Diffuse Emission and Map Making

Def 1: Map - a set of pixels (small patches of sky) and a value (counts, flux, etc.) for each pixel.

Eq. 3

\[
\begin{array}{ccc}
1 & 0 & 1 \\
2 & 9 & 3 \\
1 & 7 & 2 \\
1 & 1 & 0 \\
\end{array}
\]

grid of numbers
grey scale image

convenient: g.r.d.
equal area

\[ f(1,1) = 7 \]

0-ordered.

Def 2: Map - a discrete sampling \( f(\hat{x}, \hat{y}) \) of a continuous function \( f(x) \) with dense "enough" sample points.

Enough? Nyquist - Shannon => sampling theorem - Fourier

"If a function \( f(t) \) contains no frequencies higher than \( B \) Hertz, it is completely determined by giving its ordinates (values) at a series of points spaced \( \frac{1}{2B} \) seconds apart." - Shannon '49

"Bandlimited" function can be perfectly reconstructed from these samples. True in 2-D also.

So, are these defined the same?

Let \( s(x) \) be the "sky"

\[ k(x) \] be PSF (instrument + atmosphere, etc.)

\[ p(x) \] be pixel function

Let \( f(x) = s(x) * k(x) * p(x) \)

\[ \rightarrow \text{ same.} \Rightarrow \text{ convolution.} \]
Eg. a step function $S(x)$

$p(x)$

$k(r)$

$f(x)$

Exactly the same as $k(x)$

But wait!

What if you have additional information about each photon?

PSF, band pass (energy, $p$, pdf)

Bruni loses this information.

In optical ask the instrument bins for you.

Fermi does not. => brings it bad.
To Bin or not to Bin:

Do you have everything important in your model?

2. A correct model, just need parameter estimates and errors - formal T analysis no binny.

1. Uncertain model, don't know what we're looking for. Bin and play.

Non-trivial difference

the anomaly - descem

→ find ways to use

your neural net: see

things.

→ most things you see will be wrong.

Must iterate first, get on to next thing.

Now for map making.
Diffuse emission: What are we making a map of?

Unlike a flux \( F \) (erg/s/cm\(^2\)) from an object, diffuse emission \( \Phi \) is flux per solid angle:
\[
\text{erg/s/cm}^2/\text{sr}
\]

obviously \( F = \Phi \theta \)

related by

e.g., Aperture photometry

\[
F = \sum p_j \cdot A_{pix}
\]

flux in pixel/\( A_{pix} \)

\[
\sum F_{ij}
\]

Always keep track of whether you are talking about counts or count per sr.

May be familiar with “specific intensity”, \( I_s \)

\[
[I_s] = \text{Jy/sr} \sim \text{Jy/m}^2/\text{sr} \sim \text{erg/s/cm}^2/\text{sr}
\]

\[
[F_s] \sim [F]
\]

In gamma, we think of binning counts in energy and talk about

\[
\frac{dN}{dE} = \text{counts per energy}
\]
Could bin in \( \ln E \)

\[
\frac{dN}{d\ln E} = E \frac{dN}{dE} \quad \text{counts per log } E
\]

or mult by \( E \)

\[
E \frac{dN}{d\ln E} = E^2 \frac{dN}{dE} \quad \text{energy per log } E
\]

Recall \( I_v \) is \( \text{ergs/cm}^2 \text{/s} \text{/sr} \)

These can all be per \( \text{cm}^2 \) per sec, per sr.

E.g.

\[
I_v = \text{ergs/cm}^2/\text{s}/\text{sr}/\text{sr} \quad (\text{energy per log energy})
\]

\[
E^2 \frac{dN}{dE} \sim I_v.
\]

\[
\frac{dN}{dE} \quad \text{counts} \quad \frac{E}{\text{GeV}} \quad 5.\text{cm}^2\text{-GeV}\text{-sr}
\]

\[
I_v \sim \frac{E^2 dN}{dE} \quad \text{GeV} \quad 5.\text{cm}^2\text{-sr}
\]
How to make a map of diffuse emission.

Want $dN/dE \text{ counts}$ GeV$^{-1}$ cm$^{-2}$ sr

Have exposure (cm$^2$ s) from Fermi tools so need counts in a $\Delta E$ bin in d$\Omega$ pixel.

Any pixelization is fine, but equal-area pixelizations are nice.

E.g. Healpix

- Each square

- Hierarchical
  - Equal-area
  - Isolatitude problem

Anyway...

Event list

(e.g. dec) (time) (energy)

Counts

$\Delta E \cdot \text{Apix} \cdot \text{Expos.}$

2 with angle data quality cuts.

Easy, right?
Some issues:

- PSF different for front/back converting etc.
- Point sources: mask? Subtract?
- Bad time intervals?
- Sun/Moon?
- Smoothing to same target PSF?

So in more detail:

- Make front and back ESP map, \( (\text{mask bad, times 2\times 10^5}) \)
- Subtract sources (for wings also). \( (1873 \text{ i.e. 2FM}) \)
- Mask 400 brightest or most variable
  (mesh means remove comb, set exposure to zero). (Mask same by hand)
- Make front, back map & combine.

\[
I = \frac{N_f + N_b}{\text{exp}_f + \text{exp}_b}
\]

- In general, Smooth by \( I = \frac{\text{Smooth}(N_f)}{\text{Smooth}(E_f)} \)

prefered PSF is Gaussian,

\[
\sigma_f = \text{target}
\]

\[
\sigma_p = \sigma_f \text{ simi} \quad \Delta = \sqrt{\sigma_f^2 - \sigma_p^2}
\]

Write .fits file (map + esp in 1st ext.)

Also f, b sep, different FWHM.

Usually use f only at \( E < 1 \text{ GeV} \).

\[5-10 \text{ GeV} \text{ minus } 0.5-1 \text{ GeV} \]