LAT Analysis with ScienceTools

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Purpose of analysis

- Test for presence of a source, measure its position in the sky
- Extract fluxes of sources of interest. Measure flux vs. time (“lightcurve”) to test for variability.
- Measure spectra of sources
  - Parameters of fitted spectral type, e.g. index of power-law, energy of expenential cut-off, or “super”-exponential cutoff (pulsars)
  - Flux as function of energy (“flux in bands”)

Last time we saw...

- Maximum likelihood is framework/cookbook for estimation and hypothesis testing
- To use, must produce accurate model of data (the rest is derived by following the cookbook)
- Some portions of model are of interest to us
- Others are not
  - Background sources
  - Observational response
- Must be mindful of systematic errors

ScienceTools

- MLE and hypothesis testing is implemented for Fermi LAT data using ScienceTools.
- Data selection and binning into channels.
- Assists in producing of high-level model consisting of gamma-ray sources.
- Transformation into low-level Poisson model for each channel (observational response).
- Estimation of parameters through optimization ("minimization") using log-likelihood.
- Calculation of upper limits.

Data exploration

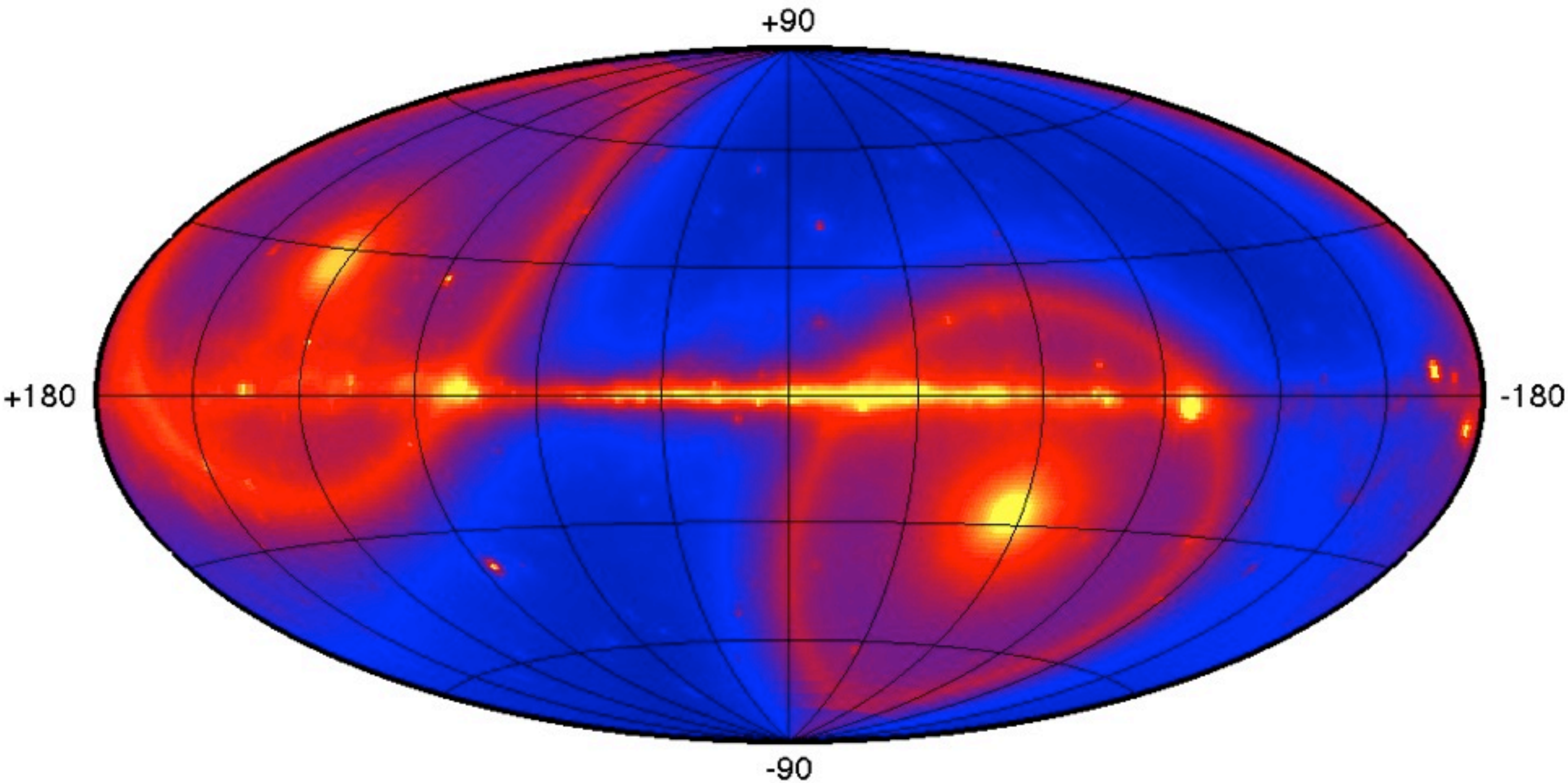
- FT1 files - list of events in FITS format

  Browser: http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi

  All-sky: http://heasarc.gsfc.nasa.gov/FTP/fermi/data/lat/weekly/p7v6/

- Events reconstructed @SLAC and consist of:
  - Estimate of direction of origin
  - Estimate of the energy
  - “Probability” of being gamma ray (event classification)
  - Zenith angle, conversion point (front or back), detection time, ...

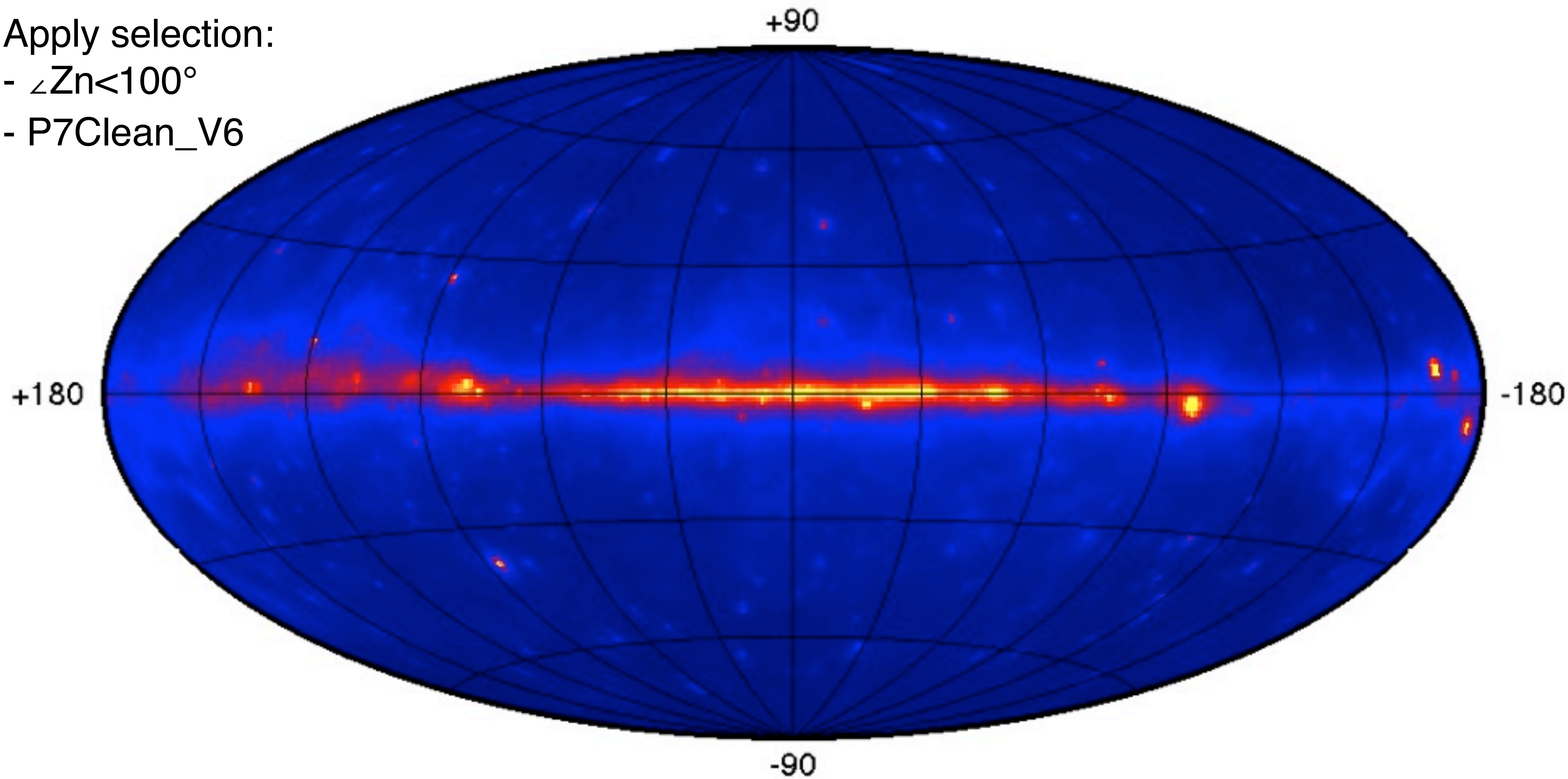
Data set (4.8 years)



- Data set that we would like to analyze (using ML).
- Or in fact, it is a simplification.. the energy and time dependence is not shown!

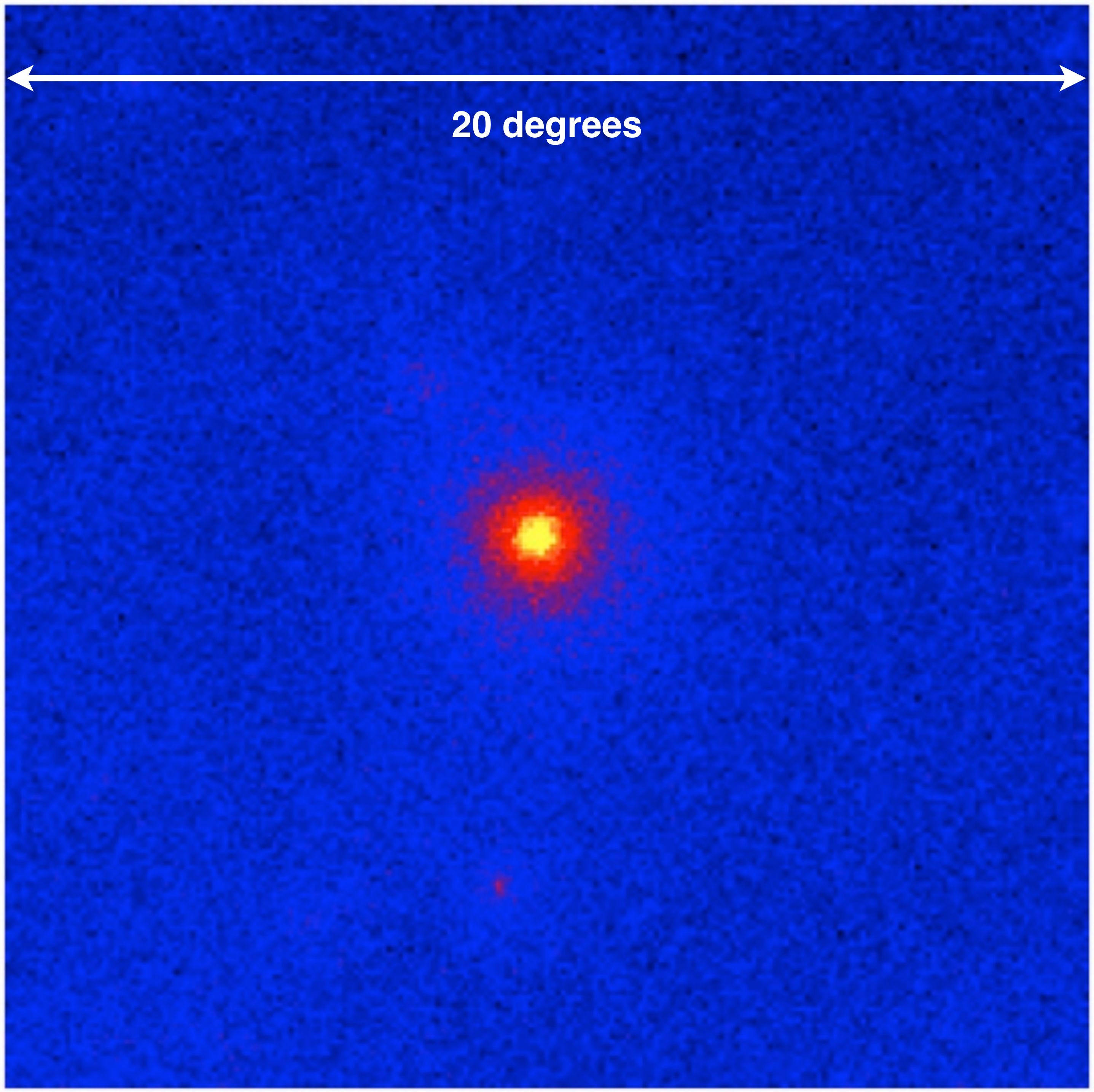
Data set with sensible cuts

Apply selection:
- ∠Zn<100°
- P7Clean_V6



- Some part of the “background” can be removed: “cuts”.
- Makes it easier to model (remaining) data.
- Rest of cannot easily be separated: must be modeled.

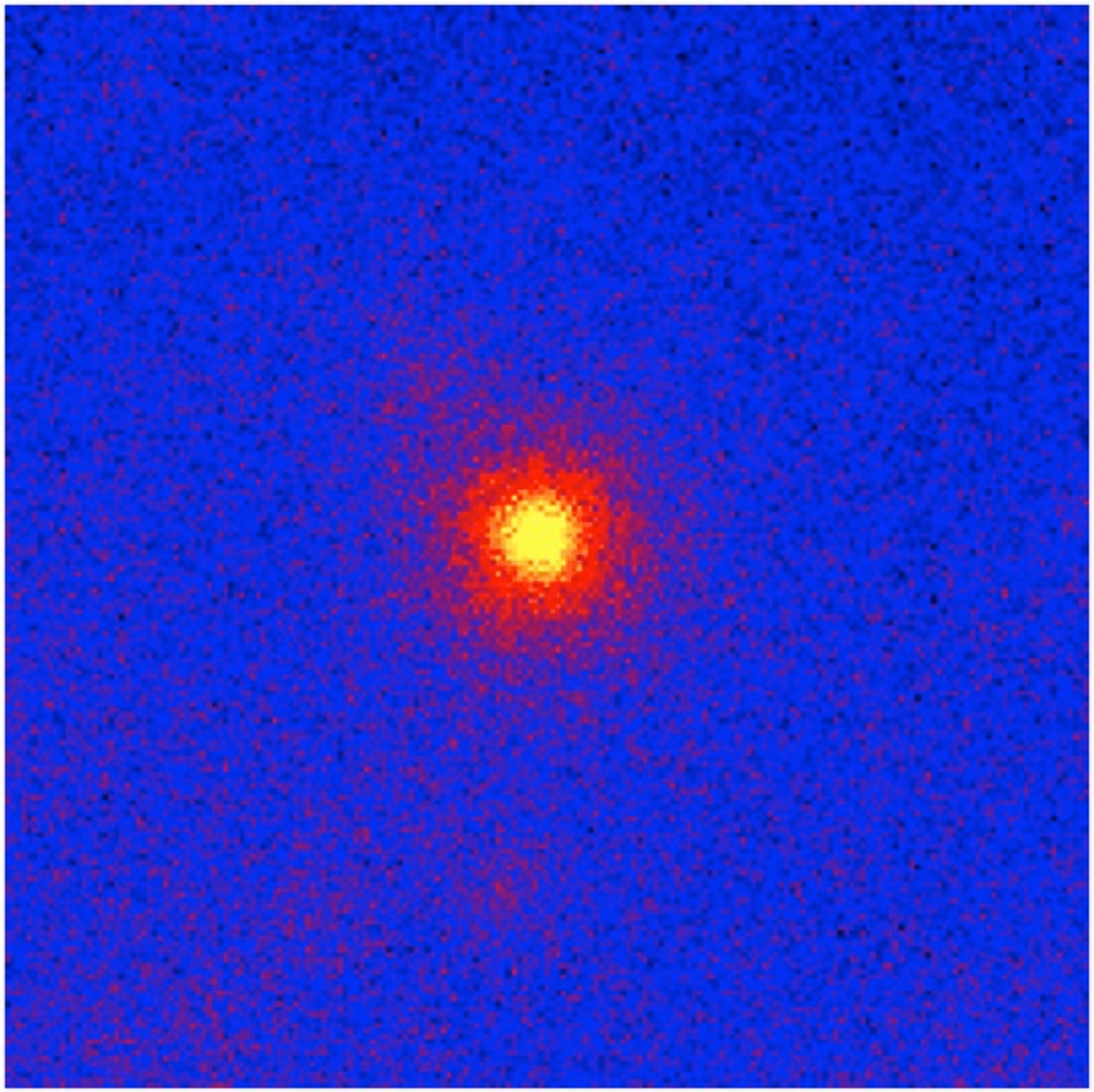
Region of interest (ROI)



0.1GeV - 100GeV

- Don't have to analyze full sky at once!
- Region of interest (RegionOI) around source.
- Larger: better measure background (>TS)
- Smaller: faster & lower systematics
- About 20 degrees is

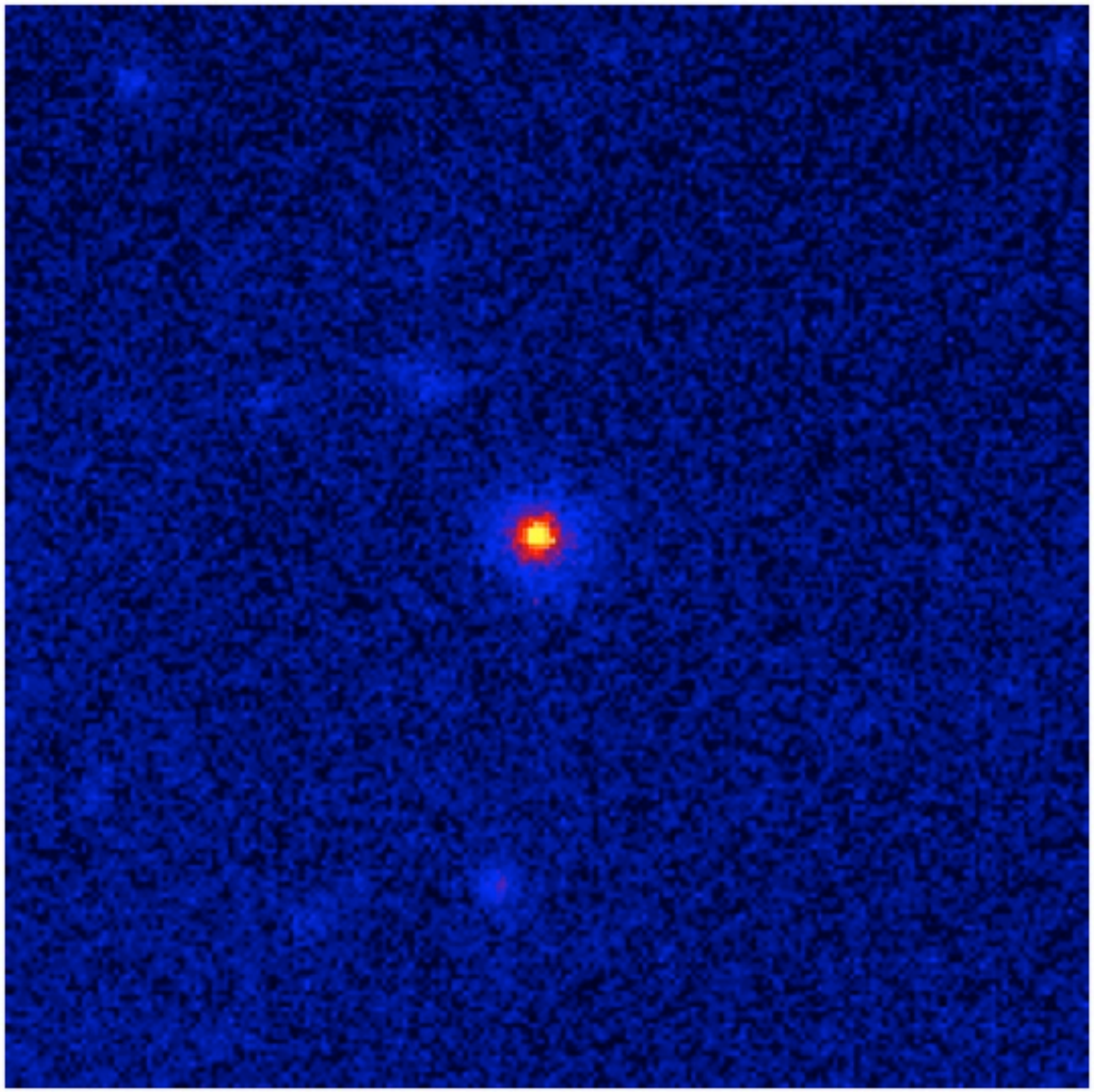
Channels of position & energy



0.1GeV - 1GeV

- Analyze events in channels of position and energy...
- ... as we are interested in spatial and energy dependence of sources
- ... best sensitivity achieved by using all information possible (as long as it can be modeled accurately!)

Channels of position & energy



1GeV - 10GeV

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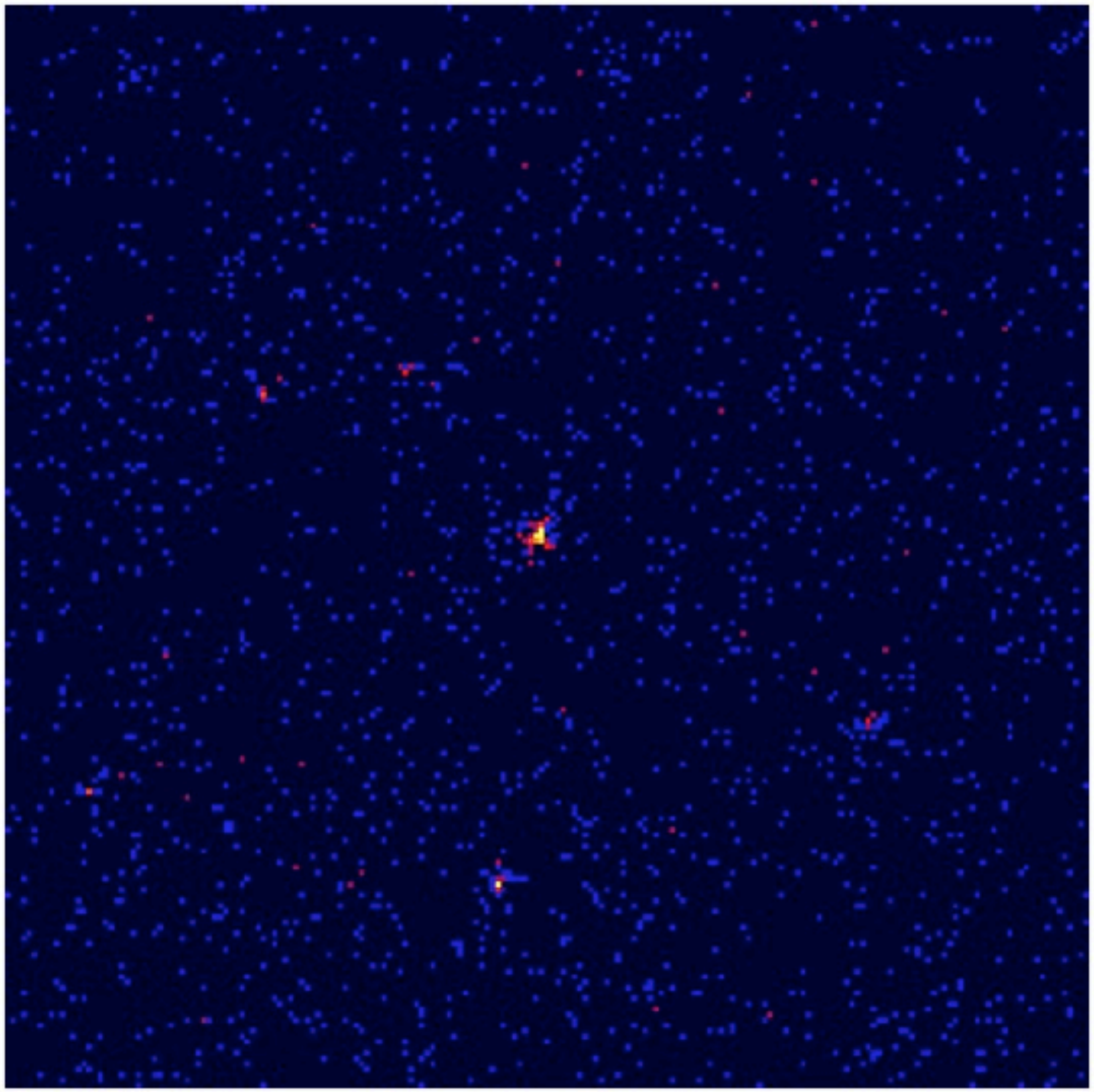

10GeV - 100GeV

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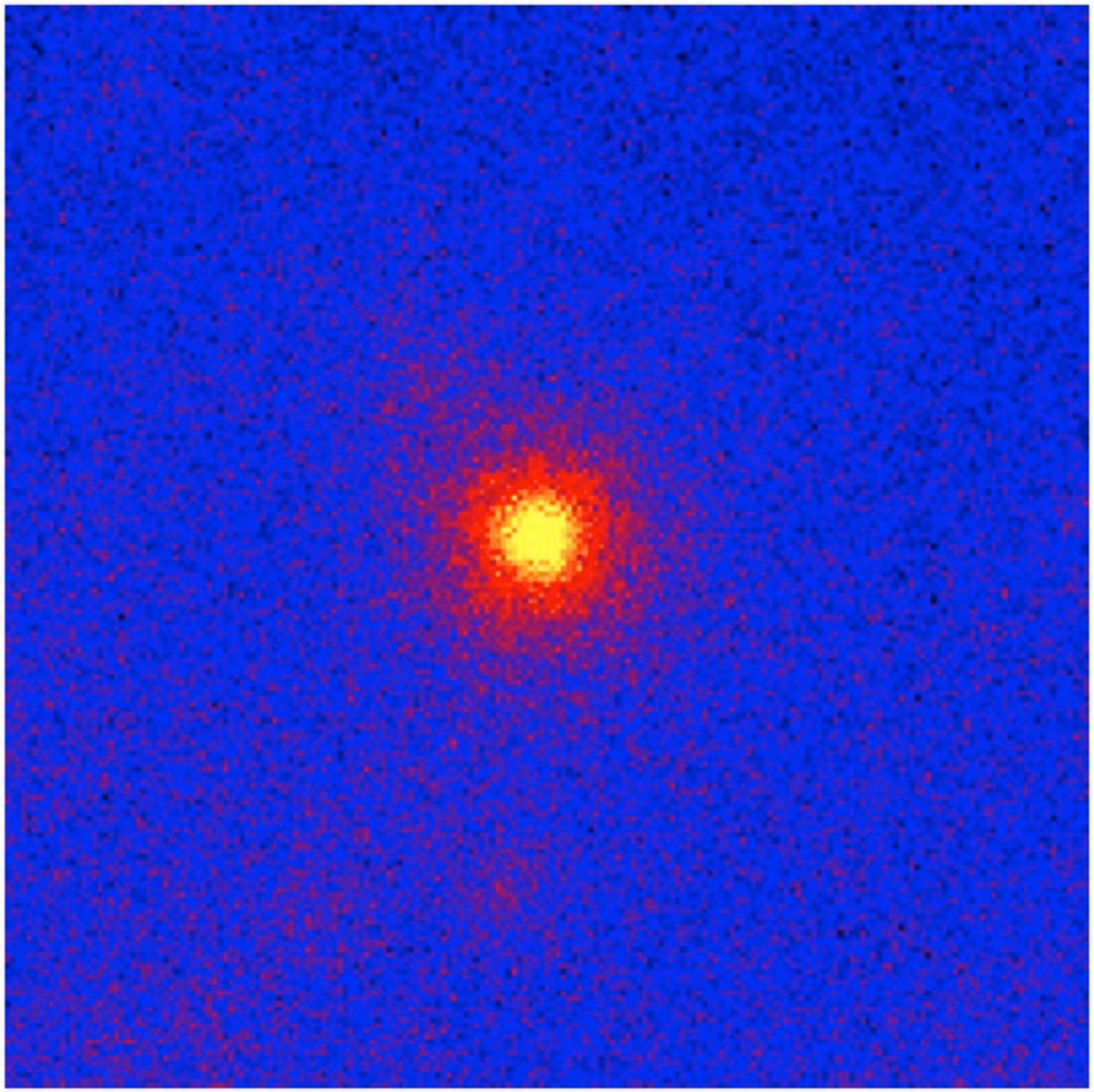
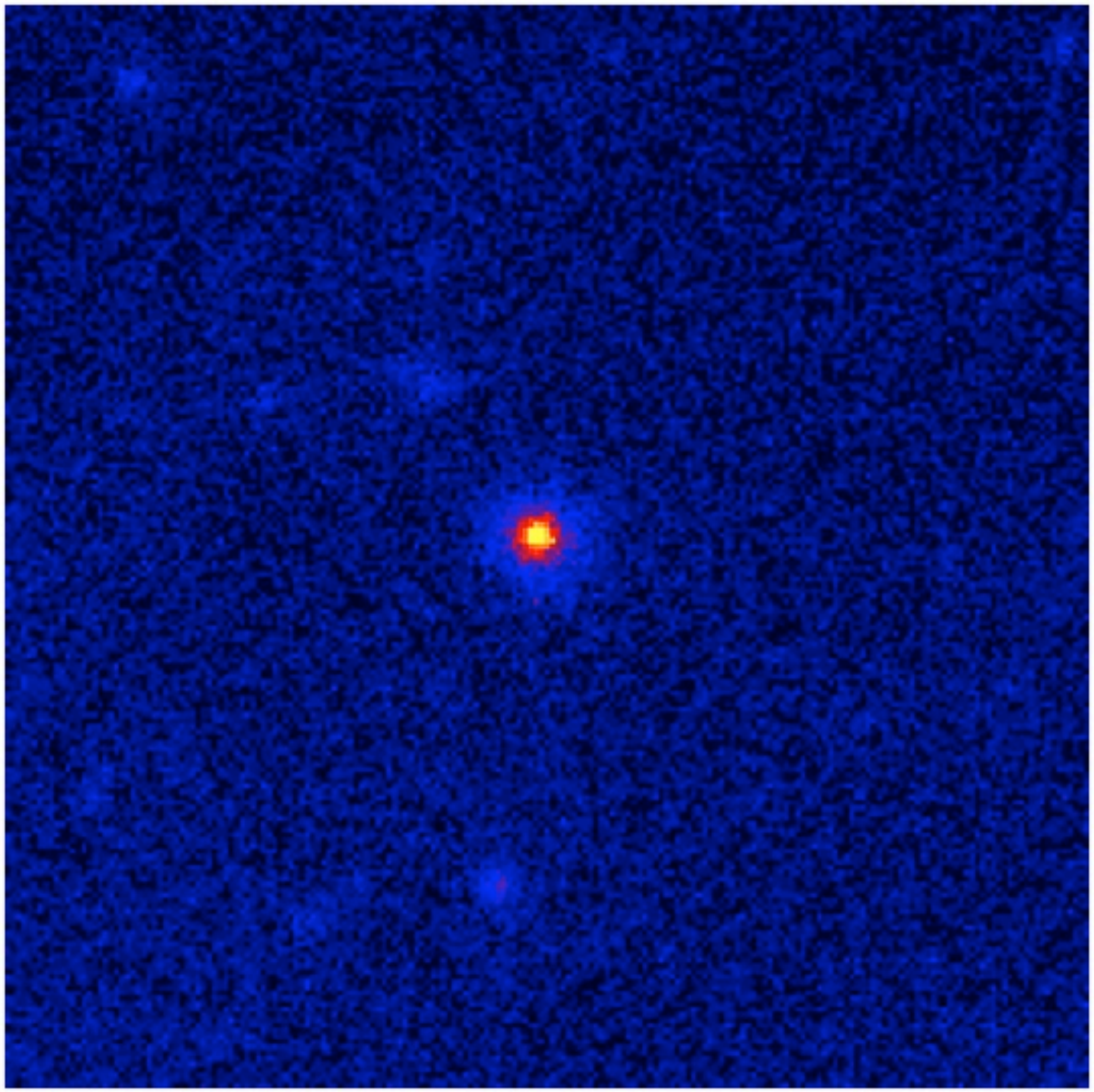
Energy dependency



0.1GeV - 1GeV

1. At higher energies there are fewer events,
2. but, sources look less spread out (PSF)
3. and there is less background.
4. Sources seem most clearly detectable somewhere in the middle range.

Energy dependency



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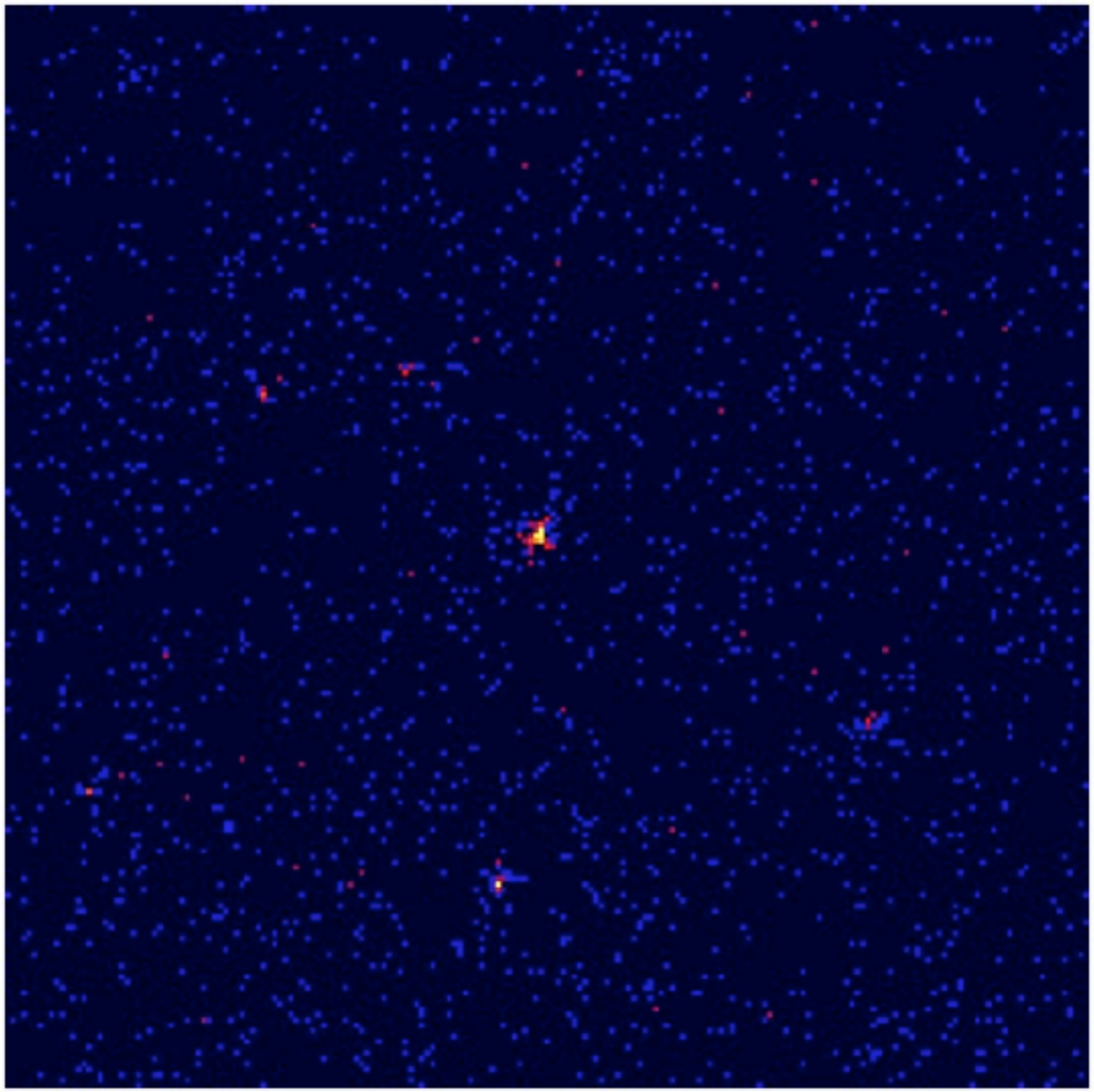

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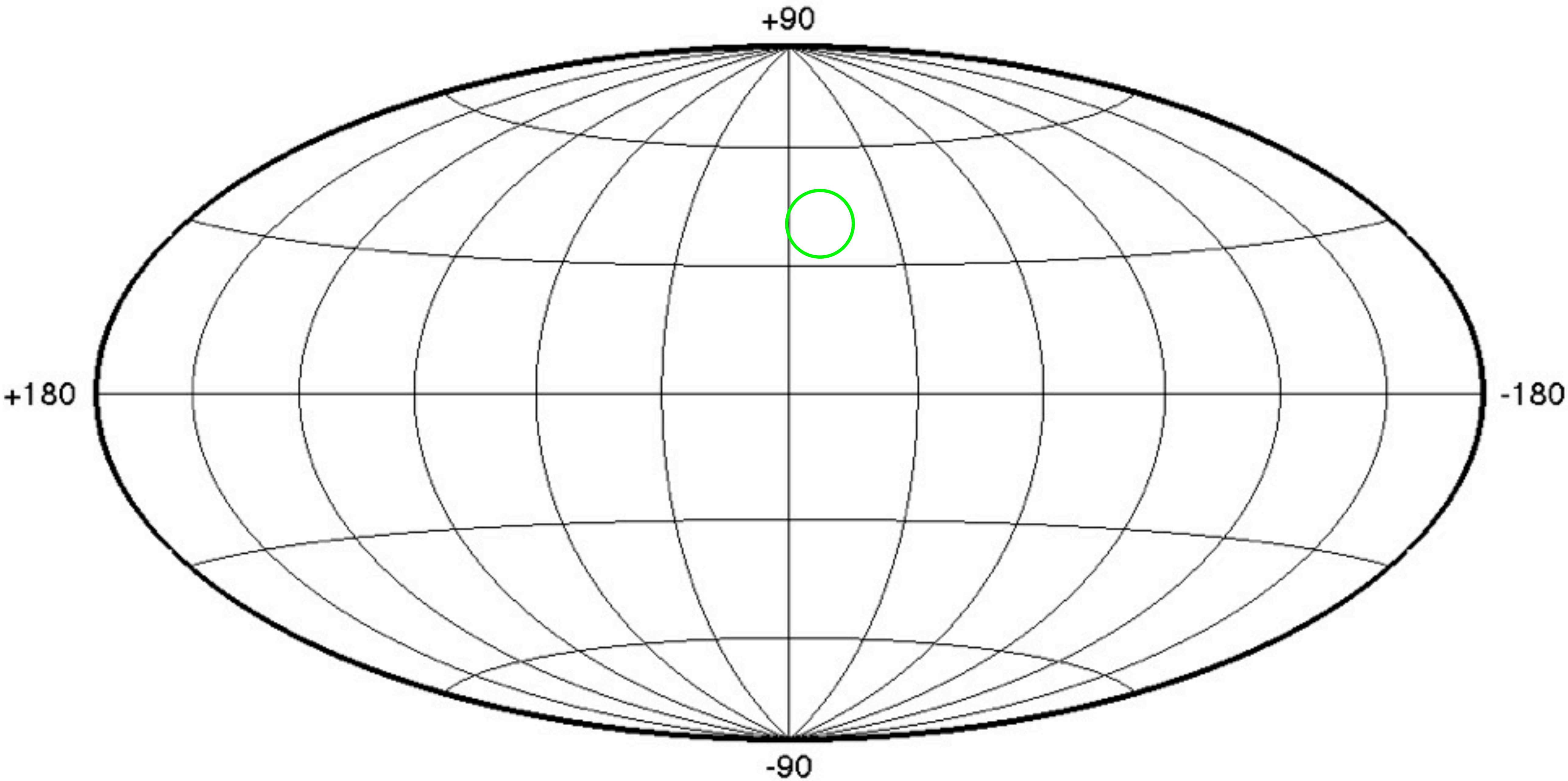

- Modeling must also account for the "observing profile".
- Rate of γ rays from source depends on its (constantly changing) position in the field of view of the LAT.

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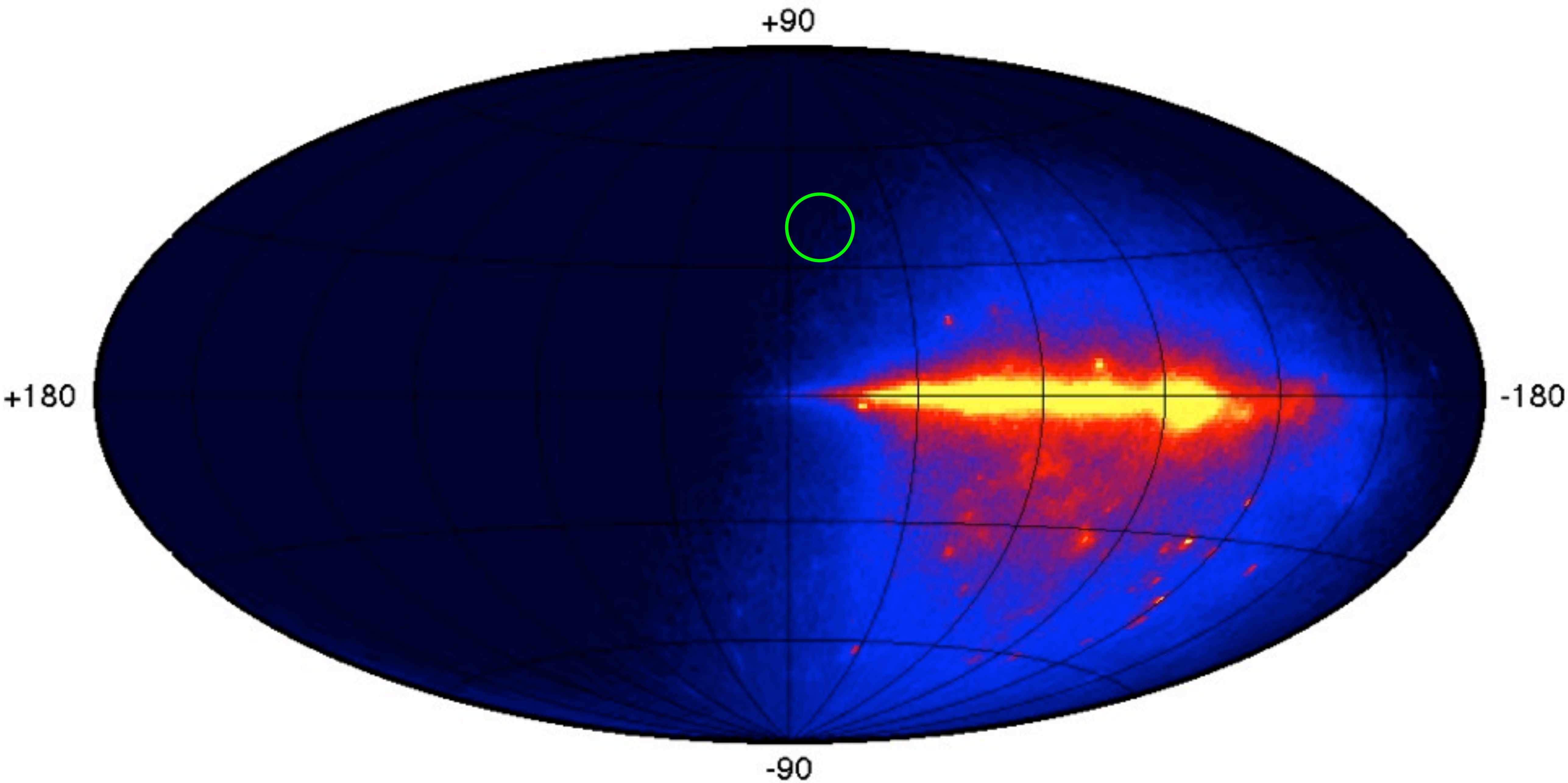

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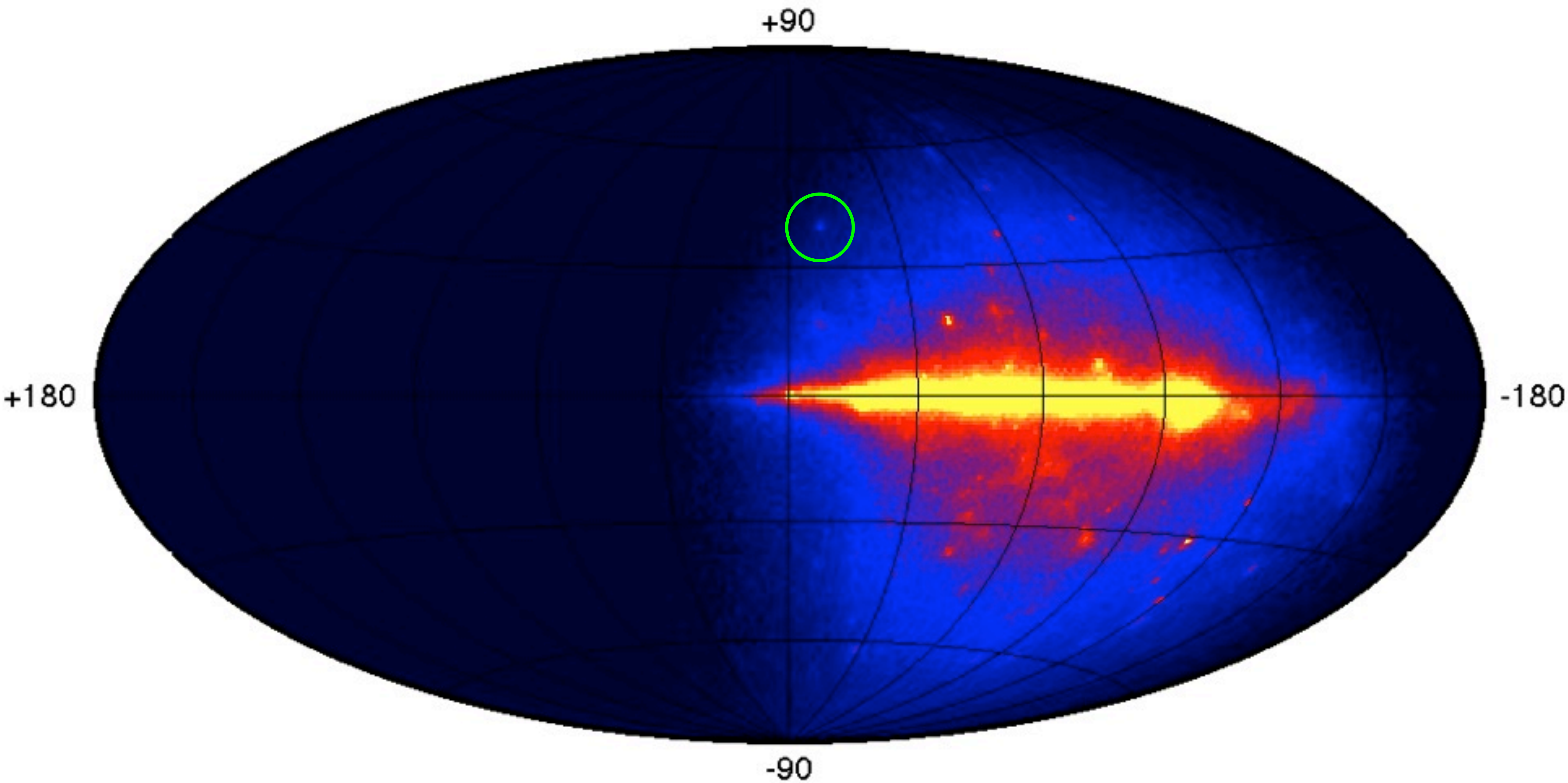

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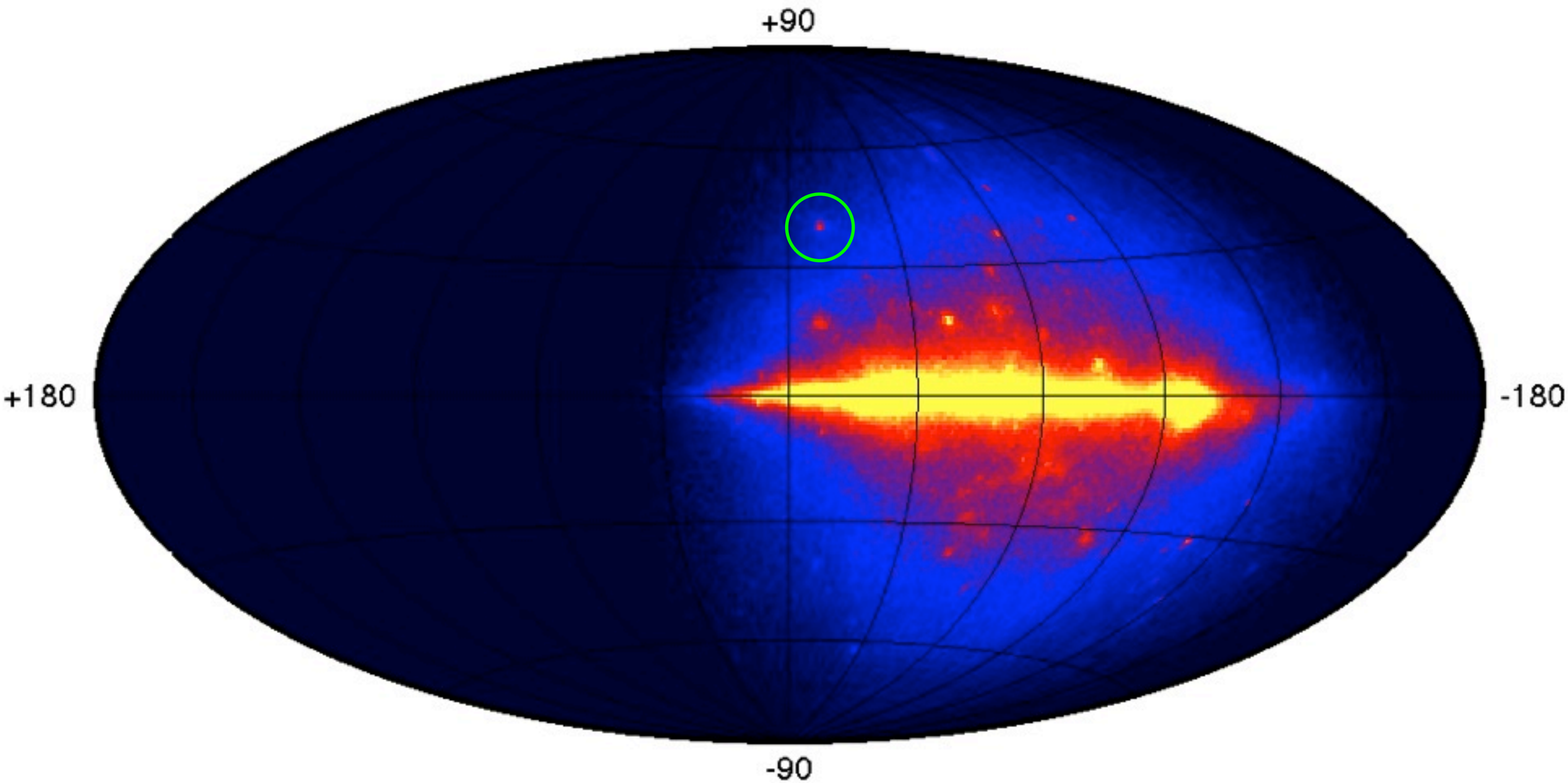

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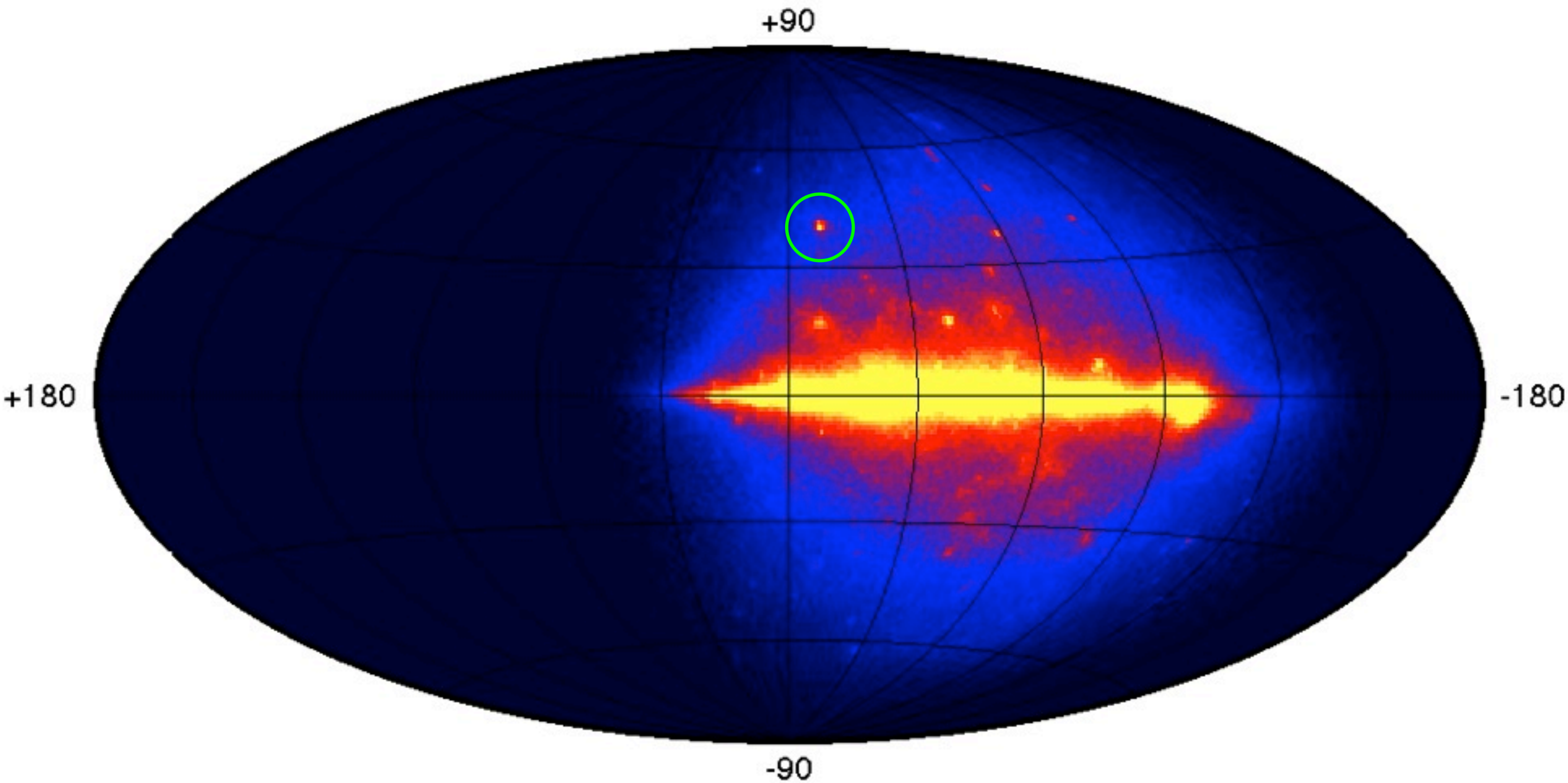

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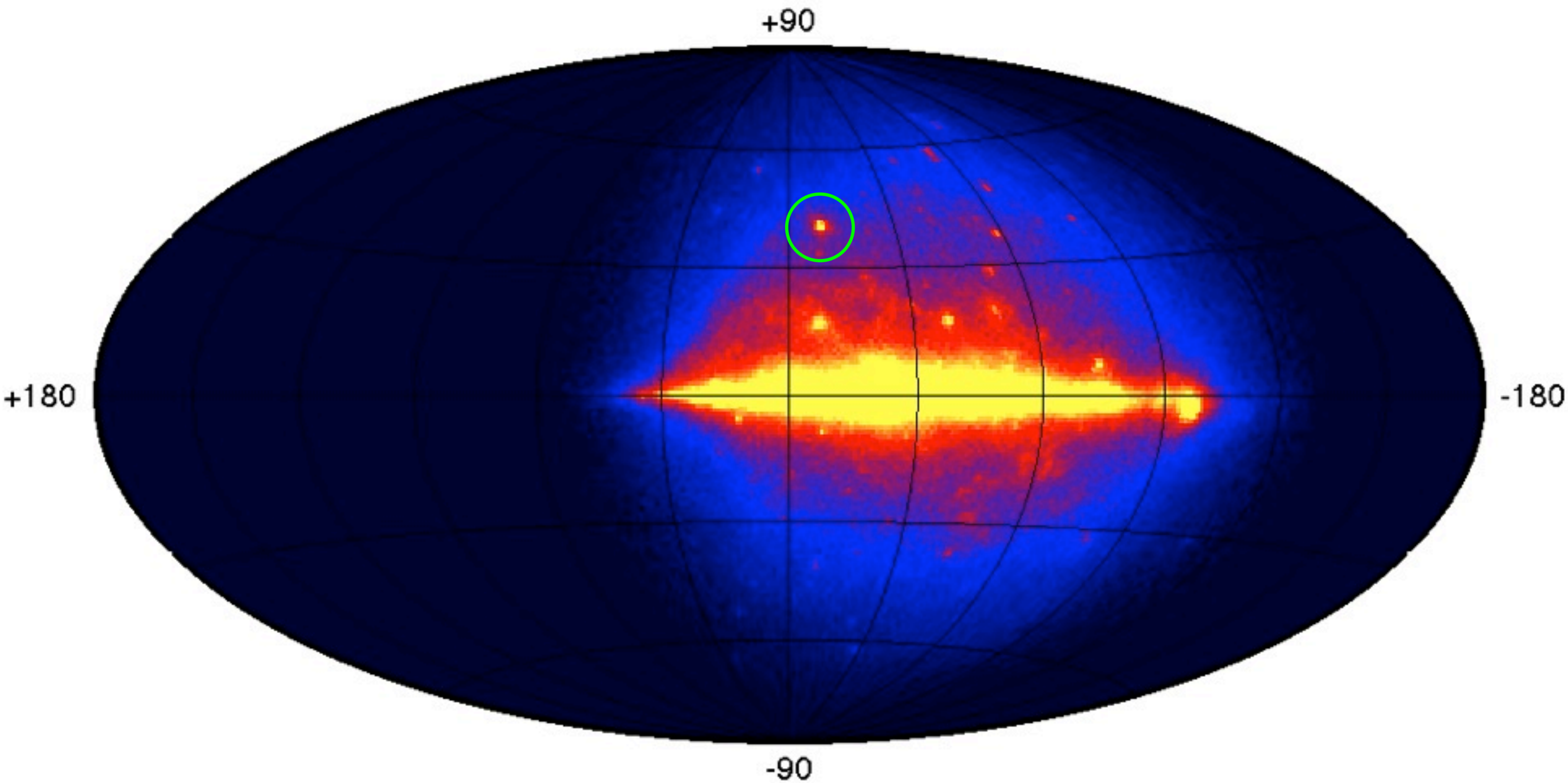

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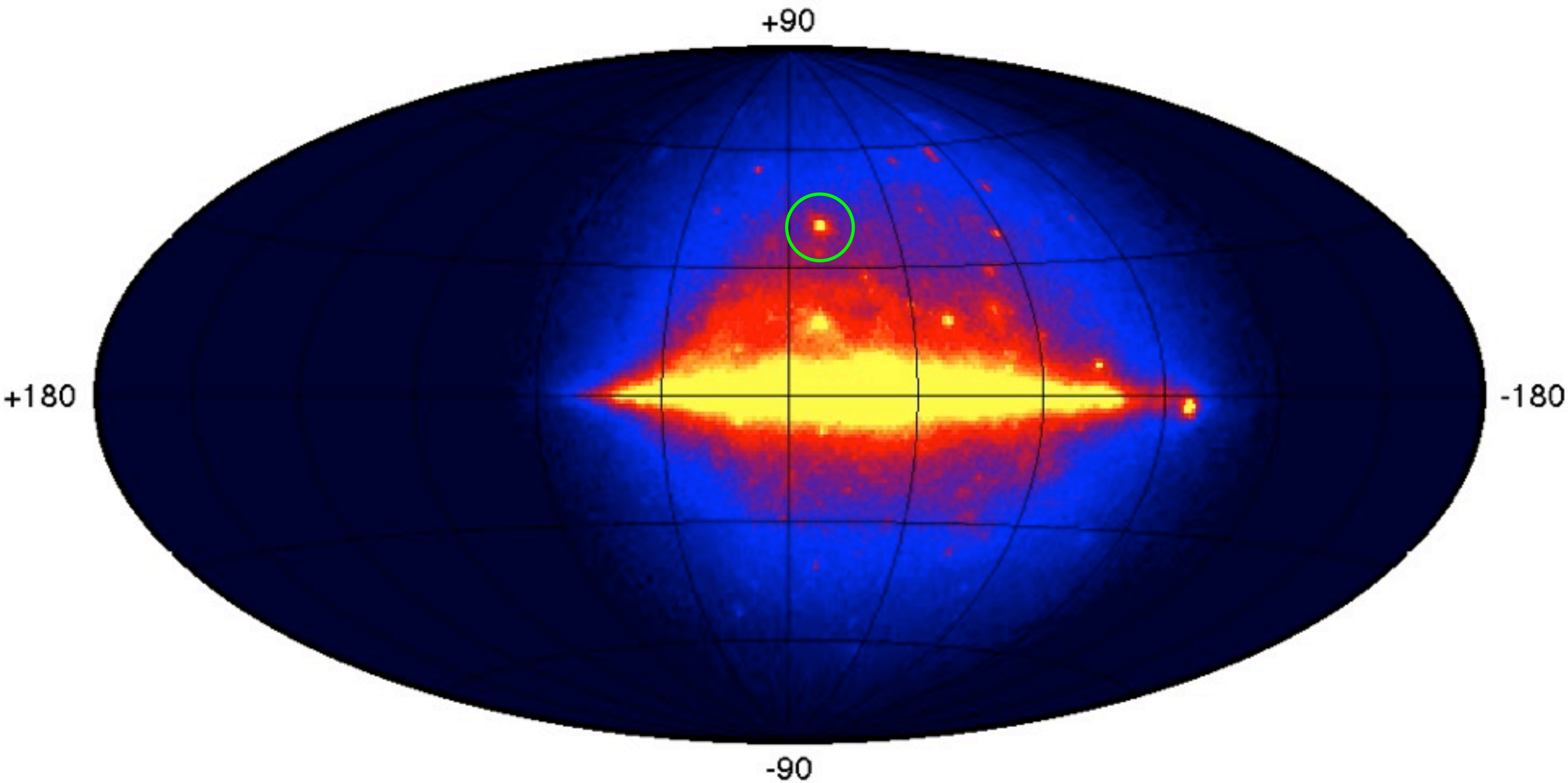

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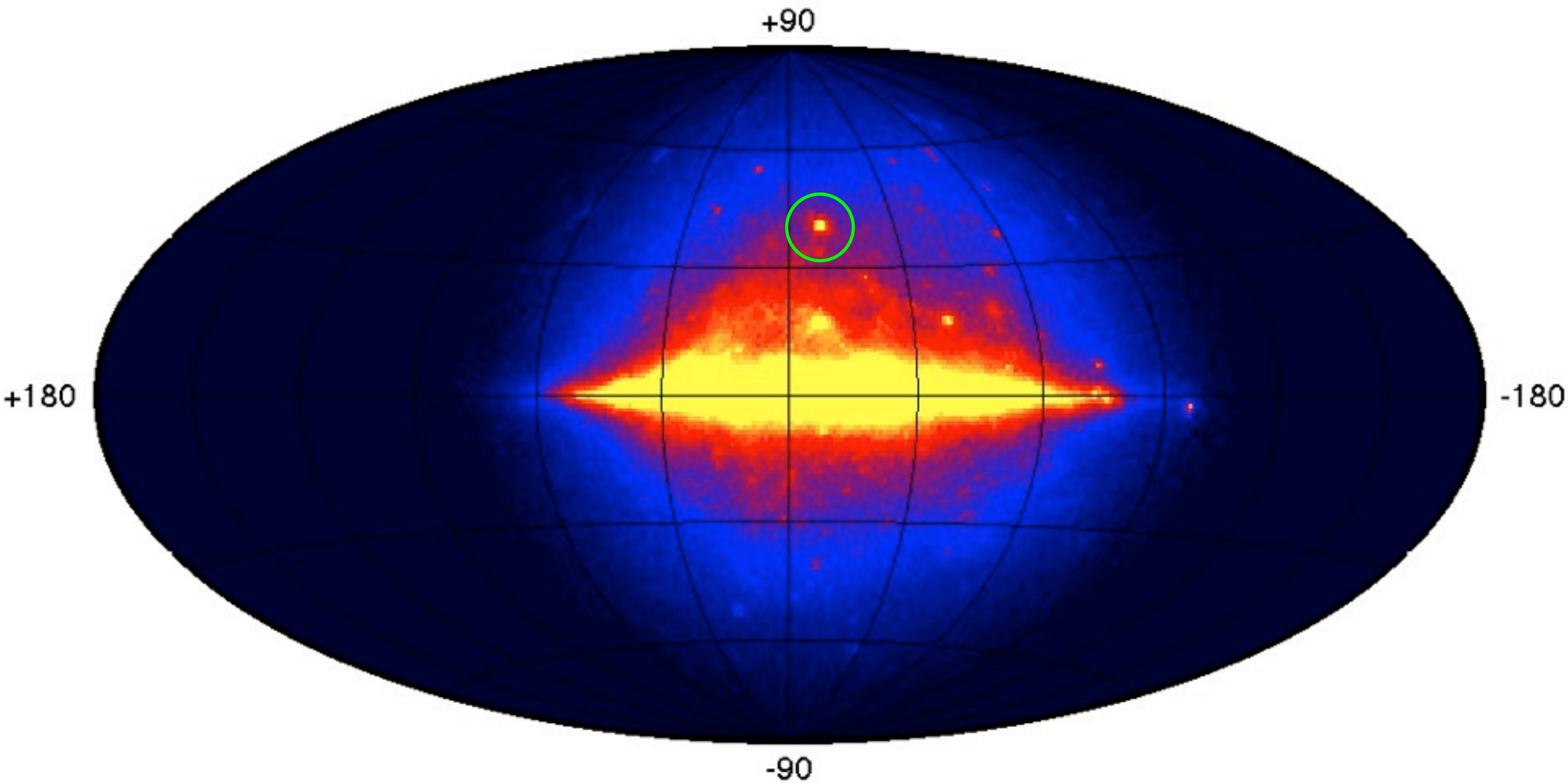

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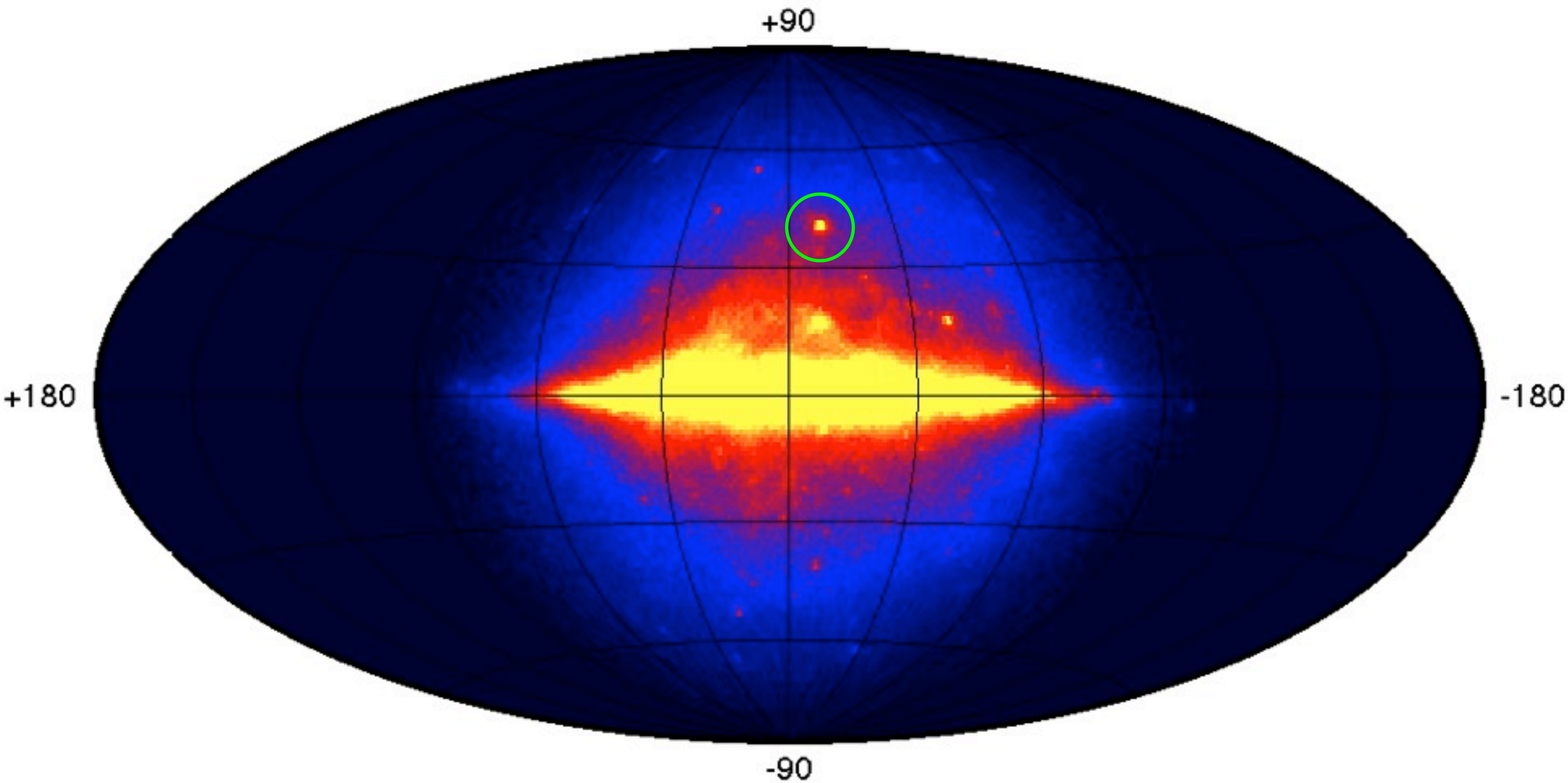

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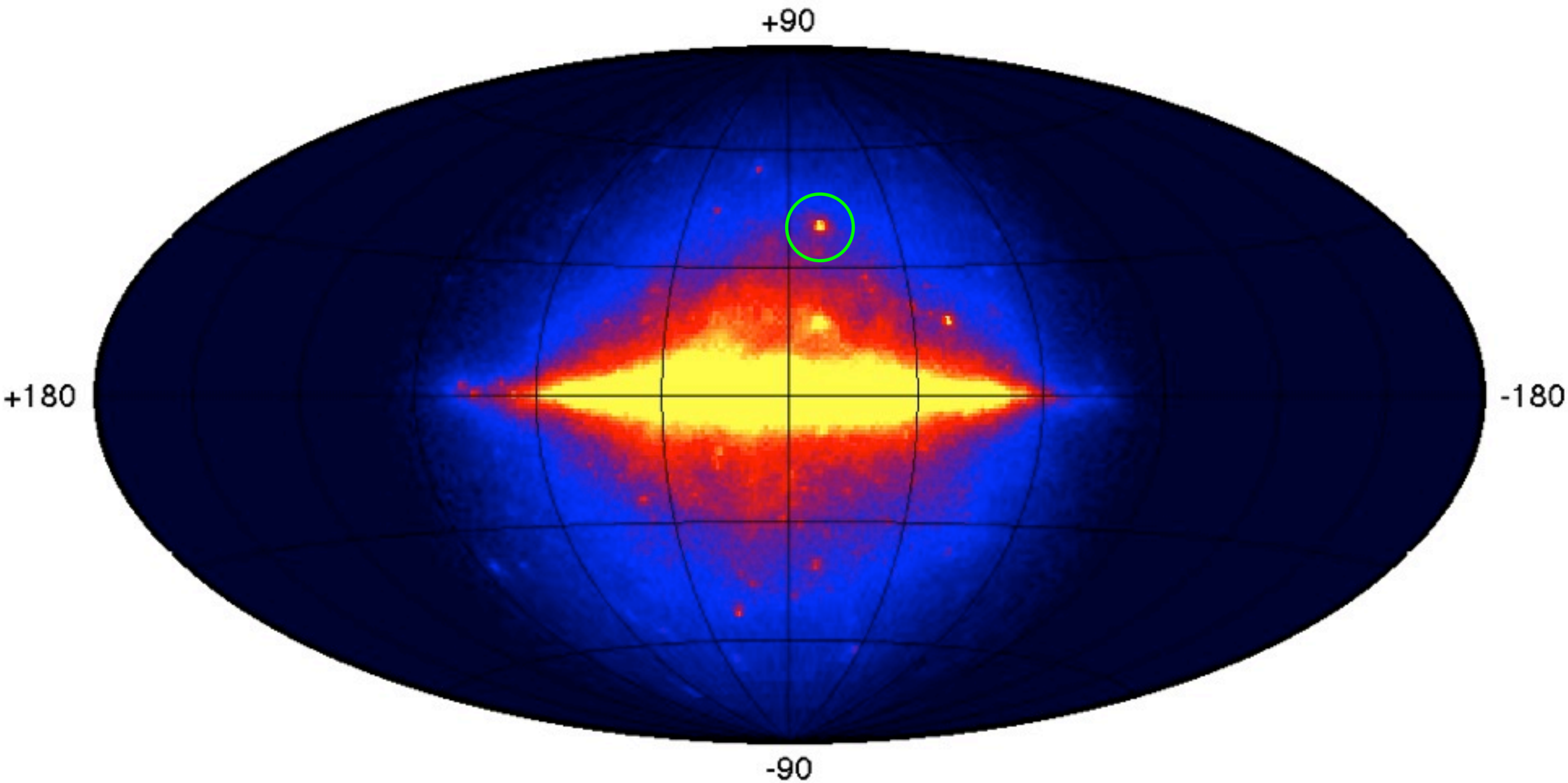

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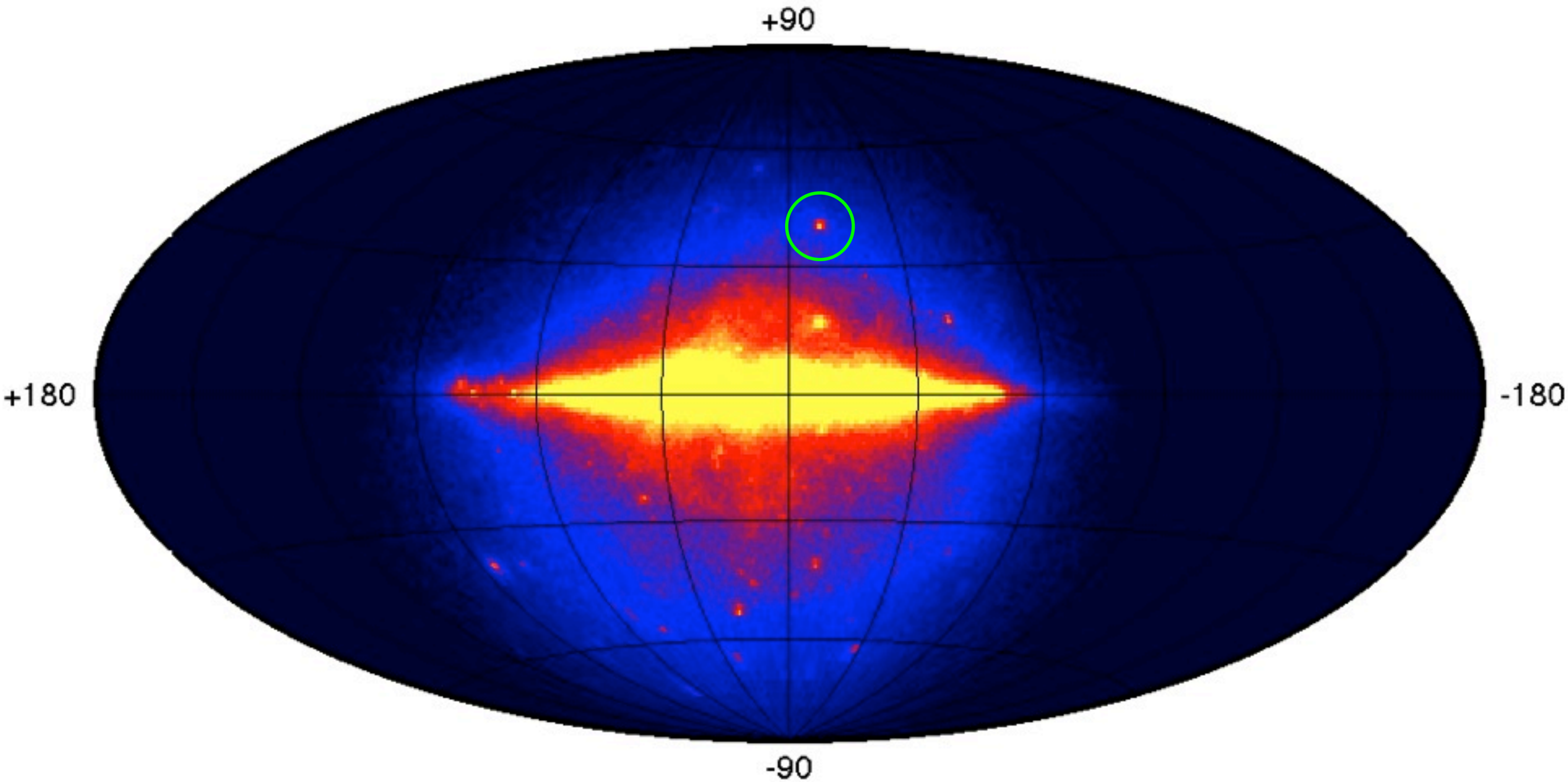

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Model

- Sky model
  - Spatial distribution of sources in ROI (point-like and extended sources)
  - Spectral model for each source
- Observational response (“exposure”)
  - Observational profile
  - Instrument response functions (IRFs)

Model

Equivalents in statistics talk:

- Sky model
  - Spatial distribution of sources in ROI (point-like and extended sources)
  - Spectral model for each source

$\{S, B\}$

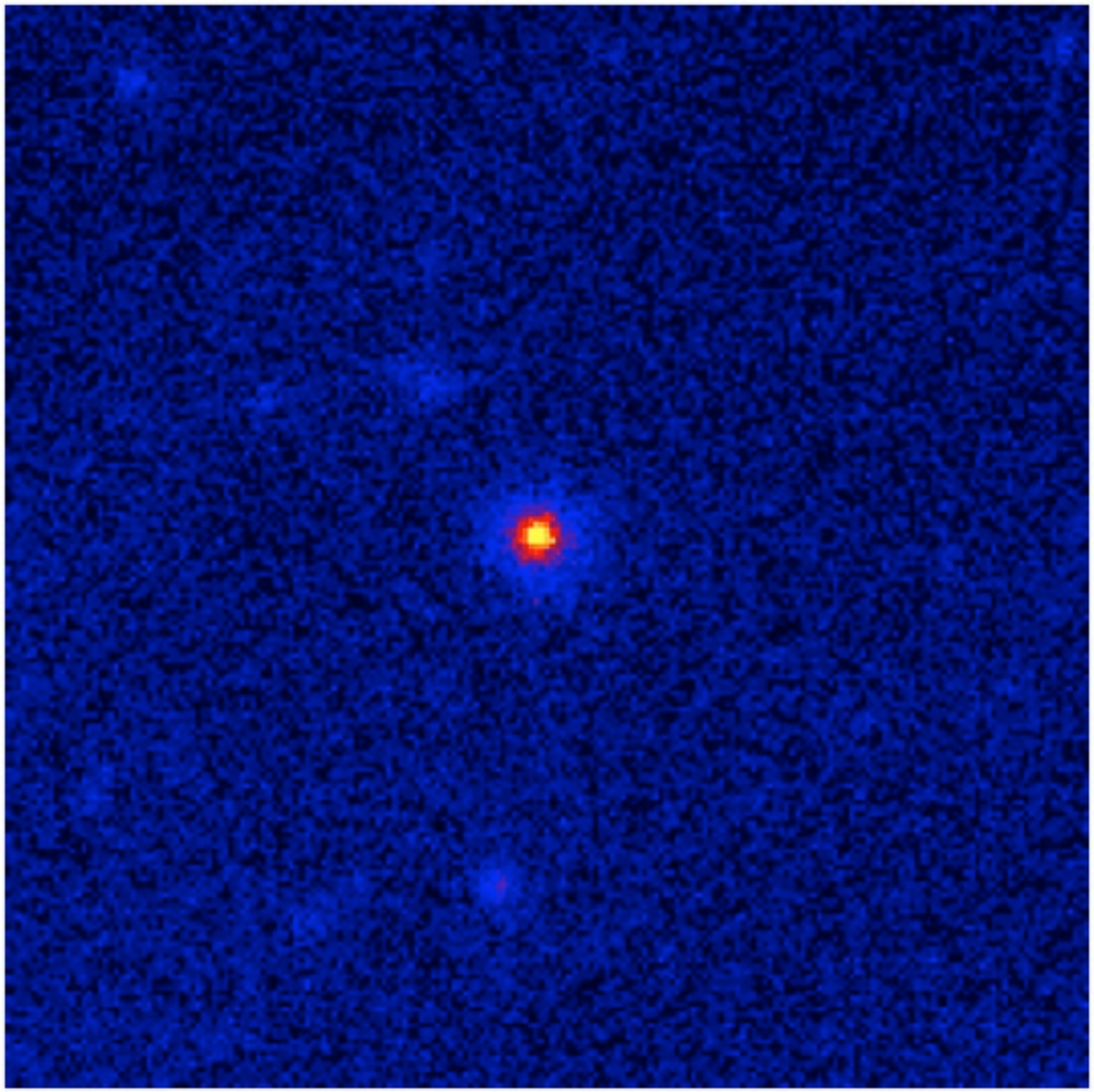
- Observational response ("exposure")
  - Observational profile
  - Instrument response functions (IRFs)

$\begin{pmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{pmatrix}$

Sky model

- Spatial and spectral model
- Point sources (coordinates: RA & Dec)
- Extended sources (map of emission)
- Diffuse sources (full sky maps)
- Spectral types (e.g. power law - index, flux)
- No time dependence!
- All these encoded in an XML input file
  - ST and LAT catalogs can help with this task

Example model for ROI



1GeV - 10GeV

- Sources from 2FGL catalog in (& on edge of) the ROI
  - Best-fit locations and spectral types (2yr)
- Diffuse isotropic
  - Extragalactic diffuse
  - Local cosmic rays
- Galactic diffuse
  - CR interactions

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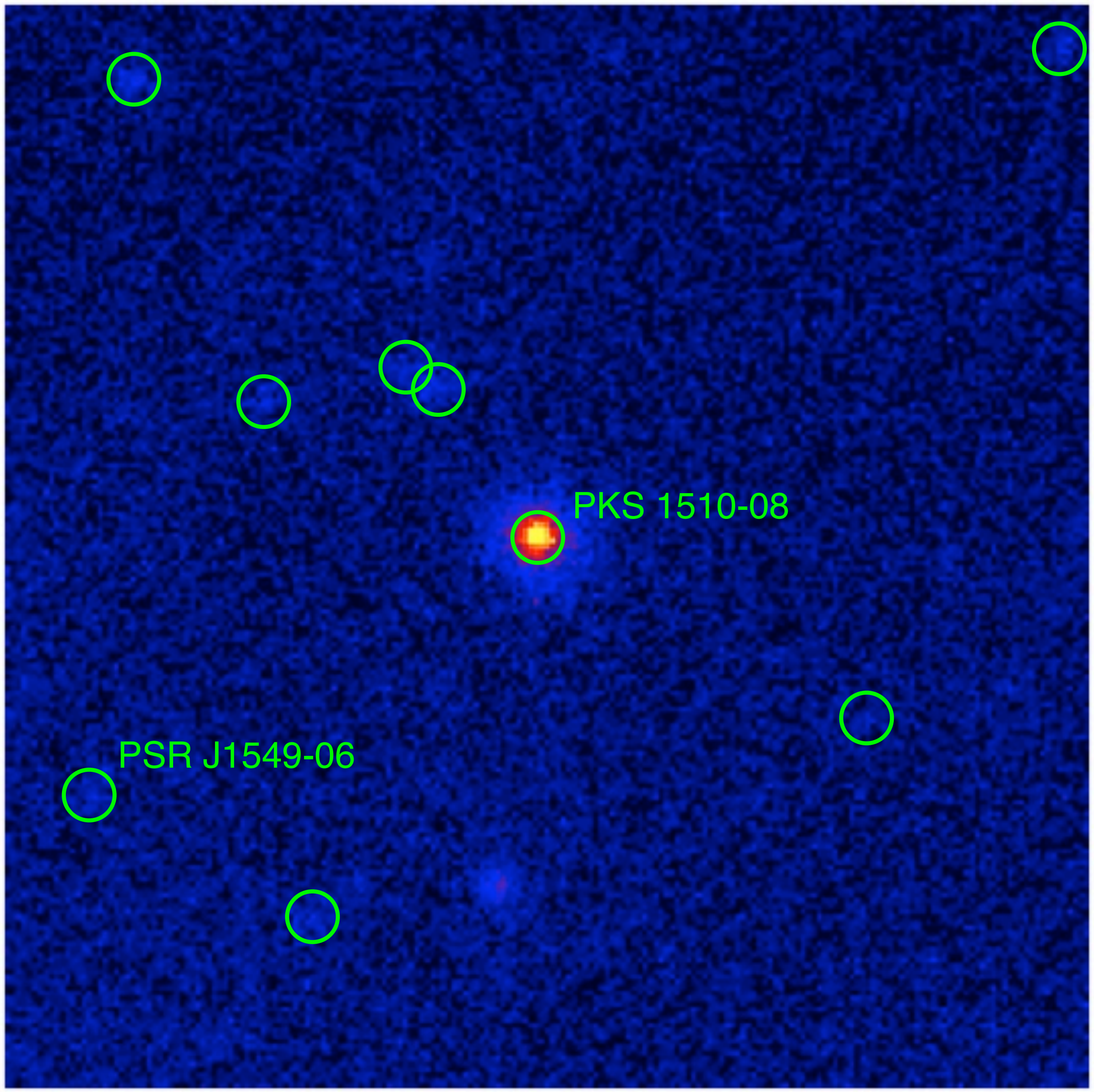

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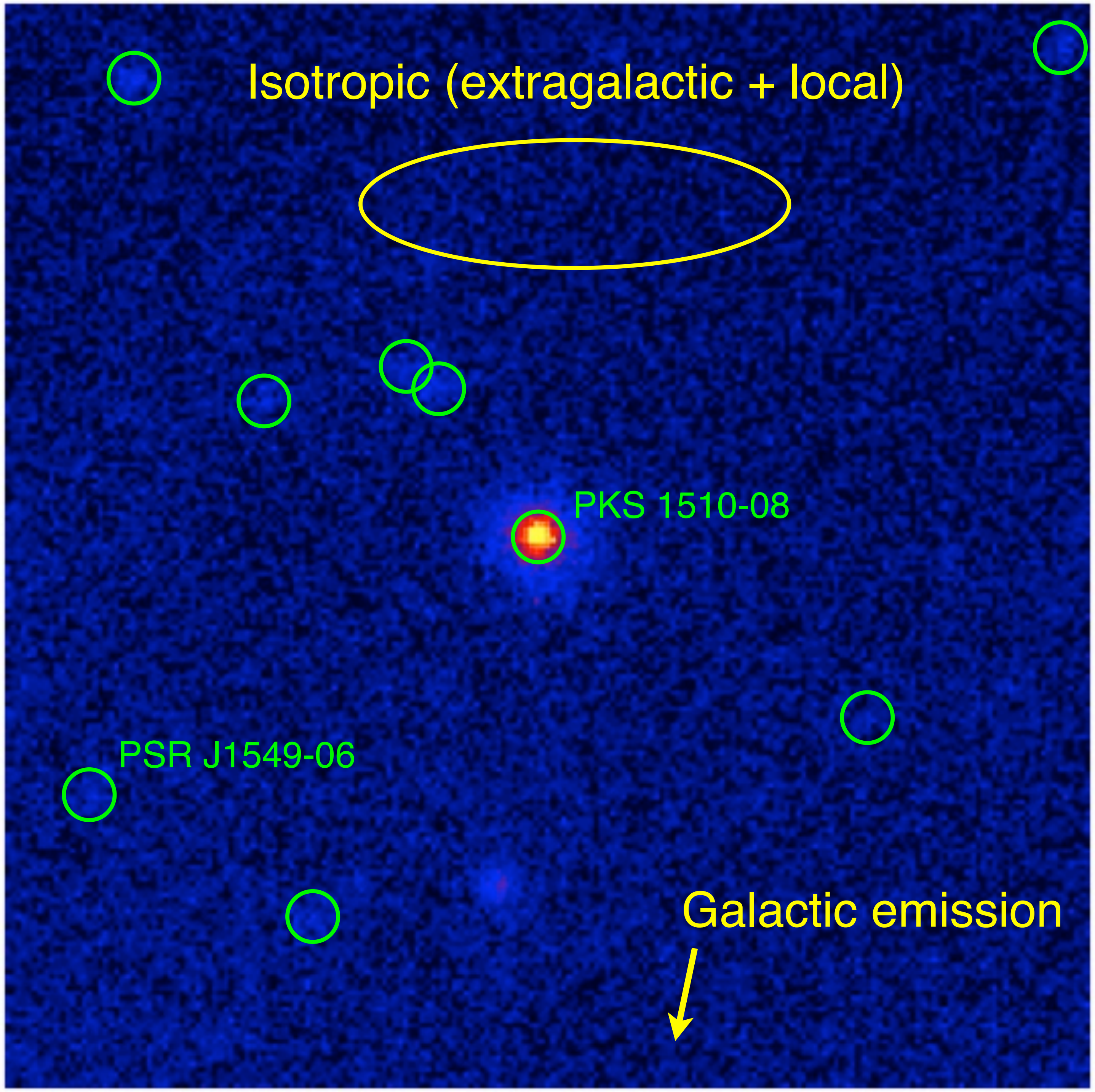

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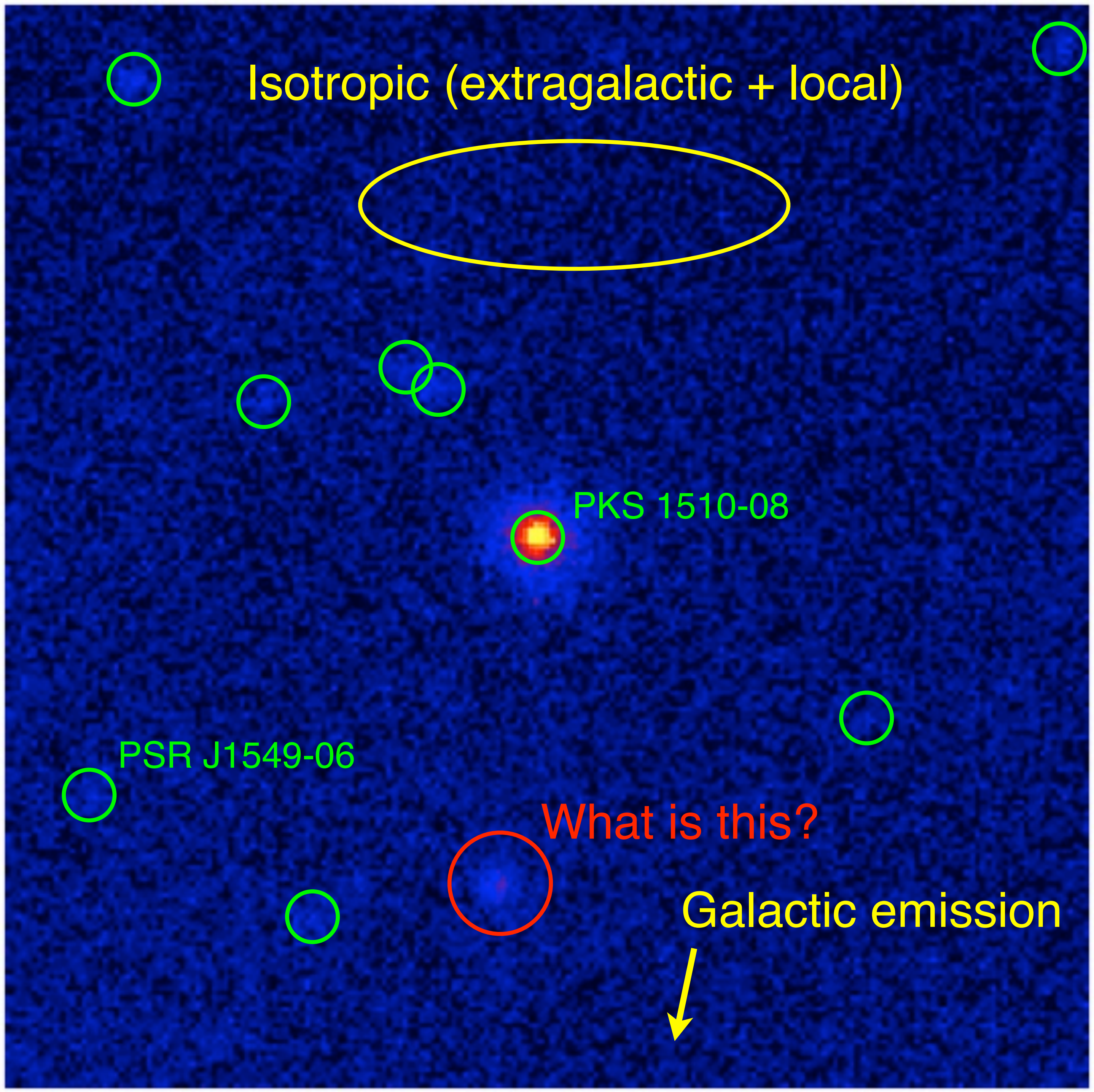

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Observational profile

- Pointing records from FT2 file - every 30 seconds
- Direction of LAT bore site (z-axis)
  - and of x-axis for phi dependence
- Observation mode - sky survey, pointed
- Jeremy described this yesterday

Instrument response functions

- Effective area - how the area of the instrument depends on energy and angle
- PSF - how the
- Energy dispersion
- Plots of all 3

Exposure

- Putting together obs profile & IRFs
- Some graphs of exposure
- Possibly an FFT?

Likelihood

- Unbinned
- Binned

The gory details

- Slide showing full likelihood function

Analysis flow - Binned

1. Create model
2. Extract data `gtselect/gtmktime`
3. Bin data into counts cube `gtbin`
4. Compute observation profile `gtltcube`
5. Compute exposure cube `gtexpcube2`
6. Produce source maps `gtsrcmaps`
7. Do MLE and compute TS `gtlike`

Analysis flow - Unbinned

1. Create model
2. Extract data `gtselect/gtmktime`
3. *Compute diffuse response* *`gtdiffrsp`*
4. Compute observation profile `gtltcube`
5. Compute diffuse exp. maps `gtexpmap`
6. Do MLE and compute TS `gtlike`