GammaLib - Feature #1948

Add smooth broken power law spectrum model

03/10/2017 09:06 AM - Knödlseder Jürgen

Status:	Closed	**Start date:**	03/10/2017
Priority:	Normal	**Due date:**	
Assigned To:	Cardenzana Josh	**% Done:**	100%
Category:		**Estimated time:**	0.00 hour
Target version:	1.3.0		

Description

A smooth broken power law spectrum model should be implemented, following the Fermi-LAT syntax (see https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/source_models.html#SmoothBrokenPowerLaw and https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/xml_model_defs.html#SmoothBrokenPowerLaw).

The XML format should be

```
<spectrum type="SmoothBrokenPowerLaw">
  <parameter free="1" max="1e10" min="0.0" name="Prefactor" scale="1e-06" value="1.0"/>
  <parameter free="1" max="-1.0" min="-5.0" name="Index1" scale="1.0" value="-2.0"/>
  <parameter free="0" max="2000.0" min="30.0" name="Scale" scale="1.0" value="100.0"/>
  <parameter free="1" max="-1.0" min="-5.0" name="Index2" scale="1.0" value="-2.0"/>
  <parameter free="1" max="5e5" min="20" name="BreakValue" scale="1.0" value="1e3"/>
  <parameter free="1" max="10" min="0.01" name="Beta" scale="1.0" value="0.2"/>
</spectrum>
```

The following alternative format, being more consistent in the namings, should also be supported:

```
<spectrum type="SmoothBrokenPowerLaw">
  <parameter free="1" max="1e10" min="0.0" name="Prefactor" scale="1e-06" value="1.0"/>
  <parameter free="1" max="-1.0" min="-5.0" name="Index1" scale="1.0" value="-2.0"/>
  <parameter free="0" max="2000.0" min="30.0" name="PivotEnergy" scale="1.0" value="100.0"/>
  <parameter free="1" max="-1.0" min="-5.0" name="Index2" scale="1.0" value="-2.0"/>
  <parameter free="1" max="5e5" min="20" name="BreakEnergy" scale="1.0" value="1e3"/>
  <parameter free="1" max="10" min="0.01" name="BreakSmoothness" scale="1.0" value="0.2"/>
</spectrum>
```

To implement the model, the best is to start from the GModelSpectralBrokenPlaw class, rename the .hpp, .cpp and .i files to GModelSpectralSmoothBrokenPlaw (see https://cta-redmine.irap.omp.eu/attachments/download/1919/6th-coding-sprint.pdf) and modify the files as needed.

History

#1 - 03/24/2017 11:12 PM - Knödlseder Jürgen

- Status changed from New to In Progress

- % Done changed from 0 to 50

#2 - 03/28/2017 02:01 PM - Knödlseder Jürgen

- File prefactor.png added

- File index1.png added

- File index2.png added

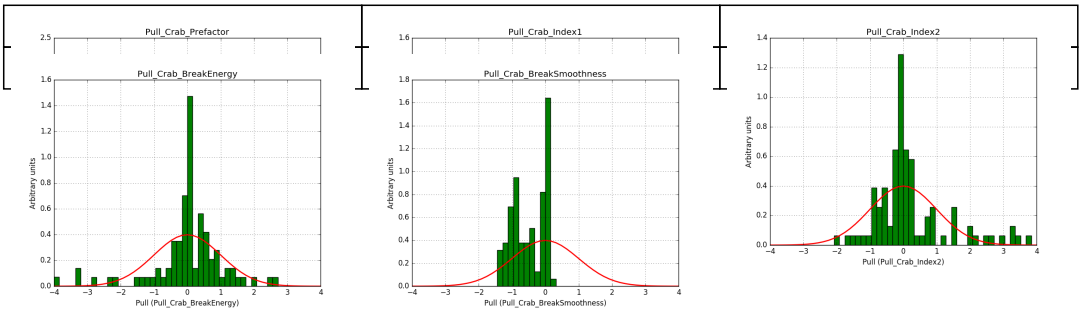
- File breakenergy.png added

- File smoothness.png added

I created 100 pulls for the following model definition XML file:

```
<?xml version="1.0" standalone="no"?>
<source_library title="source library">
  <source name="Crab" type="PointSource">
    <spectrum type="SmoothBrokenPowerLaw">
      <parameter name="Prefactor"       scale="1e-16" value="5.7"  min="1e-07" max="1000.0" free="1"/>
      <parameter name="Index1"          scale="-1"    value="2.48" min="0.0"   max="+5.0"   free="1"/>
      <parameter name="PivotEnergy"     scale="1e6"   value="0.3"  min="0.01"  max="1000.0" free="0"/>
      <parameter name="Index2"          scale="-1"    value="2.70" min="0.01"  max="+5.0"   free="1"/>
      <parameter name="BreakEnergy"     scale="1e6"   value="1.0"  min="0.01"  max="1000.0" free="1"/>
      <parameter name="BreakSmoothness" scale="1.0"   value="0.2"  min="0.01"  max="10.0"   free="1"/>
    </spectrum>
    <spatialModel type="PointSource">
      <parameter name="RA"  scale="1.0" value="83.6331" min="-360" max="360" free="0"/>
      <parameter name="DEC" scale="1.0" value="22.0145" min="-90"  max="90"  free="0"/>
    </spatialModel>
  </source>
  <source name="Background" type="CTAIrfBackground" instrument="CTA">
    <spectrum type="PowerLaw">
      <parameter name="Prefactor"   scale="1.0" value="1.0" min="1e-3" max="1e3"    free="1"/>
      <parameter name="Index"       scale="1.0" value="0.0" min="-5.0" max="+5.0"   free="1"/>
      <parameter name="PivotEnergy" scale="1e6" value="1.0" min="0.01" max="1000.0" free="0"/>
    </spectrum>
  </source>
</source_library>
```

Below the resulting pull histograms:



#3 - 03/28/2017 02:34 PM - Knödlseder Jürgen

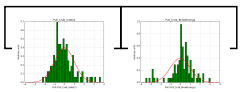
- File prefactor_nosmooth.png added

- File index1_nosmooth.png added

- File index2_nosmooth.png added

- File breakenergy_nosmooth.png added

I now tried fixing the smoothness factor. This did change the pull distributions, but did not lead to satisfactory pull histograms:



#4 - 03/28/2017 02:36 PM - Knödlseder Jürgen

- File prefactor_smooth2.0.png added

- File index1_smooth2.0.png added

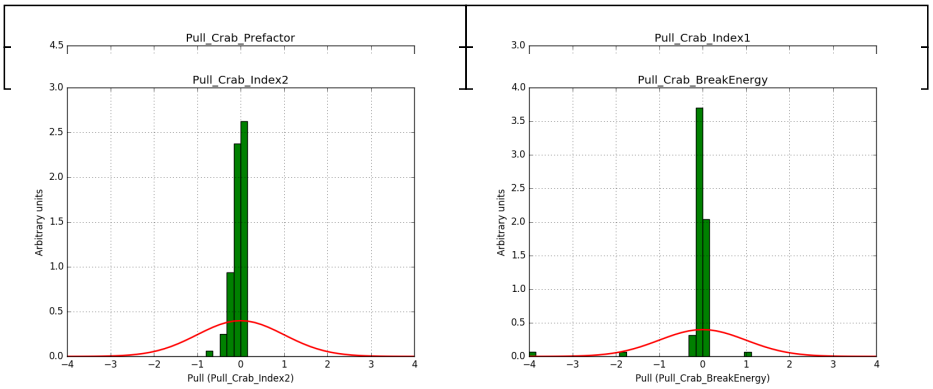
- File index2_smooth2.0.png added

- File breakenergy_smooth2.0.png added

I now made the smoothness larger:

```
<?xml version="1.0" standalone="no"?>
<source_library title="source library">
  <source name="Crab" type="PointSource">
    <spectrum type="SmoothBrokenPowerLaw">
      <parameter name="Prefactor"       scale="1e-16" value="5.7"  min="1e-07" max="1000.0" free="1"/>
      <parameter name="Index1"          scale="-1"    value="2.48" min="0.0"   max="+5.0"   free="1"/>
      <parameter name="PivotEnergy"     scale="1e6"   value="0.3"  min="0.01"  max="1000.0" free="0"/>
      <parameter name="Index2"          scale="-1"    value="2.70" min="0.01"  max="+5.0"   free="1"/>
      <parameter name="BreakEnergy"     scale="1e6"   value="1.0"  min="0.01"  max="1000.0" free="1"/>
      <parameter name="BreakSmoothness" scale="1.0"   value="2.0"  min="0.01"  max="10.0"   free="0"/>
    </spectrum>
    <spatialModel type="PointSource">
      <parameter name="RA"  scale="1.0" value="83.6331" min="-360" max="360" free="0"/>
      <parameter name="DEC" scale="1.0" value="22.0145" min="-90"  max="90"  free="0"/>
    </spatialModel>
  </source>
  <source name="Background" type="CTAIrfBackground" instrument="CTA">
    <spectrum type="PowerLaw">
      <parameter name="Prefactor"   scale="1.0" value="1.0" min="1e-3" max="1e3"    free="1"/>
      <parameter name="Index"       scale="1.0" value="0.0" min="-5.0" max="+5.0"   free="1"/>
      <parameter name="PivotEnergy" scale="1e6" value="1.0" min="0.01" max="1000.0" free="0"/>
    </spectrum>
  </source>
</source_library>
```

This had a dramatic impact on the pull distributions:



#5 - 03/28/2017 03:03 PM - Knödlseder Jürgen

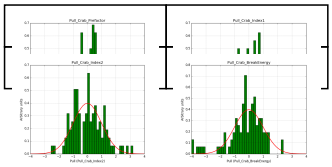
- File prefactor_smooth0.02.png added

- File index1_smooth0.02.png added

- File index2_smooth0.02.png added

- File breakenergy_smooth0.02.png added

Setting the smoothness parameters to a small value (0.02) improves things, but the break energy is still not perfect.



#6 - 03/28/2017 03:55 PM - Knödlseder Jürgen

Note that a simple simulation of 30 min of data using the initial XML model, and fitting the simulated events using ctlike indicates that there are convergence problems. This typical happens for invalid gradients:

```
2017-03-28T13:53:07: +================================+
2017-03-28T13:53:07: | Maximum likelihood optimisation |
2017-03-28T13:53:07: +================================+
2017-03-28T13:53:07:  >Iteration   0: -logL=157024.509, Lambda=1.0e-03
2017-03-28T13:53:07:    Parameter "BreakEnergy" drives optimization step (step=0.497168)
2017-03-28T13:53:07:   Iteration   1: -logL=157024.509, Lambda=1.0e-03, delta=-696.181, max(|grad|)=-38674.620105 [BreakEnergy:6] (stalled)
2017-03-28T13:53:07:    Parameter "BreakEnergy" does not drive optimization step anymore.
2017-03-28T13:53:07:   Iteration   2: -logL=157024.509, Lambda=1.0e-02, delta=-16.823, max(|grad|)=283.058569 [Index2:4] (stalled)
2017-03-28T13:53:07:  >Iteration   3: -logL=157022.062, Lambda=1.0e-01, delta=2.446, max(|grad|)=11.343717 [Index:10]
2017-03-28T13:53:08:   Iteration   4: -logL=157022.062, Lambda=1.0e-02, delta=-6.516, max(|grad|)=128.891134 [Index2:4] (stalled)
2017-03-28T13:53:08:  >Iteration   5: -logL=157021.979, Lambda=1.0e-01, delta=0.083, max(|grad|)=4.062394 [Index1:3]
2017-03-28T13:53:08:   Iteration   6: -logL=157021.979, Lambda=1.0e-02, delta=-2.265, max(|grad|)=66.600685 [Index2:4] (stalled)
2017-03-28T13:53:08:  >Iteration   7: -logL=157021.925, Lambda=1.0e-01, delta=0.054, max(|grad|)=2.610925 [Index1:3]
2017-03-28T13:53:08:   Iteration   8: -logL=157022.951, Lambda=1.0e-02, delta=-1.027, max(|grad|)=43.167592 [Index2:4] (stalled)
2017-03-28T13:53:08:  >Iteration   9: -logL=157021.701, Lambda=1.0e-01, delta=1.250, max(|grad|)=3.155219 [Index2:4]
2017-03-28T13:53:08:   Iteration  10: -logL=157021.722, Lambda=1.0e-02, delta=-0.020, max(|grad|)=14.470936 [BreakSmoothness:7] (stalled)
2017-03-28T13:53:08:  >Iteration  11: -logL=157021.597, Lambda=1.0e-01, delta=0.124, max(|grad|)=0.701246 [Index2:4]
2017-03-28T13:53:08:  >Iteration  12: -logL=157021.577, Lambda=1.0e-02, delta=0.020, max(|grad|)=-9.644692 [BreakEnergy:6]
2017-03-28T13:53:08:   Iteration  13: -logL=157021.577, Lambda=1.0e-03, delta=-100.522, max(|grad|)=-2958.702580 [BreakEnergy:6] (stalled)
2017-03-28T13:53:08:  >Iteration  14: -logL=157021.504, Lambda=1.0e-02, delta=0.073, max(|grad|)=-8.585555 [BreakEnergy:6]
2017-03-28T13:53:08:   Iteration  15: -logL=157021.504, Lambda=1.0e-03, delta=-77.307, max(|grad|)=-2626.302597 [BreakEnergy:6] (stalled)
2017-03-28T13:53:08:  >Iteration  16: -logL=157021.447, Lambda=1.0e-02, delta=0.057, max(|grad|)=-9.376360 [BreakEnergy:6]
2017-03-28T13:53:08:   Iteration  17: -logL=157021.447, Lambda=1.0e-03, delta=-53.416, max(|grad|)=-2163.691984 [BreakEnergy:6] (stalled)
2017-03-28T13:53:08:  >Iteration  18: -logL=157021.385, Lambda=1.0e-02, delta=0.061, max(|grad|)=-10.625401 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  19: -logL=157021.385, Lambda=1.0e-03, delta=-38.693, max(|grad|)=-1886.824989 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  20: -logL=157021.307, Lambda=1.0e-02, delta=0.079, max(|grad|)=-13.005929 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  21: -logL=157021.307, Lambda=1.0e-03, delta=-26.422, max(|grad|)=-1607.011273 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  22: -logL=157021.169, Lambda=1.0e-02, delta=0.137, max(|grad|)=-17.670655 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  23: -logL=157021.169, Lambda=1.0e-03, delta=-11.325, max(|grad|)=-1036.219873 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  24: -logL=157020.836, Lambda=1.0e-02, delta=0.334, max(|grad|)=-27.476821 [BreakEnergy:6]
2017-03-28T13:53:09:  >Iteration  25: -logL=157020.782, Lambda=1.0e-03, delta=0.054, max(|grad|)=-143.289056 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  26: -logL=157020.782, Lambda=1.0e-04, delta=-12.308, max(|grad|)=-1518.463100 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  27: -logL=157020.424, Lambda=1.0e-03, delta=0.358, max(|grad|)=-73.785714 [BreakEnergy:6]
2017-03-28T13:53:09:  >Iteration  28: -logL=157020.337, Lambda=1.0e-04, delta=0.087, max(|grad|)=-20.992382 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  29: -logL=157021.414, Lambda=1.0e-05, delta=-1.077, max(|grad|)=-422.701433 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  30: -logL=157021.237, Lambda=1.0e-04, delta=0.177, max(|grad|)=-286.616084 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  31: -logL=157021.237, Lambda=1.0e-05, delta=-1.526, max(|grad|)=-679.670560 [BreakEnergy:6] (stalled)
2017-03-28T13:53:09:  >Iteration  32: -logL=157020.652, Lambda=1.0e-04, delta=0.585, max(|grad|)=-212.471407 [BreakEnergy:6]
2017-03-28T13:53:09:   Iteration  33: -logL=157020.652, Lambda=1.0e-05, delta=-18.470, max(|grad|)=-804.677134 [BreakEnergy:6] (stalled)
2017-03-28T13:53:10:  >Iteration  34: -logL=157020.632, Lambda=1.0e-04, delta=0.021, max(|grad|)=-162.477223 [BreakEnergy:6]
2017-03-28T13:53:10:   Iteration  35: -logL=157020.632, Lambda=1.0e-05, delta=-2.698, max(|grad|)=-768.319088 [BreakEnergy:6] (stalled)
2017-03-28T13:53:10:   Iteration  36: -logL=157020.632, Lambda=1.0e-04, delta=-0.133, max(|grad|)=-250.945203 [BreakEnergy:6] (stalled)
2017-03-28T13:53:10:  >Iteration  37: -logL=157020.332, Lambda=1.0e-03, delta=0.300, max(|grad|)=-11.121790 [BreakEnergy:6]
2017-03-28T13:53:10:  >Iteration  38: -logL=157020.330, Lambda=1.0e-04, delta=0.002, max(|grad|)=-4.292704 [BreakEnergy:6]
```

#7 - 03/28/2017 04:20 PM - Knödlseder Jürgen

I replaced the analytical gradient computations by numerical gradient computations which did not change the results. This indicates that the problem is possibly inherent to the model.

I therefore change the slope of the second index to a stepper value as follows:

```
<?xml version="1.0" standalone="no"?>
<source_library title="source library">
  <source name="Crab" type="PointSource">
    <spectrum type="SmoothBrokenPowerLaw">
      <parameter name="Prefactor"       scale="1e-16" value="5.7"  min="1e-07" max="1000.0" free="1"/>
      <parameter name="Index1"          scale="-1"    value="2.48" min="0.0"   max="+5.0"   free="1"/>
      <parameter name="PivotEnergy"     scale="1e6"   value="0.3"  min="0.01"  max="1000.0" free="0"/>
      <parameter name="Index2"          scale="-1"    value="3.48" min="0.01"  max="+5.0"   free="1"/>
      <parameter name="BreakEnergy"     scale="1e6"   value="1.0"  min="0.01"  max="1000.0" free="1"/>
      <parameter name="BreakSmoothness" scale="1.0"   value="0.2"  min="0.01"  max="10.0"   free="1"/>
    </spectrum>
    <spatialModel type="PointSource">
      <parameter name="RA"  scale="1.0" value="83.6331" min="-360" max="360" free="0"/>
      <parameter name="DEC" scale="1.0" value="22.0145" min="-90"  max="90"  free="0"/>
    </spatialModel>
  </source>
  <source name="Background" type="CTAIrfBackground" instrument="CTA">
    <spectrum type="PowerLaw">
      <parameter name="Prefactor"   scale="1.0" value="1.0" min="1e-3" max="1e3"    free="1"/>
      <parameter name="Index"       scale="1.0" value="0.0" min="-5.0" max="+5.0"   free="1"/>
      <parameter name="PivotEnergy" scale="1e6" value="1.0" min="0.01" max="1000.0" free="0"/>
    </spectrum>
  </source>
</source_library>
```

Now the fit seems to converge nicely:

```
2017-03-28T14:11:14: +=================================+
2017-03-28T14:11:14: | Maximum likelihood optimisation |
2017-03-28T14:11:14: +=================================+
2017-03-28T14:11:14:  >Iteration   0: -logL=156311.871, Lambda=1.0e-03
2017-03-28T14:11:14:  >Iteration   1: -logL=156310.512, Lambda=1.0e-03, delta=1.360, max(|grad|)=2.459834 [Index:10]
2017-03-28T14:11:14:  >Iteration   2: -logL=156310.510, Lambda=1.0e-04, delta=0.002, max(|grad|)=-0.124483 [BreakEnergy:6]
```

#8 - 03/28/2017 04:59 PM - Knödlseder Jürgen

- Status changed from In Progress to Feedback

- % Done changed from 50 to 100

Added user documentation to GammaLib and ctools.

#9 - 06/06/2017 09:10 PM - Knödlseder Jürgen

- Status changed from Feedback to Closed

Files

prefactor.png	32.3 KB	03/28/2017	Knödlseder Jürgen
index1.png	35.5 KB	03/28/2017	Knödlseder Jürgen
index2.png	35.5 KB	03/28/2017	Knödlseder Jürgen
breakenergy.png	38 KB	03/28/2017	Knödlseder Jürgen
smoothness.png	40.3 KB	03/28/2017	Knödlseder Jürgen
prefactor_nosmooth.png	40.4 KB	03/28/2017	Knödlseder Jürgen
index1_nosmooth.png	39.2 KB	03/28/2017	Knödlseder Jürgen
index2_nosmooth.png	39.8 KB	03/28/2017	Knödlseder Jürgen
breakenergy_nosmooth.png	37.9 KB	03/28/2017	Knödlseder Jürgen
prefactor_smooth2.0.png	33.8 KB	03/28/2017	Knödlseder Jürgen
index1_smooth2.0.png	31.2 KB	03/28/2017	Knödlseder Jürgen
index2_smooth2.0.png	31.5 KB	03/28/2017	Knödlseder Jürgen
breakenergy_smooth2.0.png	34.7 KB	03/28/2017	Knödlseder Jürgen
prefactor_smooth0.02.png	40.3 KB	03/28/2017	Knödlseder Jürgen
index1_smooth0.02.png	39.1 KB	03/28/2017	Knödlseder Jürgen
index2_smooth0.02.png	39.4 KB	03/28/2017	Knödlseder Jürgen
breakenergy_smooth0.02.png	41.7 KB	03/28/2017	Knödlseder Jürgen