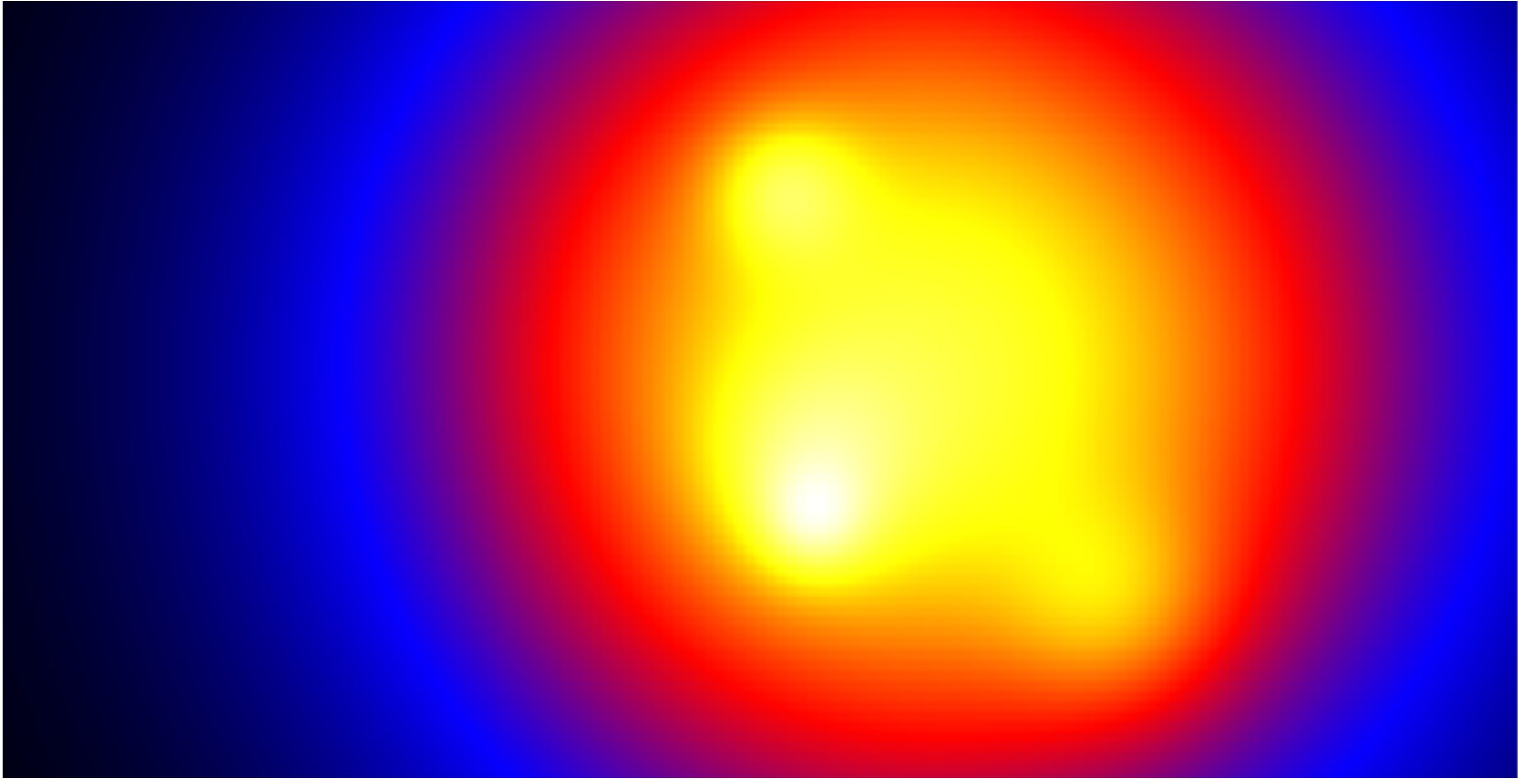


Composite Models

Michael Mayer

Use case I

- Source morphology more complicated than single (asym) Gaussian
- e.g. Vela X (radio nebula + cocoon)
- Want to model complicated source with one spectrum (but several spatial components)
- Avoid using detour using FITS templates

Use case II

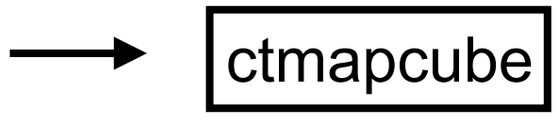
- Source spectrum more complicated than single component
- e.g. Crab in Fermi (PSR + nebula)
- Want to model source with several spectral components
- Avoid using detour using Ascii File templates

Feature #1706

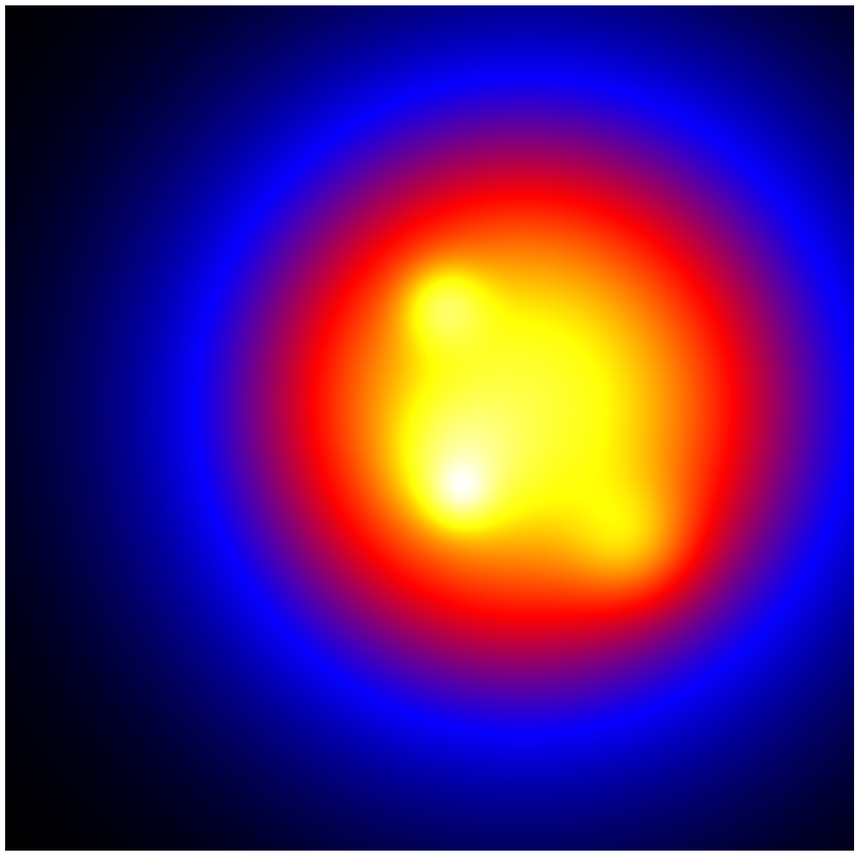
ctmapcube

Model XML File

```xml
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<source_library title="source library">
  <source name="E0" type="ExtendedSource">
    <spectrum type="LogParabola">
      <parameter name="Prefactor" value="1.9" scale="1e-11" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.17" scale="-1" min="0" max="5" free="1" />
      <parameter name="Curvature" value="0.22" scale="-1" min="0" max="5" free="1" />
      <parameter name="Scale" value="1" scale="1e+03" min="0.0001" max="10000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="80.0" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-68.0" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="3.0" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E1" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="2.05" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.4" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-68.85" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.6" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E2" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="1.5" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.0" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.97" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-66.65" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.4" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E3" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="2.05" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.25" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-69.25" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.3" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
  <source name="E4" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="1.85" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="75.25" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-69.75" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.6" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
</source_library>
```



FITS Cube template



ctmapcube

Model XML File

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<source_library title="source library">
  <source name="E0" type="ExtendedSource">
    <spectrum type="LogParabola">
      <parameter name="Prefactor" value="1.9" scale="1e-11" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.17" scale="-1" min="0" max="5" free="1" />
      <parameter name="Curvature" value="0.22" scale="-1" min="0" max="5" free="1" />
      <parameter name="Scale" value="1" scale="1e+03" min="0.0001" max="10000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="80.0" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-68.0" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="3.0" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E1" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="2.05" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.4" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-68.85" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.6" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E2" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="1.5" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.0" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.97" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-66.65" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.4" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
    <source name="E3" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="2.05" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="82.25" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-69.25" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.3" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
  <source name="E4" type="ExtendedSource">
    <spectrum type="PowerLaw2">
      <parameter name="Integral" value="1.85" scale="1e-8" min="1e-09" max="1e+06" free="1" />
      <parameter name="Index" value="2.13" scale="-1" min="0" max="5" free="1" />
      <parameter name="LowerLimit" value="100" scale="1" min="0.0001" max="10000" free="0" />
      <parameter name="UpperLimit" value="1e6" scale="1" min="0.0001" max="10000000" free="0" />
    </spectrum>
    <spatialModel type="GaussFunction">
      <parameter name="RA" value="75.25" scale="1" min="27.898" max="137.898" free="0" />
      <parameter name="DEC" value="-69.75" scale="1" min="-81.4065" max="-50" free="0" />
      <parameter name="Sigma" value="0.6" scale="1" min="0.0001" max="10" free="0" />
    </spatialModel>
  </source>
</source_library>
```

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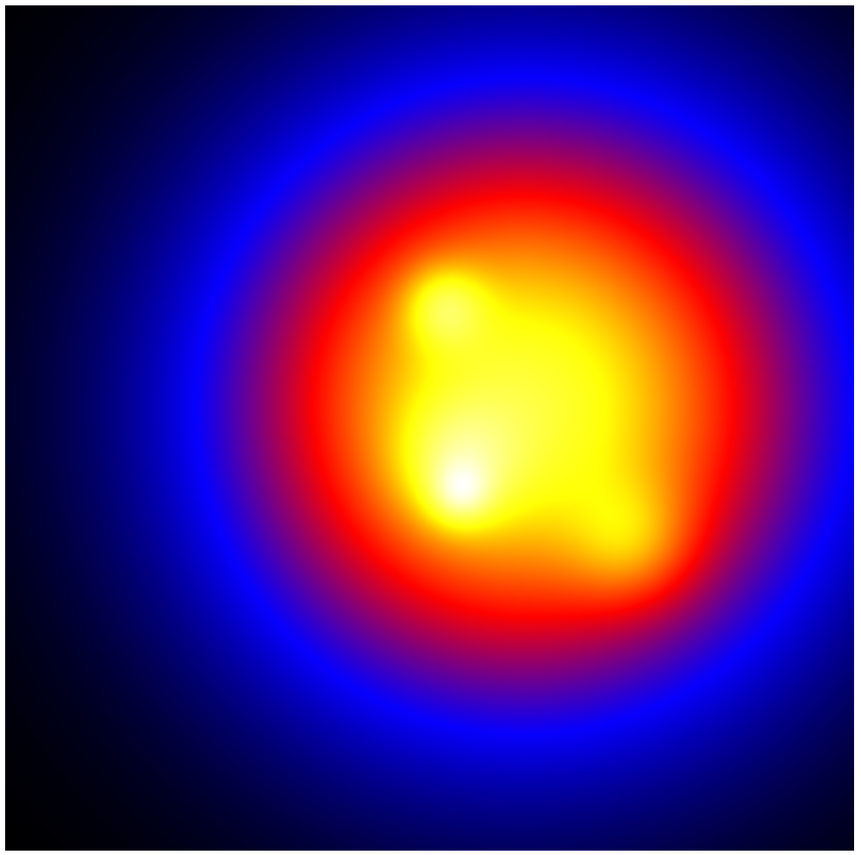
FITS Cube template



- **Requires knowledge of spectrum of each component**
- **Need to reproduce template if you want to change a component**

Proposal I - Linked Parameters

```
<?xml version="1.0" standalone="no"?>
<source_library title="source library">
    <source name="Crab pulsar" type="PointSource">
        <spectrum type="PowerLaw">
           <parameter name="Prefactor" scale="1e-16" value="5.7"  min="1e-07" max="1000.0" free="1"/>
           <parameter name="Index"     scale="-1"    value="2.48" min="0.0"   max="+5.0"   free="1"/>
           <parameter name="Scale"     scale="1e6"   value="0.3"  min="0.01"  max="1000.0" free="0"/>
        </spectrum>
        <spatialModel type="SkyDirFunction">
            <parameter max="360" min="-360" name="RA" scale="1" value="83.6331" free="1" />
            <parameter max="90" min="-90" name="DEC" scale="1" value="22.0145" free="1" />
        </spatialModel>
    </source>
    <source name="Crab nebula" type="PointSource">
        <spectrum type="PowerLaw">
           <parameter name="Prefactor" scale="1e-16" value="5.7"  min="1e-07" max="1000.0" free="1"/>
           <parameter name="Index"     scale="-1"    value="2.48" min="0.0"   max="+5.0"   free="1"/>
           <parameter name="Scale"     scale="1e6"   value="0.3"  min="0.01"  max="1000.0" free="0"/>
        </spectrum>
        <spatialModel type="SkyDirFunction">
            <parameter max="360" min="-360" name="RA" scale="1" value="83.6331" free="1" />
            <parameter max="90" min="-90" name="DEC" scale="1" value="22.0145" free="1" />
        </spatialModel>
    </source>
    <link>
        <source name="Crab pulsar" parameter="RA">
        <source name="Crab nebula" parameter="RA">
        <parameter max="360" min="-360" name="RA" scale="1" value="83.6331" free="1" />
    </link>
</source_library>
```

Proposal I - Linked Parameters

- Add the <link> information to Model container
- Fix all linked parameters automatically
- Introduce a new (more global) parameter
- Need to figure out how to resolve parameters in model evaluation

Advantages:
Very flexible
Can link across sources
Keep XML source definition

Drawbacks:
More complicated XML file
Difficult to implement?

Proposal II - New XML model definitions (GModelSpectralComposite, GModelSpatialComposite)

```
<source name="Crab" type="PointSource" tscalc="1">
  <spectrum type="Composite">
      <spectrum type="PowerLaw" component="PSR">
          <parameter name="Prefactor" value="5" scale="1e-16" min="0.1" max="10" free="1" />
          <parameter name="Index" value="-2.2" scale="1" min="-6" max="-1" free="1" />
          <parameter name="Scale" value="1" scale="1e+06" free="0" />
      </spectrum>
      <spectrum type="PowerLaw" component="Nebula">
          <parameter name="Prefactor" value="8.0" scale="1e-16" min="0.1" max="10" free="1" />
          <parameter name="Index" value="-2.5" scale="1" min="-6" max="-1" free="1" />
          <parameter name="Scale" value="1" scale="1e+06" free="0" />
      </spectrum>
  </spectrum>
  <spatialModel type="SkyDirFunction">
      <parameter name="RA" value="83.6331" scale="1" min="0" max="260" free="0" />
      <parameter name="DEC" value="22.01" scale="1" min="-90" max="90" free="0" />
  </spatialModel>
</source>
```

Proposal IIa - Multiple spectra per source

```
<source name="Crab" type="PointSource" tscalc="1">
  <spectrum type="PowerLaw" component="PSR">
      <parameter name="Prefactor" value="5" scale="1e-16" min="0.1" max="10" free="1" />
      <parameter name="Index" value="-2.2" scale="1" min="-6" max="-1" free="1" />
      <parameter name="Scale" value="1" scale="1e+06" free="0" />
  </spectrum>
  <spectrum type="PowerLaw" component="Nebula">
      <parameter name="Prefactor" value="8.0" scale="1e-16" min="0.1" max="10" free="1" />
      <parameter name="Index" value="-2.5" scale="1" min="-6" max="-1" free="1" />
      <parameter name="Scale" value="1" scale="1e+06" free="0" />
  </spectrum>
  <spatialModel type="SkyDirFunction">
      <parameter name="RA" value="83.6331" scale="1" min="0" max="260" free="0" />
      <parameter name="DEC" value="22.01" scale="1" min="-90" max="90" free="0" />
  </spatialModel>
</source>
```

Could think of adding a “weight” attribute

```
<source name="Source" type="ExtendedSource" tscalc="1">
  <spectrum type="PowerLaw">
    <parameter name="Prefactor" value="5" scale="1e-16" min="0.1" max="10" free="1" />
    <parameter name="Index" value="-2.2" scale="1" min="-6" max="-1" free="1" />
    <parameter name="Scale" value="1" scale="1e+06" free="0" />
  </spectrum>
  <spatialModel type="GaussFunction" weigth="0.8">
    <parameter name="RA" value="83.6331" scale="1" min="0" max="360" free="0" />
    <parameter name="DEC" value="22.01" scale="1" min="-90" max="90" free="0" />
    <parameter name="Sigma" value="0.2" scale="1" min="0" max="1" free="0" />
  </spatialModel>
  <spatialModel type="GaussFunction" weigth="0.2">
    <parameter name="RA" value="83.6331" scale="1" min="0" max="360" free="0" />
    <parameter name="DEC" value="22.01" scale="1" min="-90" max="90" free="0" />
    <parameter name="Sigma" value="0.6" scale="1" min="0" max="1" free="0" />
  </spatialModel>
</source>
```

Proposal II - Change XML source definition

- Implement new composite spatial and spectral model
- allow multiple spectral and spatial (or temporal) components per model
- Model evaluation is just the sum of model components (normalisation has to be worked out)
- Should work straight-forward (in my mind)

Advantages:
Intuitive
Easy to use
Keep XML files clean

Drawbacks:
Some sensible changes to the code
Work out normalisation