Sample average extinction curves plotted along with the "average" Milky Way curve (CCM with $R_V = 3.1$).

Figure 1: Gordon 2003 Plot

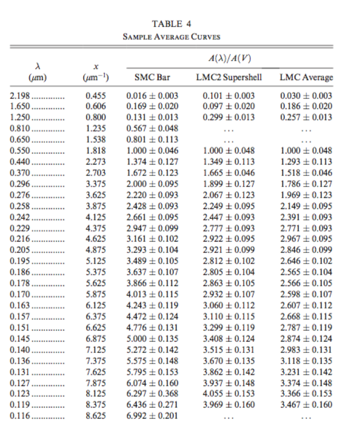

TABLE 4
SAMPLE AVERAGE CURVES

λ (μm)	x (μm^{-1})	$A(\lambda)/A(V)$ SMC Bar	LMC2 Supershell	LMC Average
2.198	0.455	0.016 ± 0.003	0.101 ± 0.003	0.030 ± 0.003
1.650	0.606	0.169 ± 0.020	0.097 ± 0.020	0.186 ± 0.020
1.250	0.800	0.131 ± 0.013	0.299 ± 0.013	0.257 ± 0.013
0.810	1.235	0.567 ± 0.048	...	...
0.650	1.538	0.801 ± 0.113	...	...
0.550	1.818	1.000 ± 0.046	1.000 ± 0.048	1.000 ± 0.048
0.440	2.273	1.374 ± 0.127	1.349 ± 0.113	1.293 ± 0.113
0.370	2.703	1.672 ± 0.123	1.665 ± 0.046	1.518 ± 0.046
0.296	3.375	2.000 ± 0.095	1.899 ± 0.127	1.786 ± 0.127
0.276	3.625	2.220 ± 0.093	2.067 ± 0.123	1.969 ± 0.123
0.258	3.875	2.428 ± 0.093	2.249 ± 0.095	2.149 ± 0.095
0.242	4.125	2.661 ± 0.095	2.447 ± 0.093	2.391 ± 0.093
0.229	4.375	2.947 ± 0.099	2.777 ± 0.093	2.771 ± 0.093
0.216	4.625	3.161 ± 0.102	2.922 ± 0.095	2.967 ± 0.095
0.205	4.875	3.293 ± 0.104	2.921 ± 0.099	2.846 ± 0.099
0.195	5.125	3.489 ± 0.105	2.812 ± 0.102	2.646 ± 0.102
0.186	5.375	3.637 ± 0.107	2.805 ± 0.104	2.565 ± 0.104
0.178	5.625	3.866 ± 0.112	2.863 ± 0.105	2.566 ± 0.105
0.170	5.875	4.013 ± 0.115	2.932 ± 0.107	2.598 ± 0.107
0.163	6.125	4.243 ± 0.119	3.060 ± 0.112	2.607 ± 0.112
0.157	6.375	4.472 ± 0.124	3.110 ± 0.115	2.668 ± 0.115
0.151	6.625	4.776 ± 0.131	3.299 ± 0.119	2.787 ± 0.119
0.145	6.875	5.000 ± 0.135	3.408 ± 0.124	2.874 ± 0.124
0.140	7.125	5.272 ± 0.142	3.515 ± 0.131	2.983 ± 0.131
0.136	7.375	5.575 ± 0.148	3.670 ± 0.135	3.118 ± 0.135
0.131	7.625	5.795 ± 0.153	3.862 ± 0.142	3.231 ± 0.142
0.127	7.875	6.074 ± 0.160	3.937 ± 0.148	3.374 ± 0.148
0.123	8.125	6.297 ± 0.368	4.055 ± 0.153	3.366 ± 0.153
0.119	8.375	6.436 ± 0.271	3.969 ± 0.160	3.467 ± 0.160
0.116	8.625	6.992 ± 0.201	...	...

Figure 2: Gordon 2003 Table

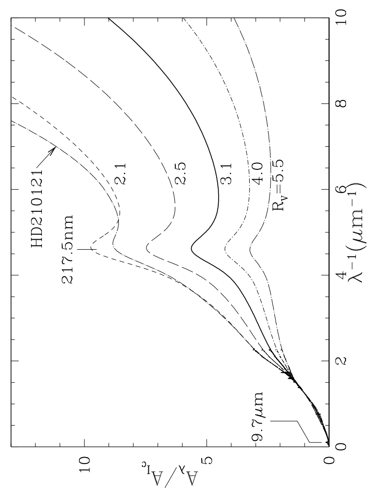

Figure 3: Draine 2011 Plot

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:

$$F_\lambda = \frac{f_{\rm peak}}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\lambda-\mu}{\sigma}\right)^2}, \tag{14}$$

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

- 6th Order Gauss-Hermite Polynomial:

$$F_\lambda = [f_{\rm peak}\alpha(w)/\sigma]\left(1 + \sum_{j=3}^{6} h_j H_j(w)\right), \tag{15}$$

$$w \equiv (\lambda - \mu)/\sigma, \tag{16}$$

$$\alpha(w) = \frac{1}{2\sqrt{\pi}} e^{-\frac{1}{2}w^2}. \tag{17}$$

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):

$$H_3(w) = \frac{w(2w^2-3)}{\sqrt{3}}, \tag{18}$$

$$H_4(w) = \frac{w^2(4w^2-12)+3}{2\sqrt{6}}, \tag{19}$$

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

$$H_6(w) = \frac{w^2[w^2(8w^2-60)+90]-15}{12\sqrt{5}}. \tag{21}$$

- Lorentzian

$$F_\lambda = \frac{f_{\rm peak}}{\pi}\frac{\frac{1}{2}\sigma}{(\lambda-\mu)^2+(\frac{1}{2}\sigma)^2}, \tag{22}$$

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

- Powerlaw profile:

Code Parameters

- $\forall$ Gaussian component:
  - `param1` central wavelength (μ)
  - `param2` width (σ)
  - `param3` amplitude ($f_{\rm peak}$)
- $\forall$ 6th Order Gauss-Hermite Polynomial:
  - `param1` central wavelength (μ)
  - `param2` width of the Gaussian component(σ)
  - `param3` amplitude of the Gauss-Hermite series ($f_{\rm peak}$)
  - `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 ($f_{\rm peak}$)
- $\forall$ 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=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 μ_i = constant for all i

- σ_i: flat prior between 0 and 1200 km s^{-1} with σ_i = 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)

- $F_\lambda > 0$

- $F_{\rm peak}/F{\rm cont}$: 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, $\boldsymbol{\lambda_{0,n}}$

- [Ne V] λ3425.900Å
- [O II] $\lambda\lambda$3726.000, 3728.800Å
  - **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] λ3868.800Å
- He II (actual λ = 4685.650Å)
- Hβ λ = 4861.320Å
  - **Local Prior:** ratio of narrow Hβ:[O III] λ5007; flat prior in range TBD by BPT diagram results (my experience 0-0.4:1)
- [O III] $\lambda\lambda$4958.920, 5006.850Å
  - **Local Prior:** doublet ratio 1:3 (Osterbrock); flat prior in range $1:3 \pm 0.5$
- [O III] λ5007 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] λ5007 flux ratio with 4959.
- [N II] $\lambda\lambda$6548.060, 6583.39Å

– **Local Prior:** doublet ratio 1:3 (Osterbrock); flat prior in range $1:3 \pm 0.5$

- Hα $\lambda = 6562.780$Å
  - **Local Prior:** ratio of narrow Hα:[N II]; flat prior in range TBD by BPT diagram results.
- [Si II] $\lambda\lambda$6716.420, 6730.780Å
  - **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, 5006.850Å.

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).
- $F_\lambda > 0$
- $F_{\rm peak}/F$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, $\boldsymbol{\lambda_{0,b}}$

- Lyα λ1215 (actual $\lambda = 1215.670$Å)
- N V λ1240 (doublet at $\lambda\lambda$1238.808, 1242.796Å)
- "1400 Feature": Si IV (doublet at $\lambda\lambda$1393.755, 1402.770Å) plus O IV] blend ($\lambda\lambda$1397.210, 1399.780, 1404.790, 1407.390Å)
- N IV] λ1486 (actual $\lambda = 1486.500$Å)
- C IV λ1549 (unresolved doublet at $\lambda\lambda$1548.188, 1550.762Å)

- He II $\lambda1640$ (actual $\lambda = 1640.720$Å)
- He II $\lambda1640$ blue component
  - **Local Prior:** set very loose priors on existence, location and strength; if the overall region fits better between He II $\lambda1640$ and C IVwith 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] $\lambda1663$ (doublet at $\lambda\lambda1660.800, 1666.140$Å)
- C III] $\lambda1909$: actually a blend of Al III $\lambda\lambda1854.720, 1862.780$Å, Si III] $\lambda = 1892.030$Å, and C III] $\lambda = 1908.734$Å.
- Mg II $\lambda2798$ (doublet at $\lambda\lambda2796.350, 2803.530$Å)
- Hδ $\lambda = 4101.735$Å
- Hγ $\lambda = 4340.450$Å
- He II $\lambda4686$ (actual $\lambda = 4685.650$Å)
- He II $\lambda4686$ blue component
  - **Local Prior:** set very loose priors on existence, location and strength; if the overall region fits better between He II $\lambda4686$ 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.
- Hβ $\lambda = 4861.320$Å
- He I $\lambda4922$ (actual $\lambda = 4921.9$Å)
- He I $\lambda = 5016$Å
- He I $\lambda5876$ (actual $\lambda = 5875.680$Å)
- He I $\lambda6678$ (actual $\lambda = 6678.000$Å)
- He I $\lambda7065$ (actual $\lambda = 7065.300$Å)
- Hα $\lambda = 6562.780$Å

***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 $\lambda4922$ and He I $\lambda = 5016$Åare highly blended with Hβ, [O III], and possibly Fe II, and thereby hard to independently constrain. The condition is therefore that "if" He I $\lambda5876$ is present in the spectrum, $\sigma_{4922} = \sigma_{5016} = \sigma 5876$.
- As listed above; the potential presence of a blue component to He II $\lambda1640$ and He II $\lambda4686$. 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.