COMPTEL All-Sky Imaging at 2.2 MeV

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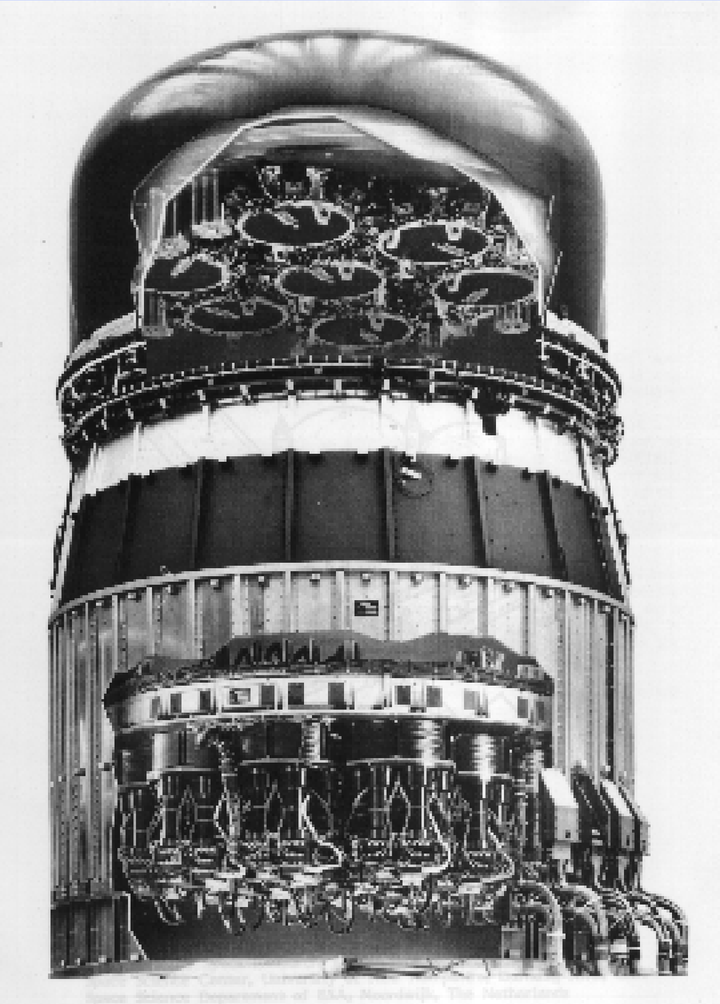


the COMPTEL experiment
on the Compton Gamma-Ray observatory

Scientific Motivation

☞ **2.223 MeV γ-ray line emission arises from thermal neutron capture on hydrogen.**

☞ **Formation of this feature requires:**

① **supply of free (thermal) neutrons**

② **a hydrogen target**

☞ **In a solar flare:**

➔ **a supply of neutrons results from interactions of accelerated ions**

➔ **hydrogen target is supplied by the photosphere**

☞ **In an X-ray binary system:**

➔ **a supply of neutrons can be generated within the accretion disk or perhaps as a result of particle acceleration processes.**

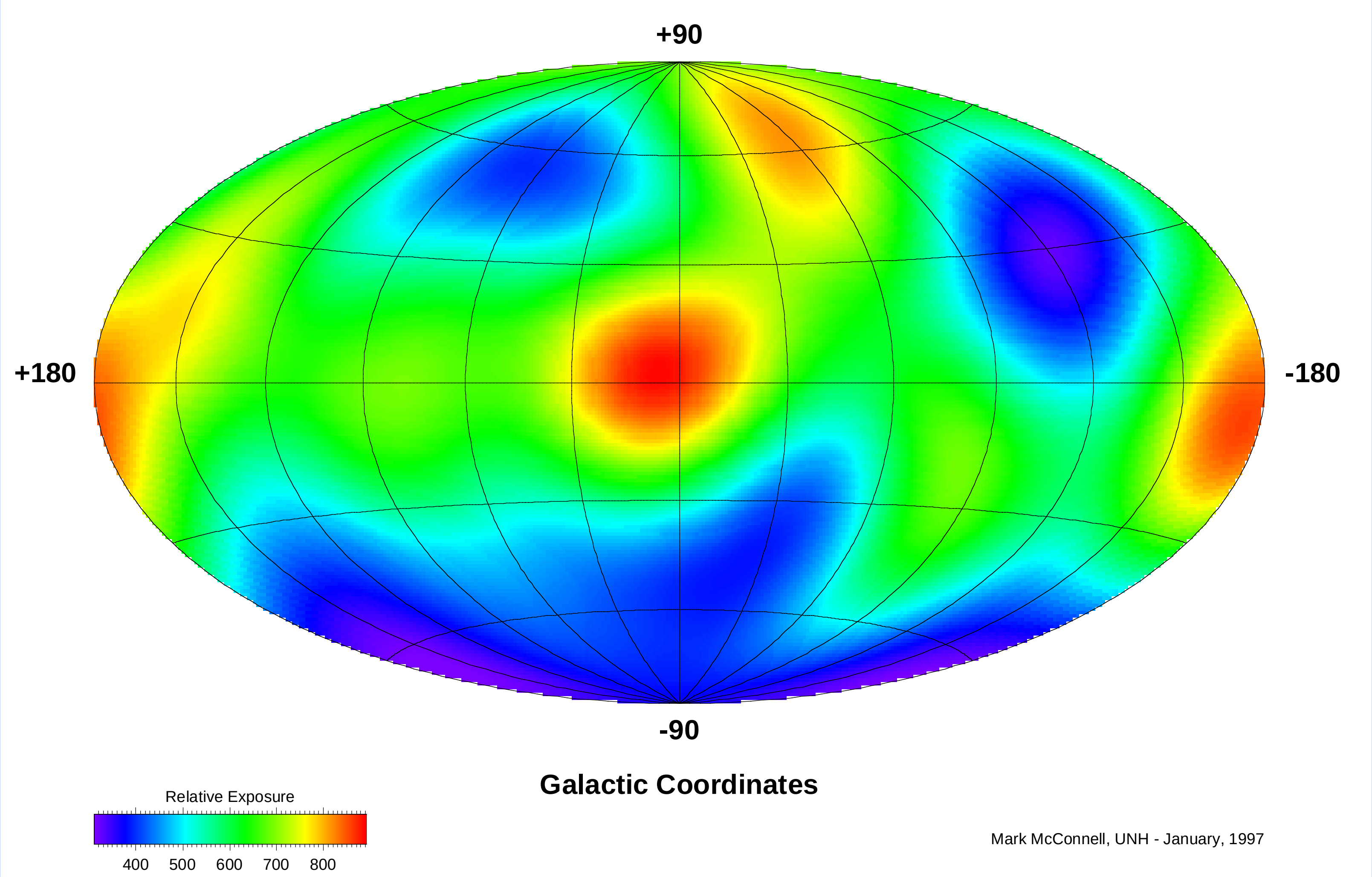
➔ **hydrogen target can be provided by companion star or the outer regions of an accretion disk (for *unshifted* 2.2 MeV emission).**

➔ **hydrogen target can alternatively be provided by neutron star surface or inner accretion disk (for *redshifted* 2.2 MeV emission).**

☞ **Here we report on the all-sky map of *unshifted* 2.223 MeV line emission.**

COMPTEL 2.2 MeV Exposure Map

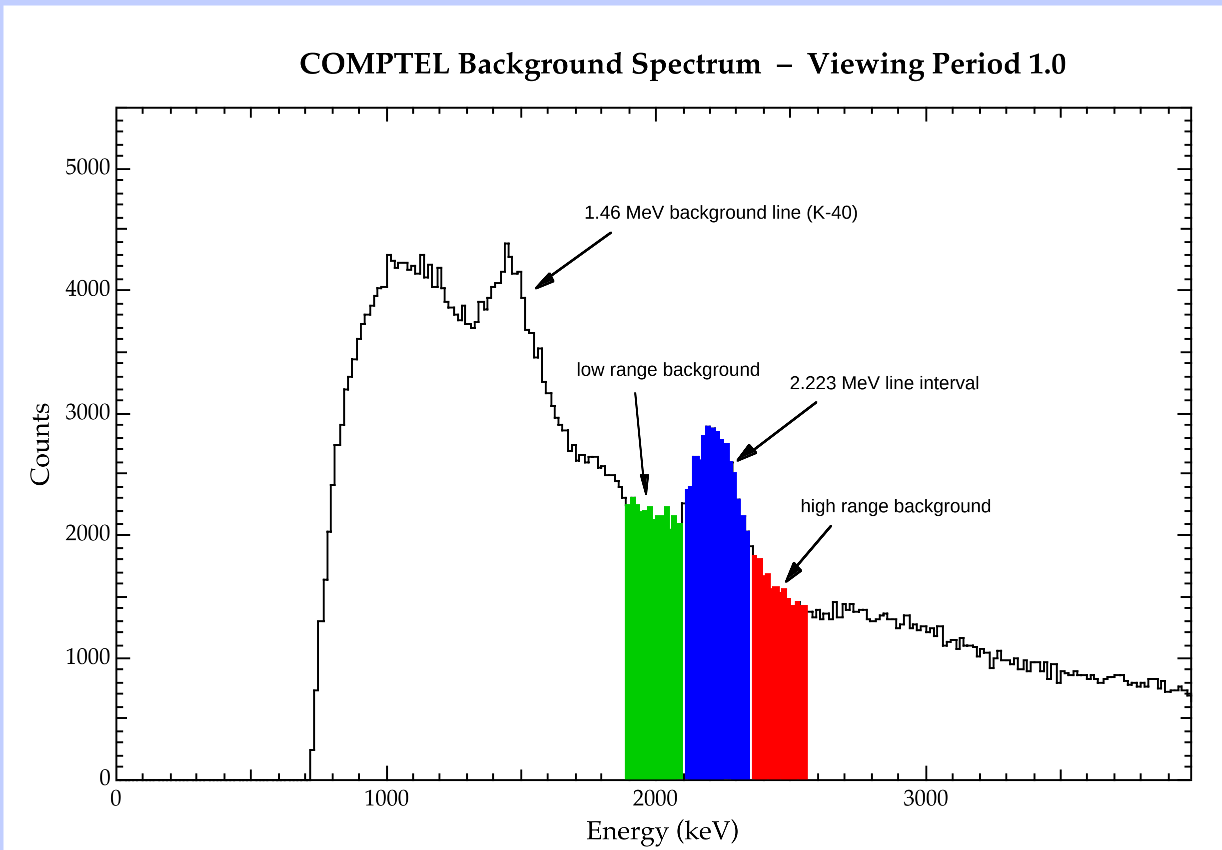
VPs 1.0 - 523.0 (April, 1991 - July, 1996)



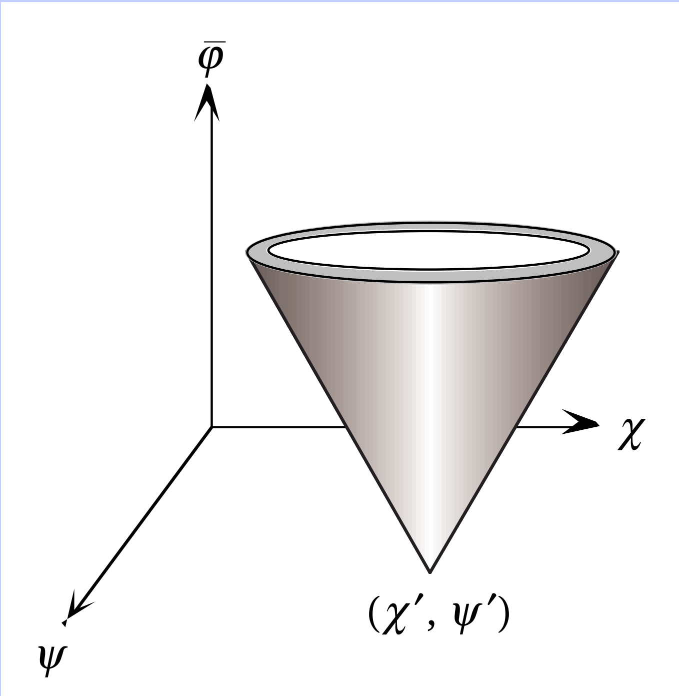
COMPTEL Background Spectrum

The spectrum below represents a typical orbital background. The most prominent features include a 1.46 MeV line from ^{40}K (which originates in the D1 PMTs) and the 2.223 MeV line from thermal neutron capture in D1.

The various spectral ranges used in the present study are highlighted.



The COMPTEL 3-d Dataspace



Idealized PSF
in the 3-d Dataspace

For a specified energy range, we can define a 3-dimensional distribution of events.

The 3-dimensional dataspace is defined by:

1) **the photon scatter direction (χ,ψ)**
2) **the photon scatter angle (φ)**

The scatter direction comes from event locations in D1 and D2.

The scatter angle comes from energy deposits in D1 and D2:

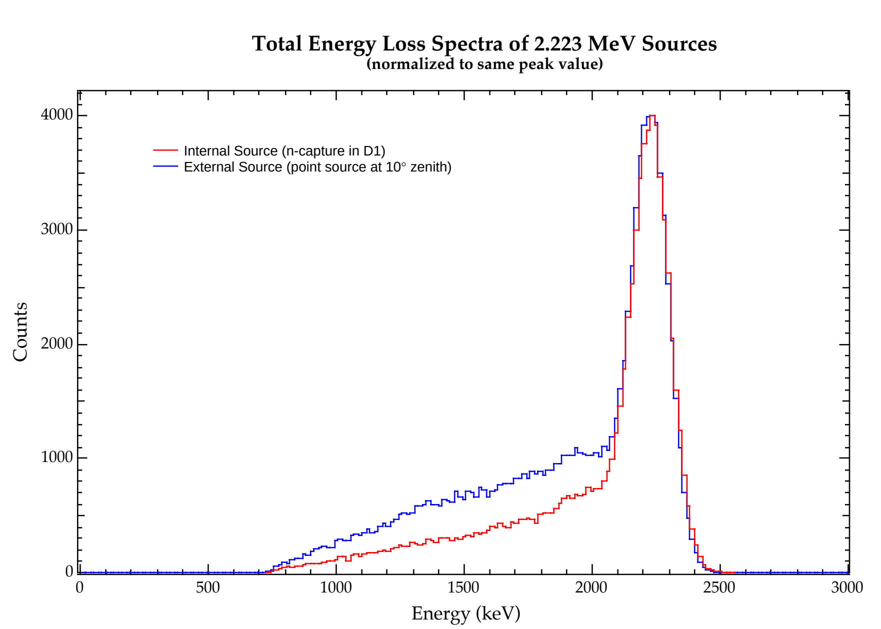
$$\cos\bar{\varphi} = 1 - m_e c^2 \left[\frac{1}{E_{D1}} - \frac{1}{\left(E_{D1} + E_{D2}\right)} \right]$$

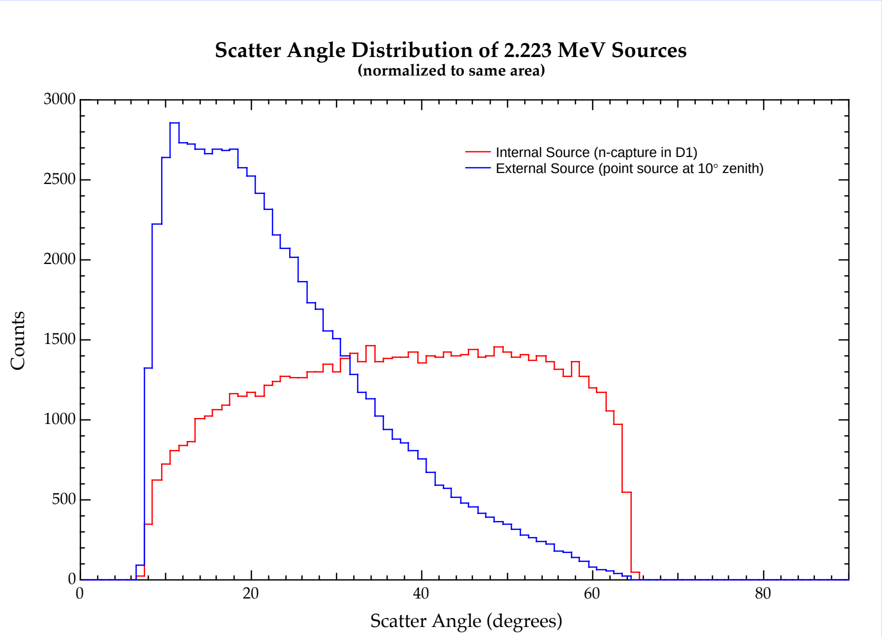
COMPTEL Point Spread Functions (PSFs) are derived from Monte Carlo simulations which have been validated by comparison with pre-flight calibration data.

Signature of Internal Background

The internally-generated 2.223 MeV photons generate a very different signature in the COMPTEL dataspace from those photons which come from an external (i.e., astrophysical) source. The following figures show a comparison (from simulations) between external and internal photon sources.

Note in particular that the internally generated photons are more readily absorbed (larger photofraction) and tend to scatter at much larger angles.





Background Modeling

Several modeling methods have been developed. In this study, we have made use of two alternative techniques for estimating the 3-d background :

1) Dataspace Smoothing (SRCLIX) –

- Background derived by smoothing the measured 3-d dataspace
- Removes the high-frequency (source) components
- Maintains the low-frequency (background) components

2) Synthesis Using Adjacent Energy Bands (BGDLNE) –

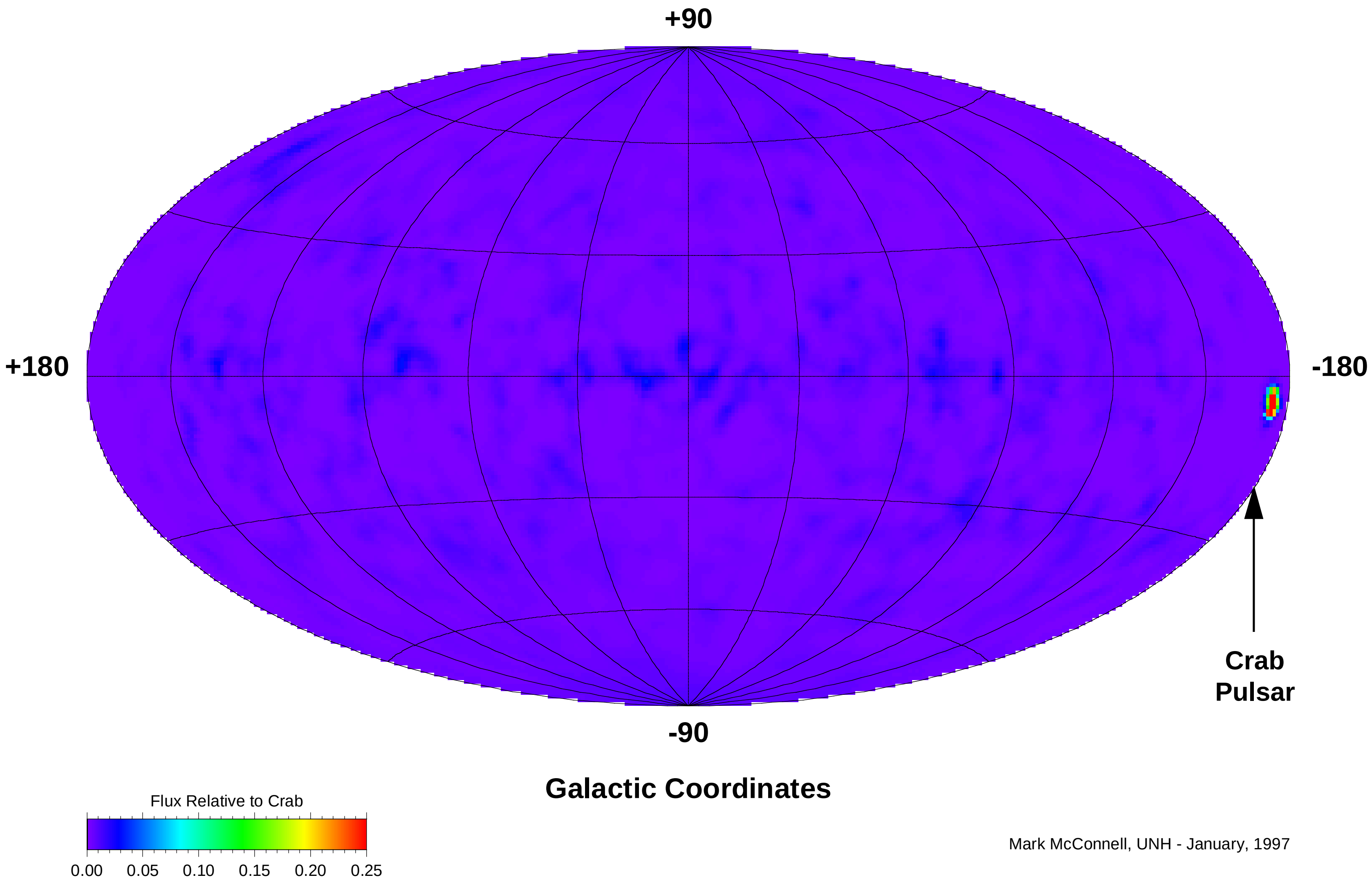
- Background synthesized by combining two distributions
- Estimates the (χ,ψ) distribution from adjacent energy bands
- Estimates the ϕ distribution from the energy band of interest
- Relies on variations of (χ,ψ) distribution to image sources
- Tends to remove the continuum sources from resulting images
- Images sources of pure line emission (e.g., ^{26}Al at 1.8 MeV)

Standard Imaging Results

- As a first step, we generated a series of images using a smoothed (SRCLIX) background model.
- Images of this type will tend to be sensitive to sources of both line and continuum emission. A comparison of adjacent energy bands may indicate possible sources of line emission
- We have generated maps in three separate energy-loss intervals surrounding the 2.223 MeV line:
  - » 1.900 – 2.100 MeV (low-energy interval)
  - » 2.110 – 2.336 MeV (line interval - 1.2 $\times$ FWHM)
  - » 2.350 – 2.550 MeV (high-energy interval)
- In each case, we have generated :
  - – a full-sky intensity map using maximum entropy imaging
  - – a galactic plane probability map using maximum likelihood imaging (Likelihood values > 20-25 may indicate significant sources of emission.)
- Typical line flux sensitivity level ~ 2×10^{-5} cm^{-2} sec^{-1}.

1.9-2.1 MeV Maximum Entropy Map

Smoothed (SRCLIX) Background



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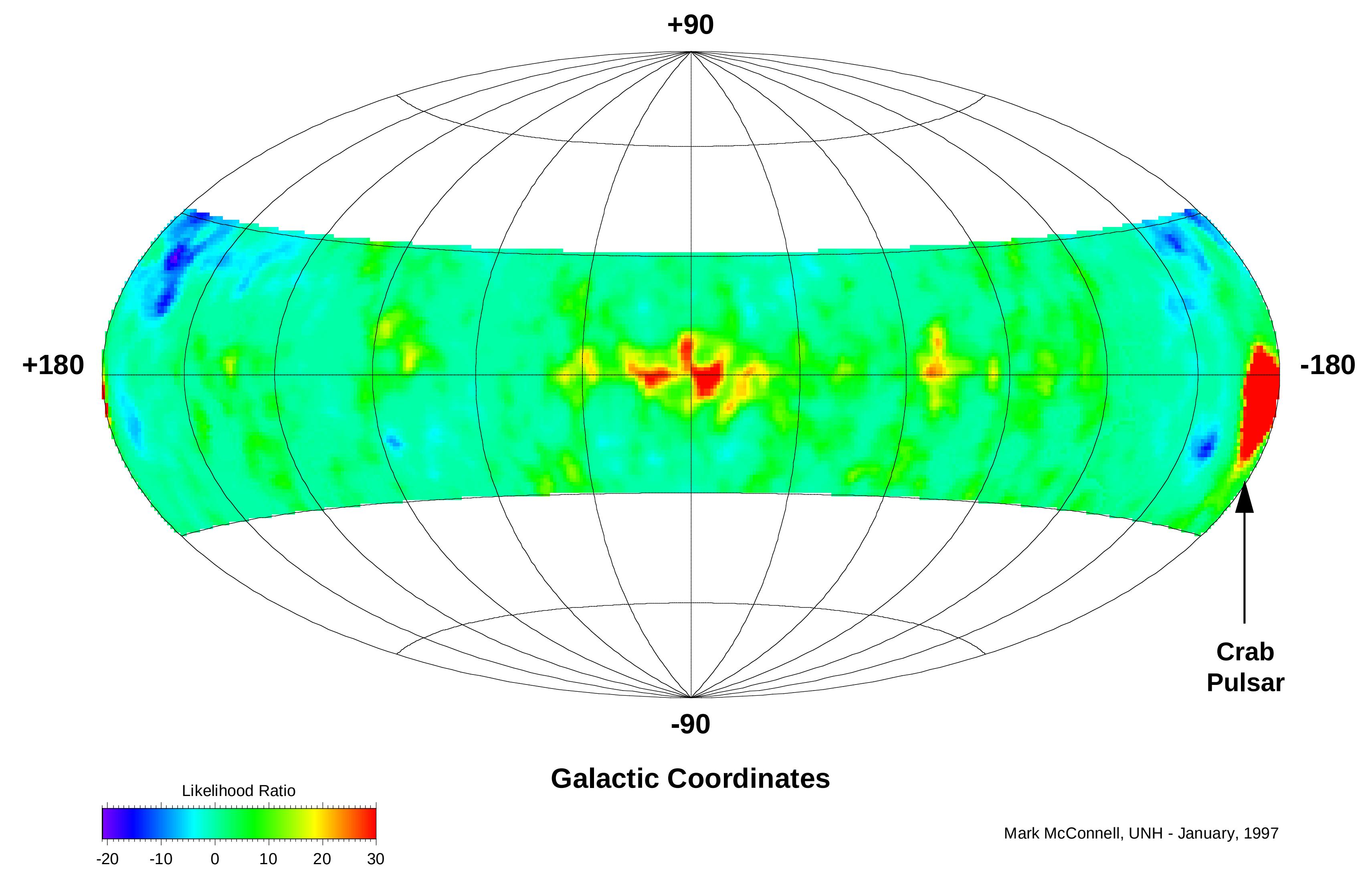
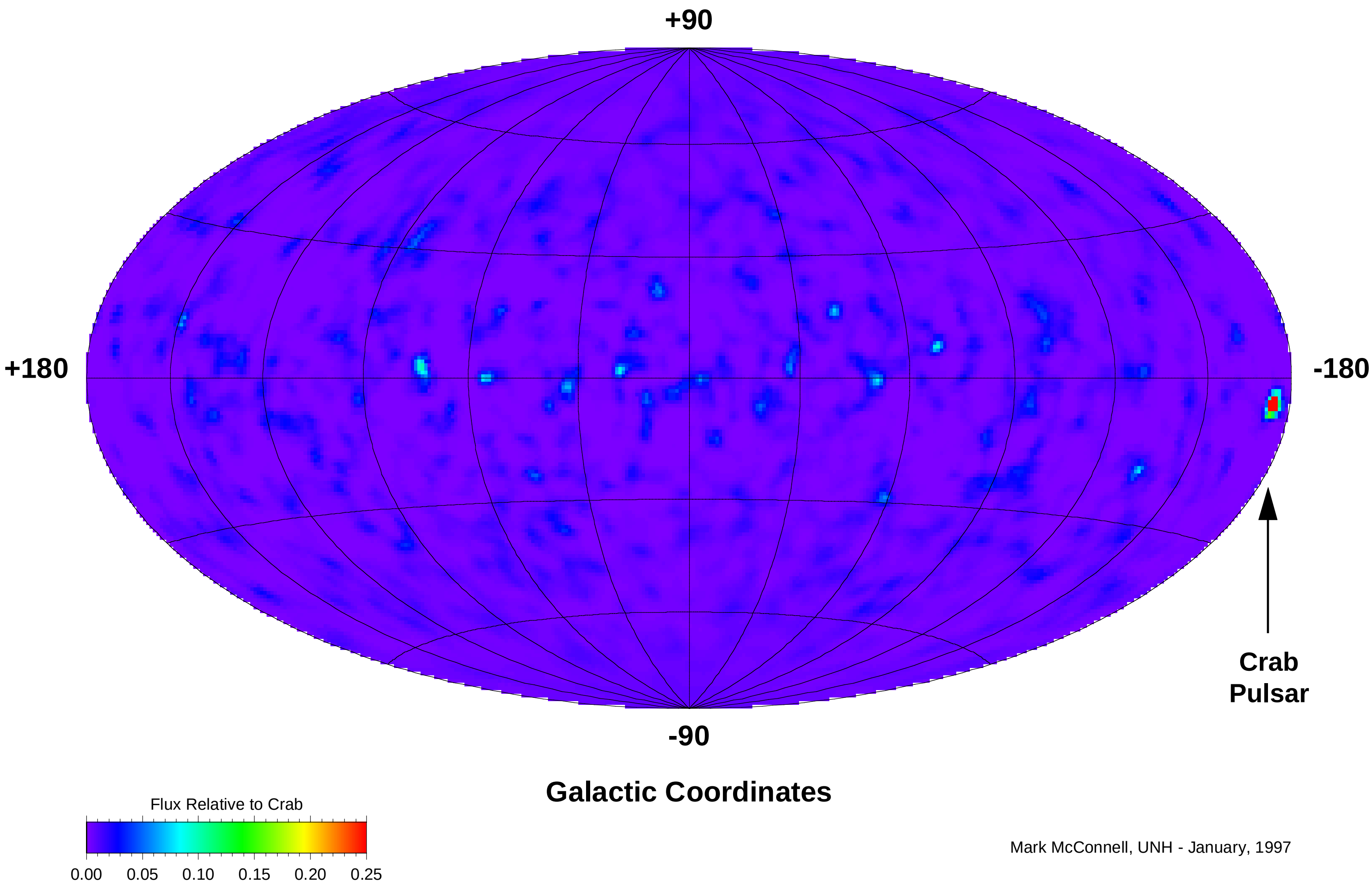
1.9-2.1 MeV Maximum Likelihood Map

Smoothed (SRCLIX) Background



2.110-2.336 MeV Maximum Entropy Map

Smoothed (SRCLIX) Background



Galactic Coordinates

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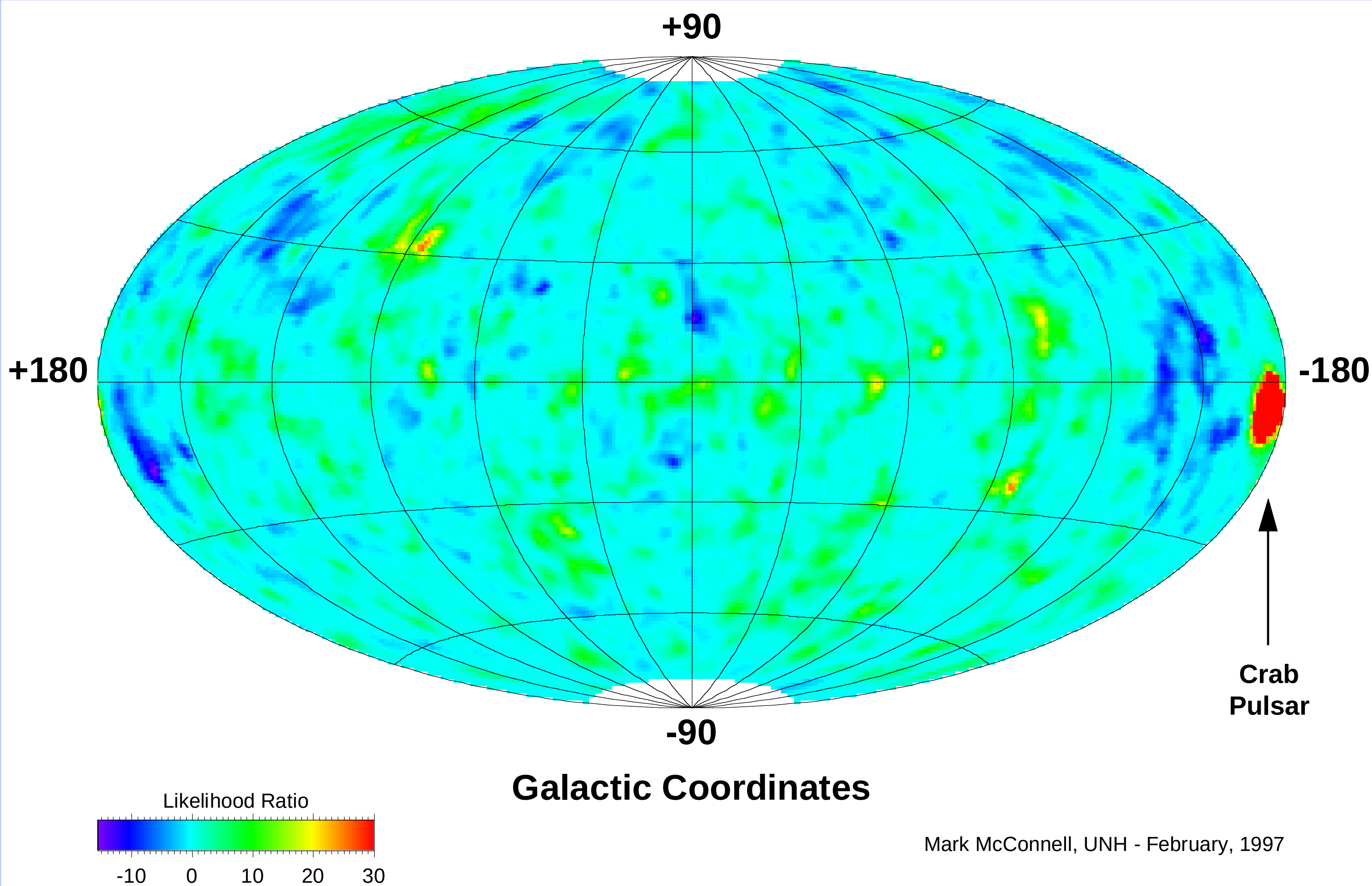
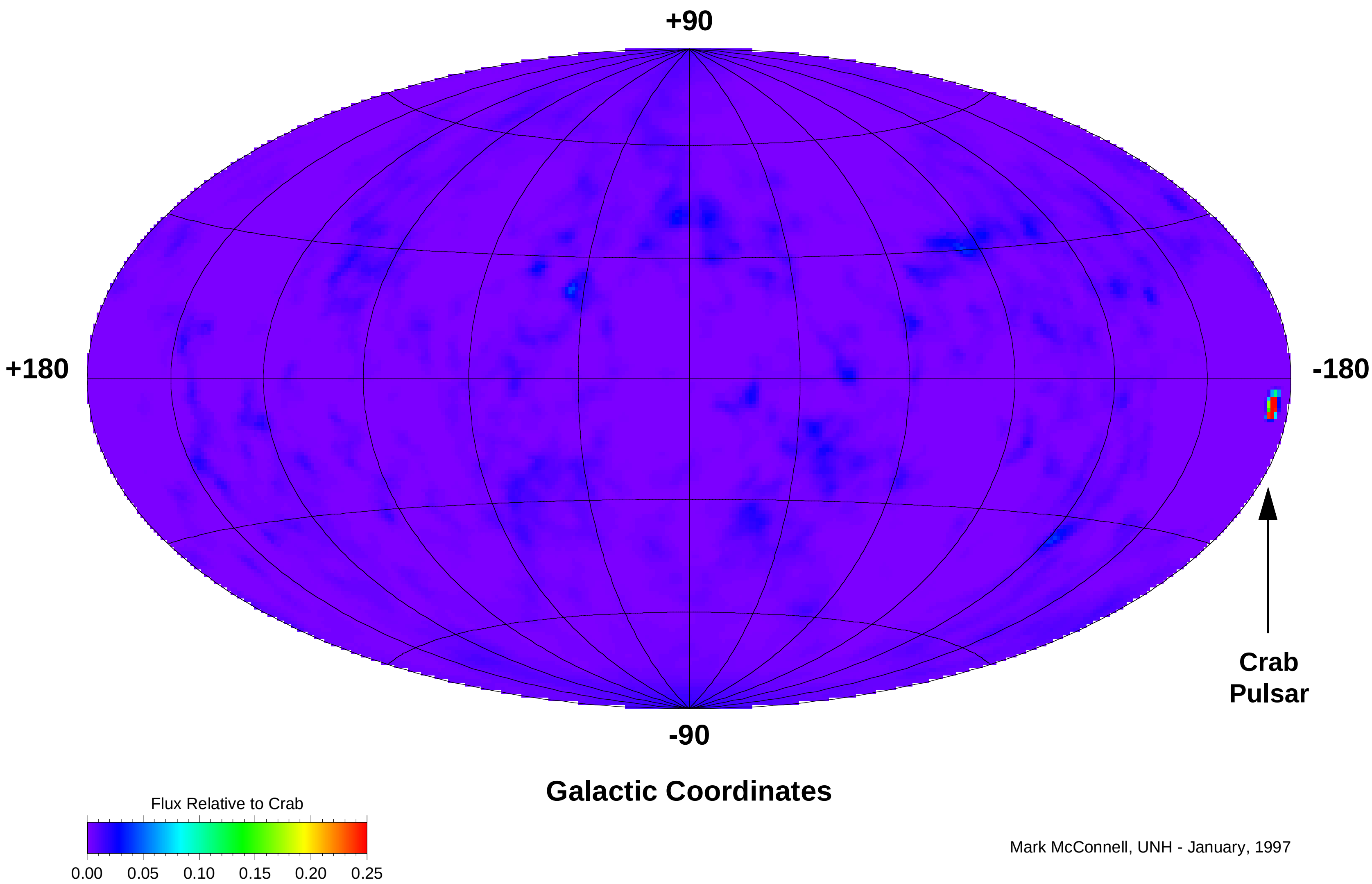
2.110-2.336 MeV Maximum Likelihood Map

Smoothed (SRCLIX) Background



2.35-2.55 MeV Maximum Entropy Map

Smoothed (SRCLIX) Background



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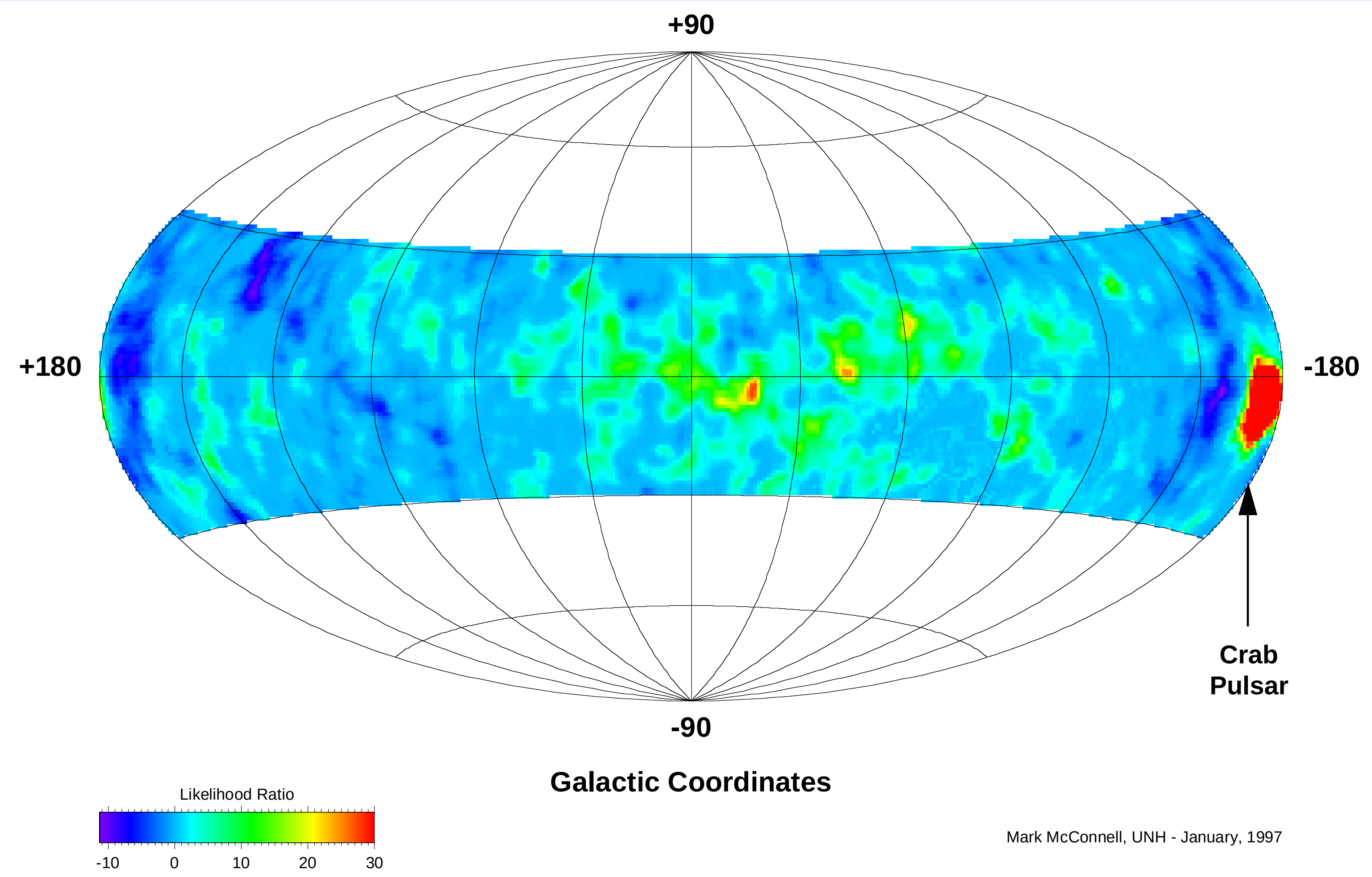
2.35-2.55 MeV Maximum Likelihood Map

Smoothed (SRCLIX) Background

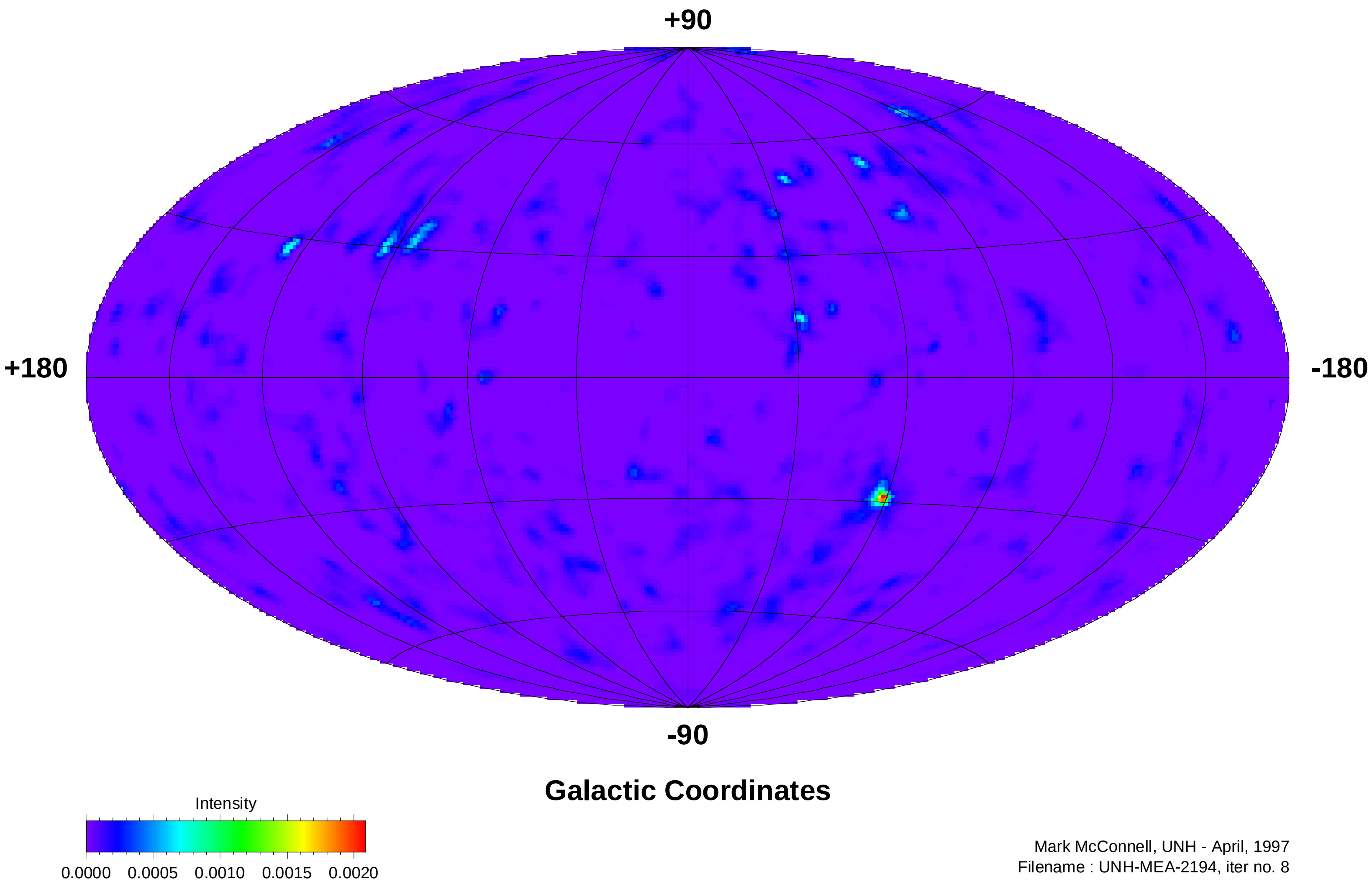


Line Imaging Results

- ☞ The following images were generated with the synthesized background model (BGDLNE).
- ☞ Both a maximum entropy and a maximum likelihood map are shown.
- ☞ These images are more sensitive to sources of line emission.
- ☞ Note that strong continuum sources (e.g., the Crab) are removed.
- ☞ Many of the remaining features are also visible (to some extent) in the previous maps.
- ☞ Typical line flux sensitivity level ~ 1-2 $\times$ 10^{-5} cm^{-2} sec^{-1}.
- ☞ One candidate source detection :
  - – Just under 3σ significance level
  - – Located at (l,b) = (298.2°, -30.6°)
  - – No obvious counterpart

2.110-2.336 MeV Maximum Entropy Map

Synthesized (BGDLNE) Background



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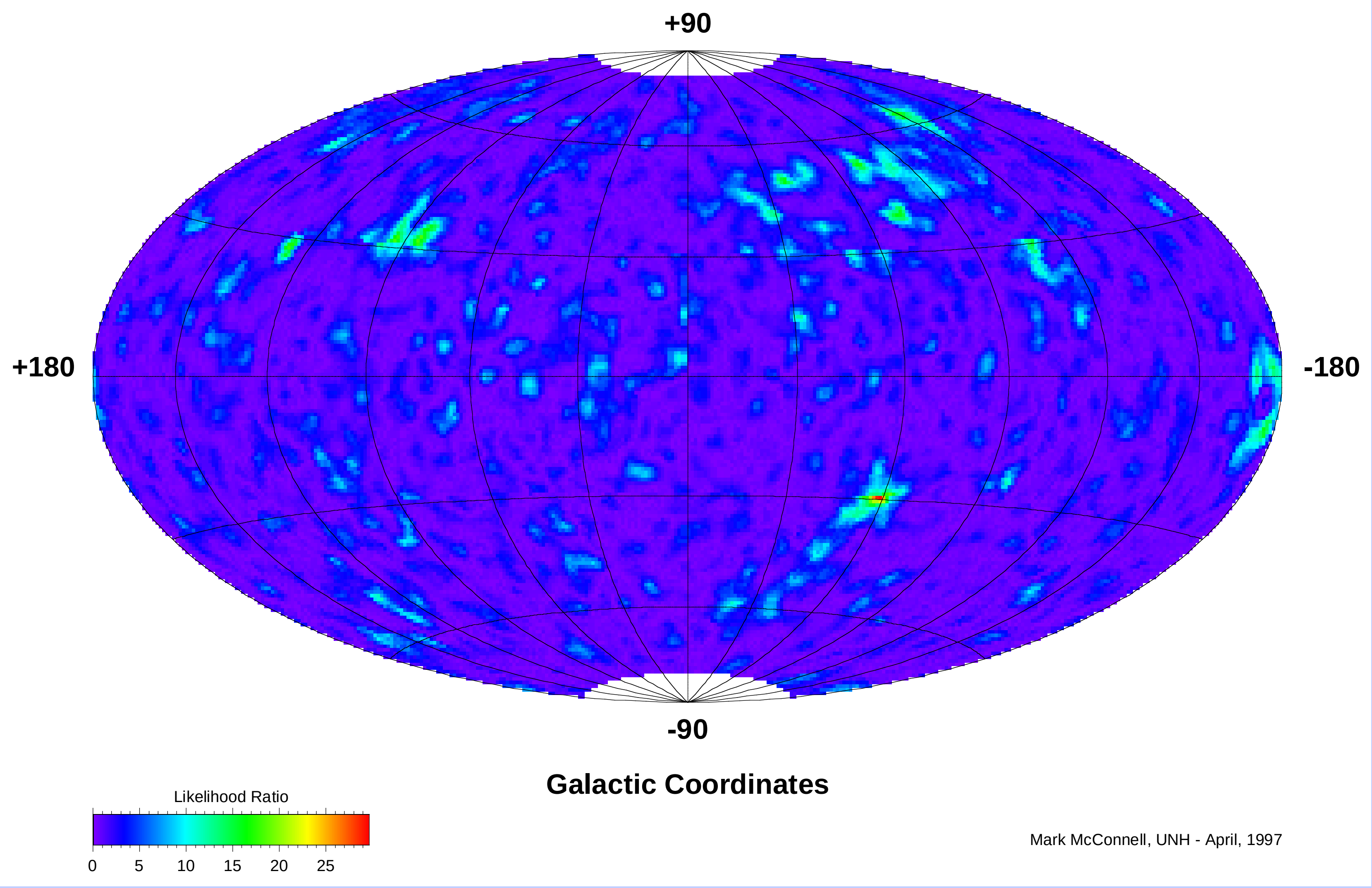
Filename : UNH-MEA-2194, iter no. 8

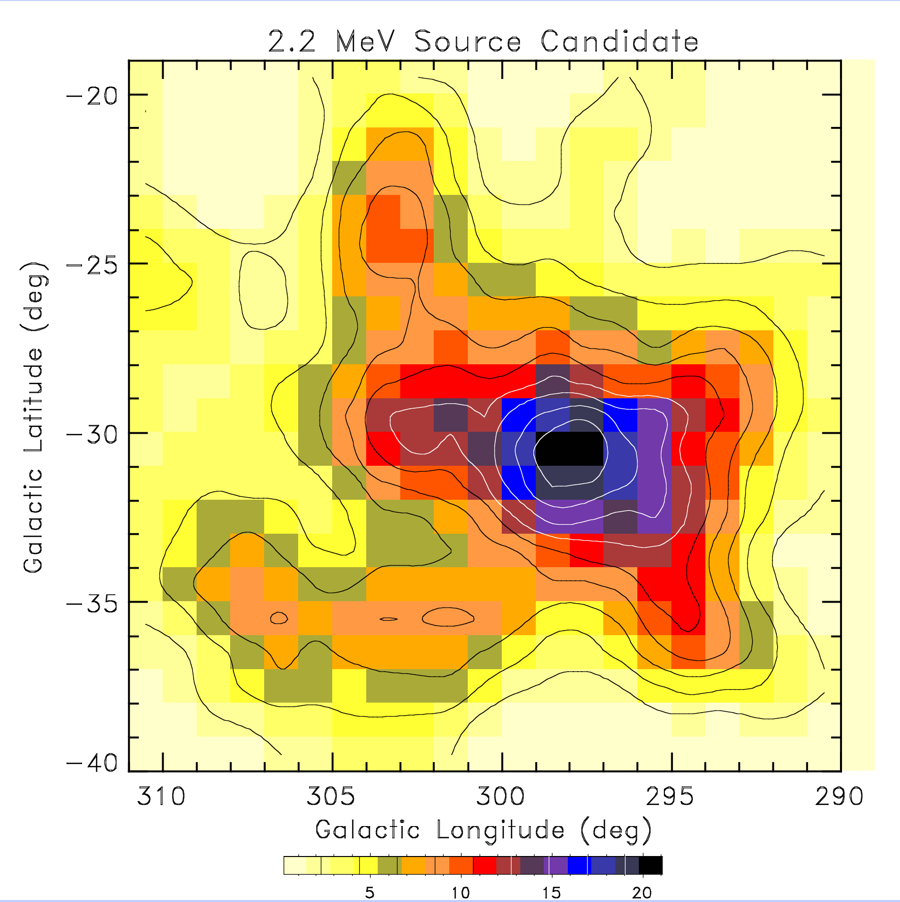
2.110-2.336 MeV Maximum Likelihood Map

Synthesized (BGDLNE) Background

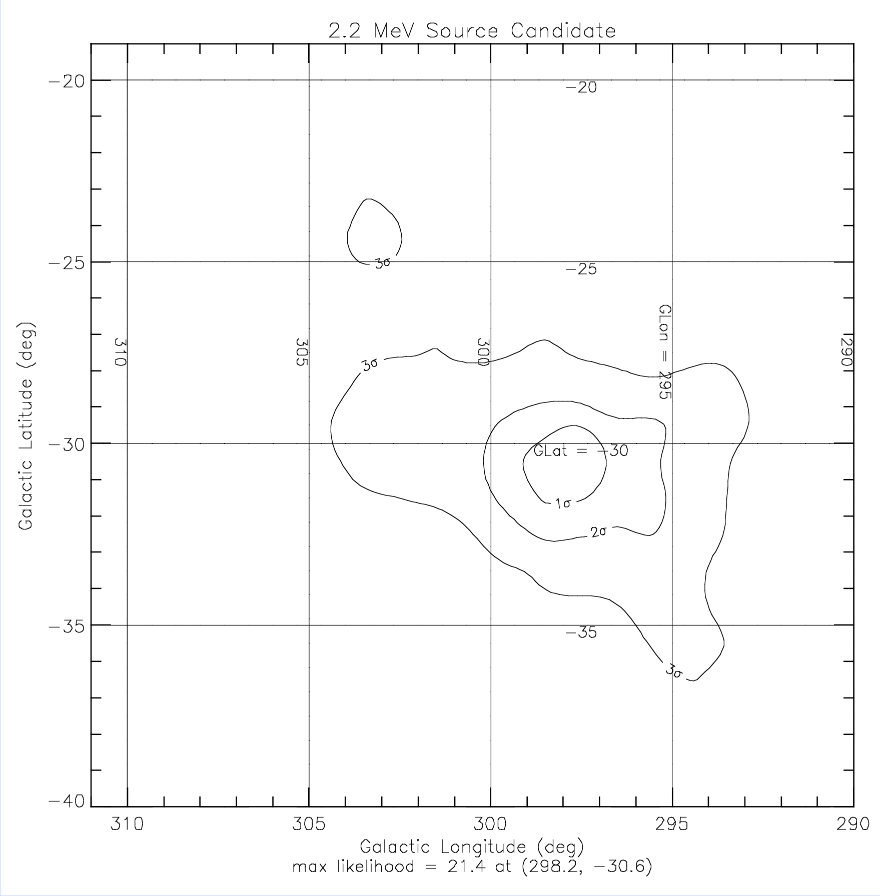


Potential Source Candidate

One potentially significant feature shows up in the synthesized background images.



likelihood map



location contour map

X-Ray Binary Survey

- We have used the X-Ray binary catalog of van Paradijs (1995) to extract flux values (limits).
- Flux values (limits) derived from both the SRCLIX-based and BGDLNE-based maps.
- The BGDLNE-based maps provide somewhat better sensitivity.
- Typical line flux sensitivity level ~ 1-2 $\times$ 10^{-5} cm^{-2} sec^{-1}.
- No XRB is found to be a strong candidate for 2.2 MeV emission.
- Future work will involve the selection of specific sources for a phase-resolved analysis.

Cygnus X-1

☞ No positive detection based on the time-integrated analysis.

☞ 3σ upper limit is 1.84×10^{-5} photons cm^{-2} sec^{-1}.

☞ This is about an order-of-magnitude better than the upper limit derived from SMM data (Harris and Share 1991).

☞ These data can be used to place constraints on the model of Guessom and Dermer (1988), which is based on theescape of neutrons from a two-temperature accretion plasma.

☞ For an ion temperature (T_i) of ~20 MeV, these data suggest that less than 25% of the escaping neutrons are captured by the companion star.

☞ A phase-resolved analysis (in progress) should provide a more sensitive test of this model.

Summary

- We have successfully generated all-sky maps for a narrow energy range centered at 2.223 MeV.
- COMPTEL data from Viewing Periods 1.0 - 523.0 have been incorporated into the analysis.
- One candidate of marginal significance has been noted with no obvious counterpart.
- Upper limits on the time integrated flux from a number of X-ray binaries have been derived. Typical limits are ~1-2 $\times$ 10^{-5} cm^{-2} sec^{-1}.
- A phase-resoled analysis of selected X-ray binaries (including Cygnus X-1) is now in progress.