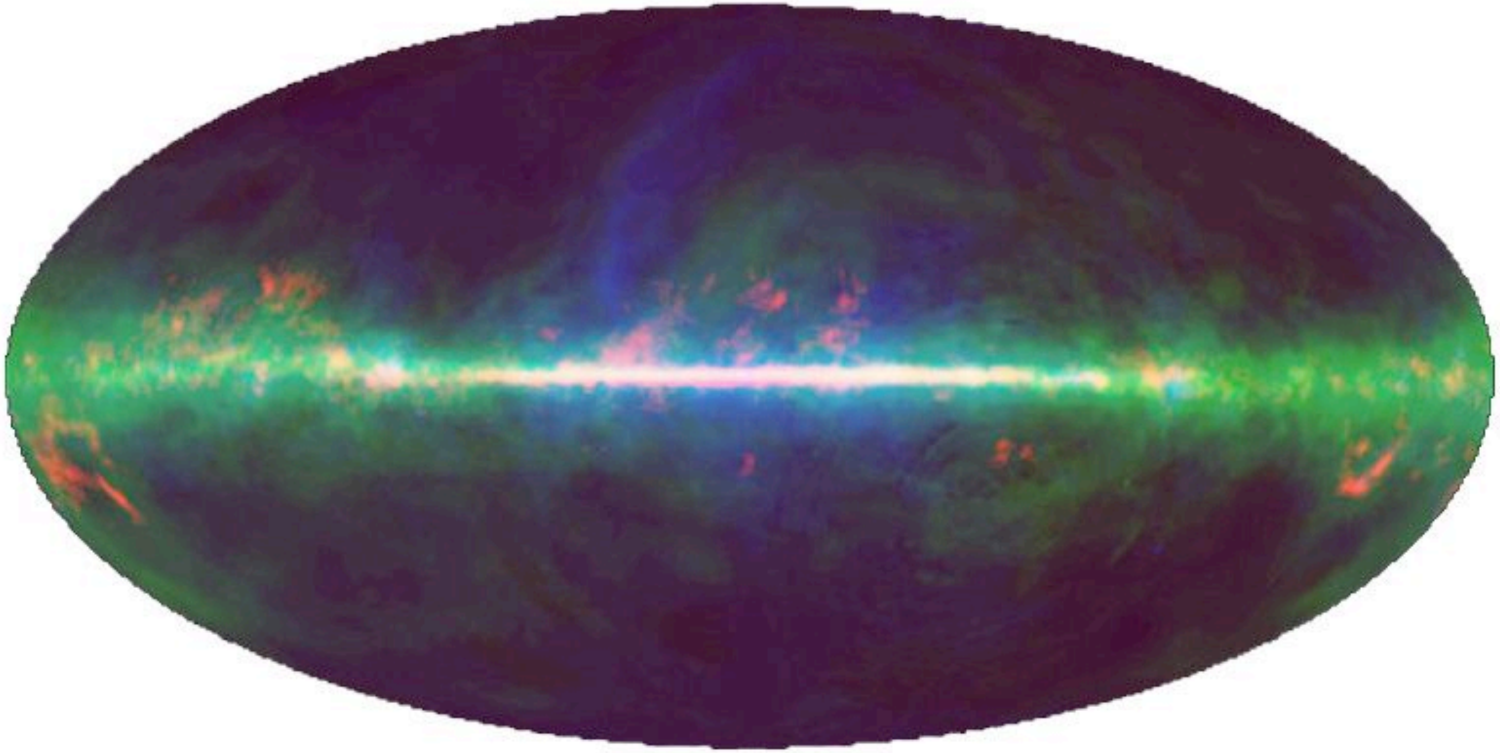
Observing the X- and Gamma-Ray Sky

Diffuse emission



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Lecture Outline

I. What is diffuse emission ?

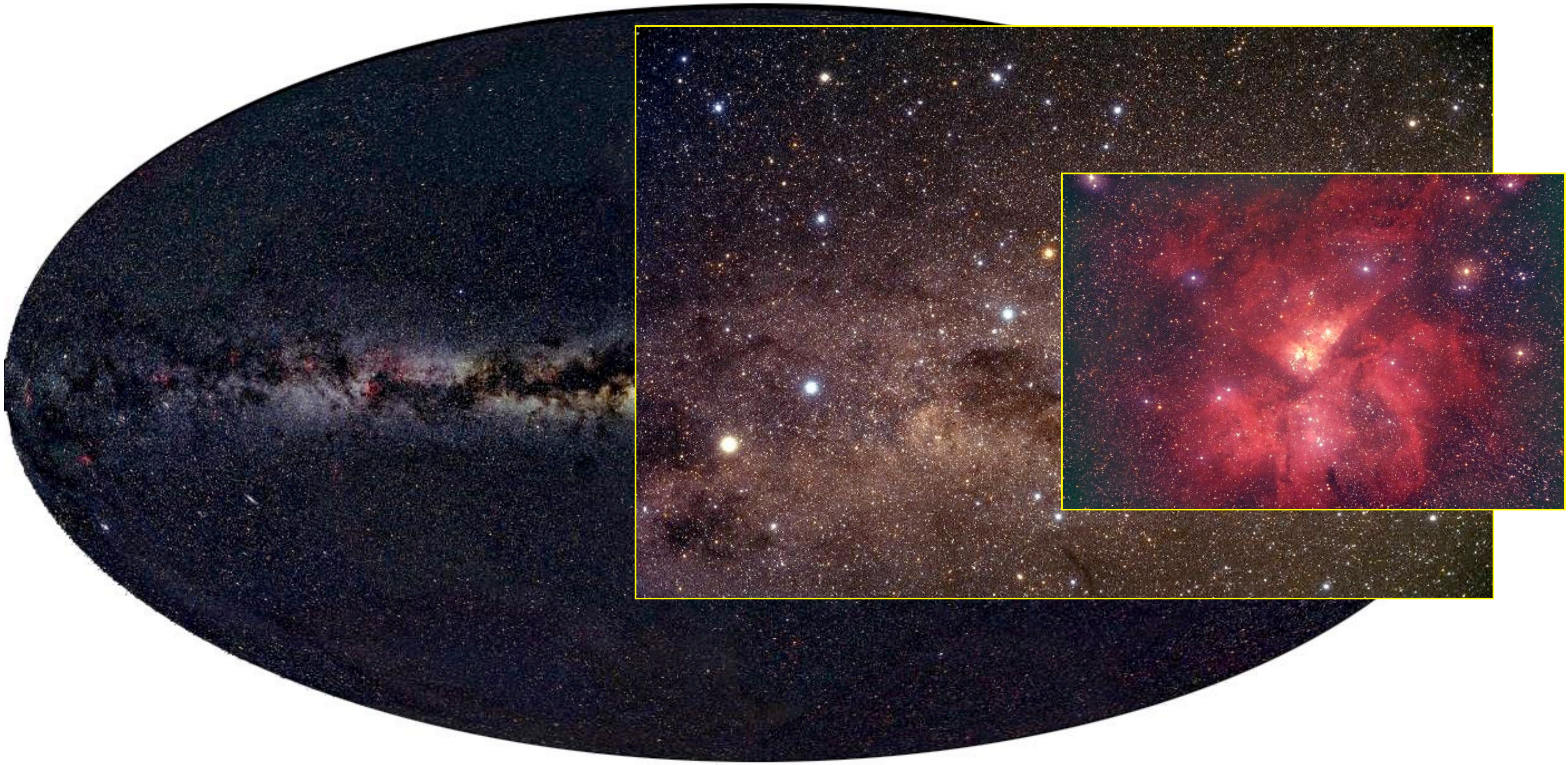
II. Diffuse emission processes

III. The X- and Gamma-Ray Sky
• Sky images
• The galactic emission spectrum

IV. The nature of galactic X- and Gamma-Ray emissions
• The Galactic Ridge X-ray emission (GRXE)
• The hard X-ray Sky
• Positron annihilation
  (imaging diffuse emission)
• Galactic Radioactivities
• The MeV - GeV Sky
• The TeV Sky

V. Summary & Bibliography

Diffuse or not diffuse - that is the question



Allsky image in visible light (Mellinger 2000)

A working definition for diffuse emission

Dictionary:

Diffuse = widely spread; not localized or confined; with no distinct margin

Astronomer:

"all emission that I cannot resolve into individual (point-) sources"

- depends on instrument characteristics (angular resolution, sensitivity)
- is not of much help for an astrophysicist

Astrophysicist:

"all emission processes that are related to interstellar (-planetary, -galactic) matter"

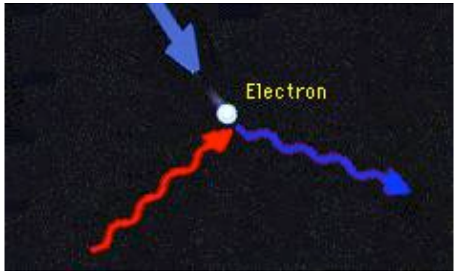
- emission of gaz and dust (thermal, non-thermal)
- emission related to magnetic fields (synchroton)
- emission related to diffuse stellar ejecta (particle diffusion)
- also applicable to extragalactic diffuse (e.g., intergalactic matter in clusters)
- also applicable for cosmic backgrounds (e.g., primordial matter for CMB)

Diffuse emission processes

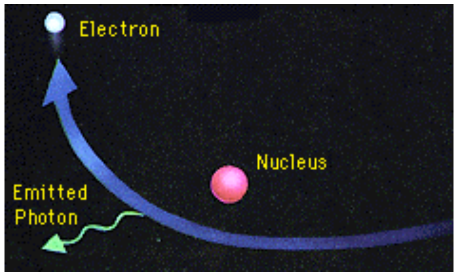
Continuum emission

Interaction of high-energy CR **electrons** and **nucleons** with gas and radiation in the ISM:

Inverse Compton **electron** scattering



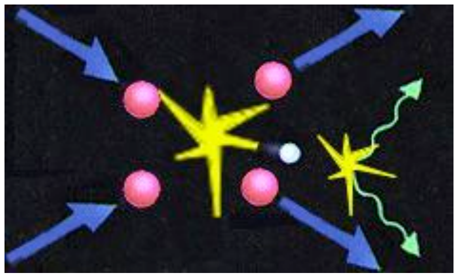
electron Bremsstrahlung



Pion (π^0) production and decay

$p + p \rightarrow p + p + \pi^0 \rightarrow 2\gamma$

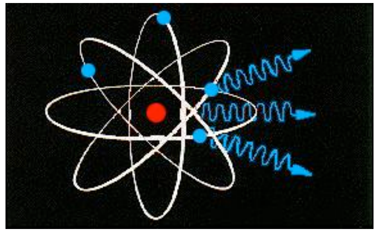
$E_p > 300$ MeV



Line emission

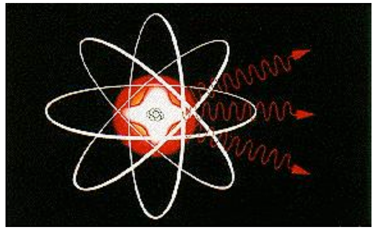
Excitation of **electrons** and **nucleons** in an atom; antimatter **annihilation**:

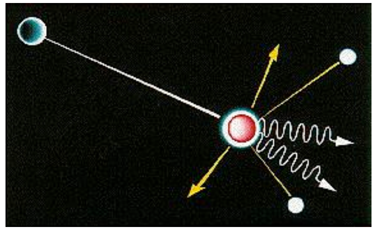
ionic lines (below 10 keV)



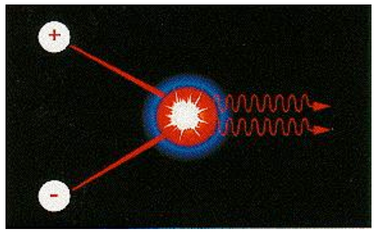
nuclear radioactive decay

nuclear excitation

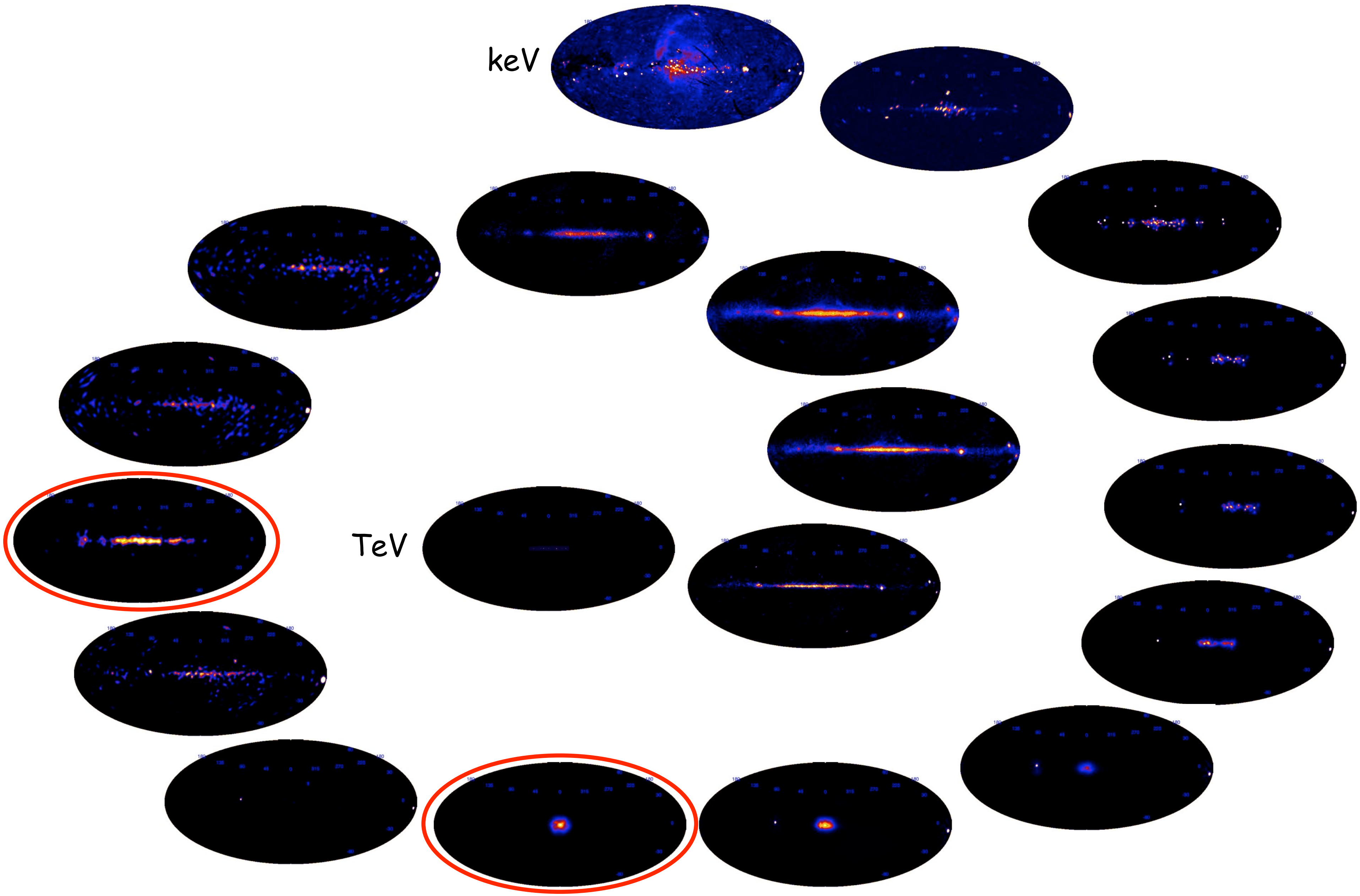




positron-electron **annihilation** (511 keV line)

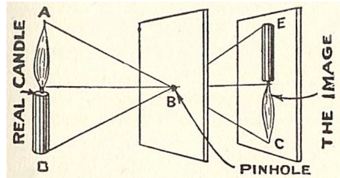


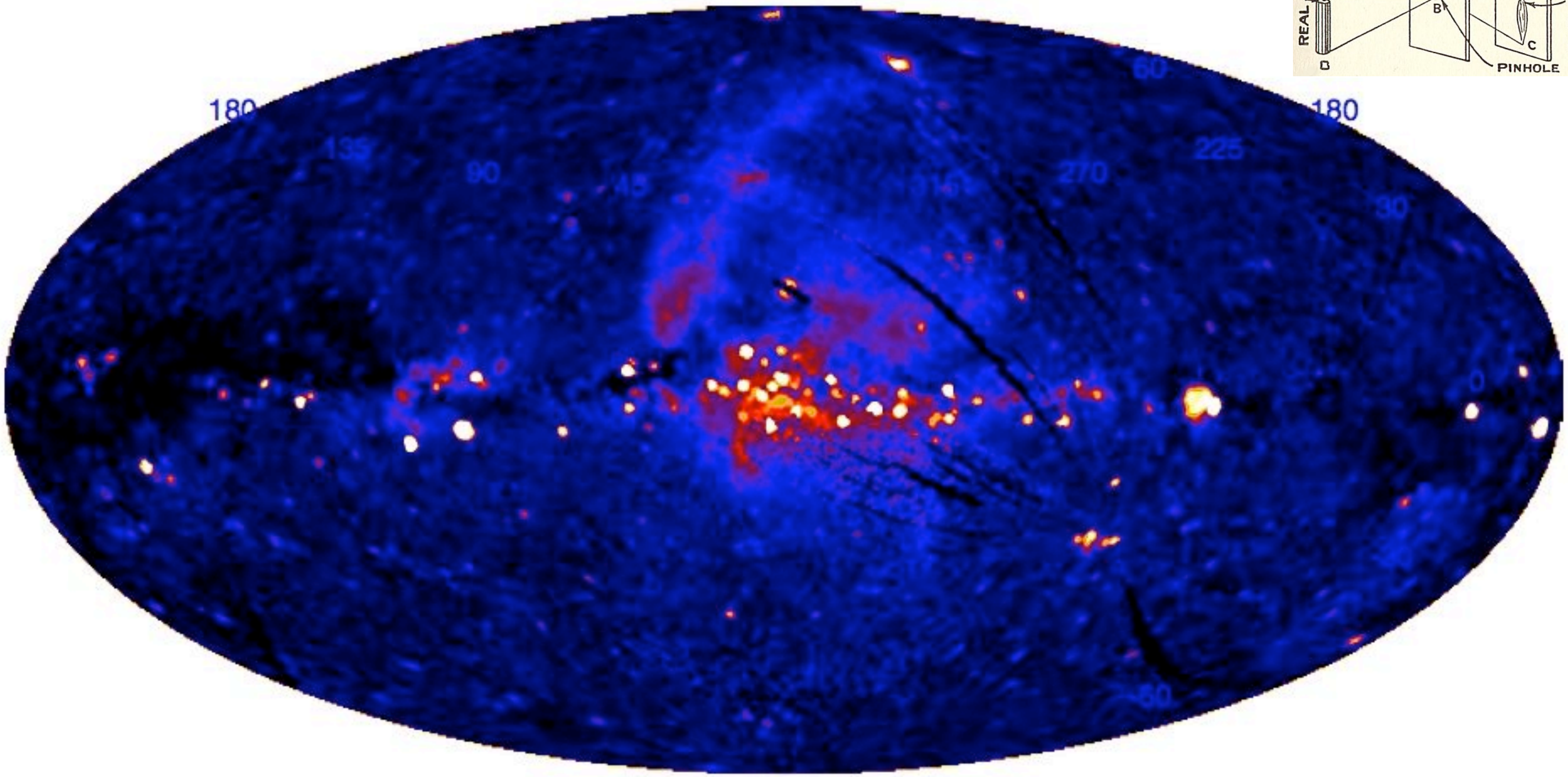
A high-energy gallery of the sky

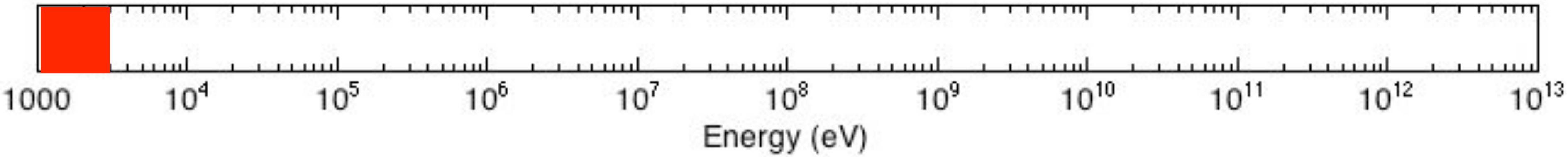


The Soft X-Ray Sky (1 - 3 keV)

ROSAT

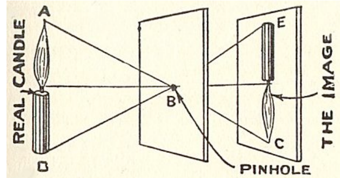


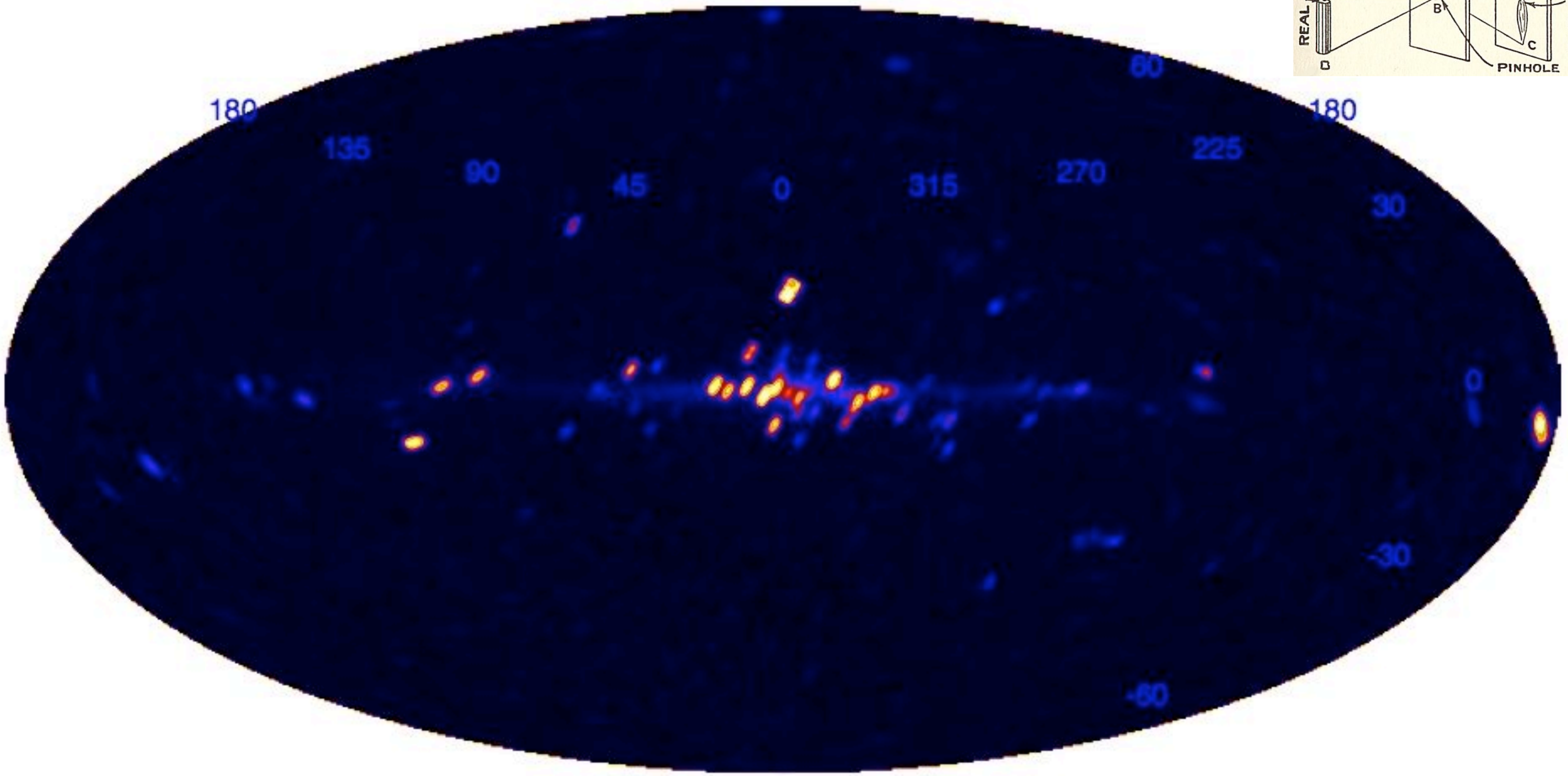


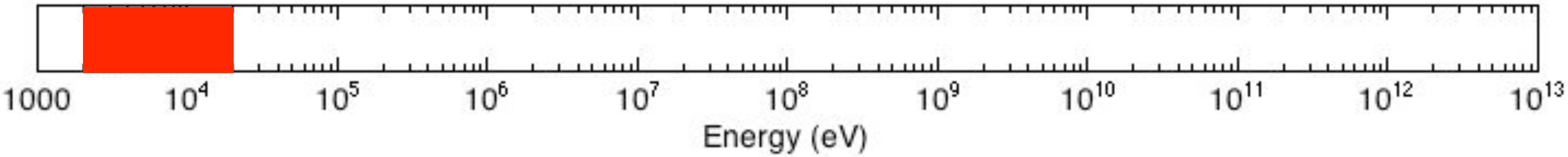


The X-Ray Sky (2 - 20 keV)

HEAO-1

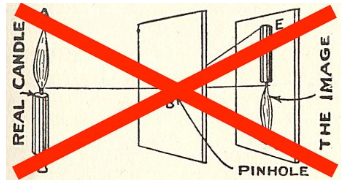


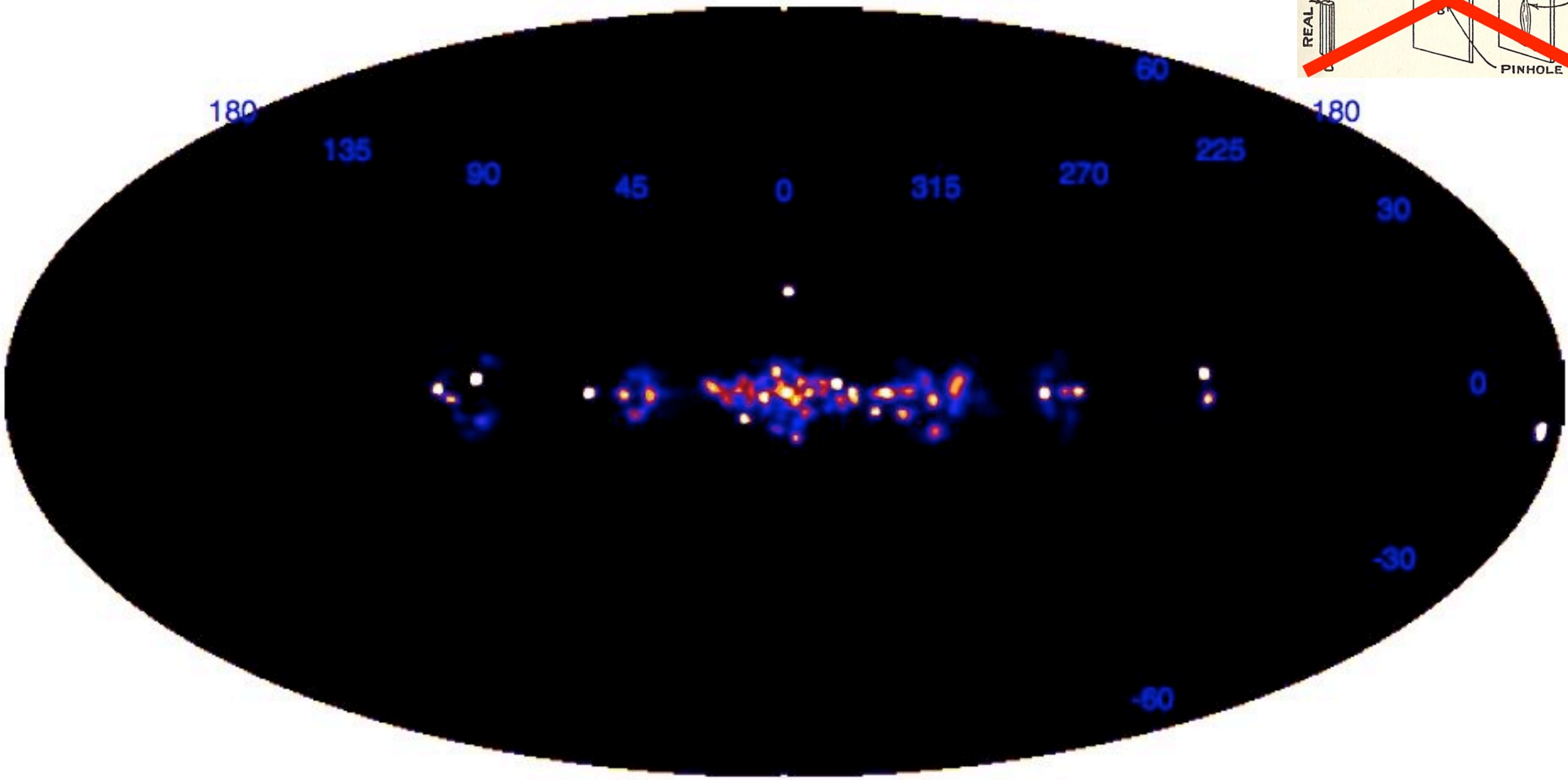


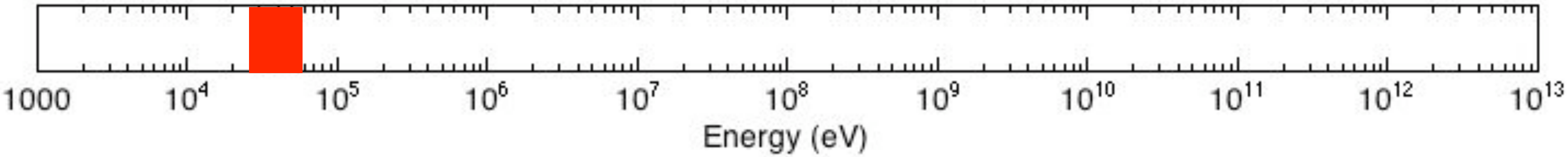


The Hard X-Ray Sky (25 - 50 keV)

SPI / INTEGRAL (2 yr)

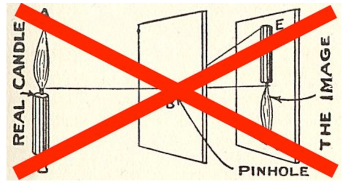


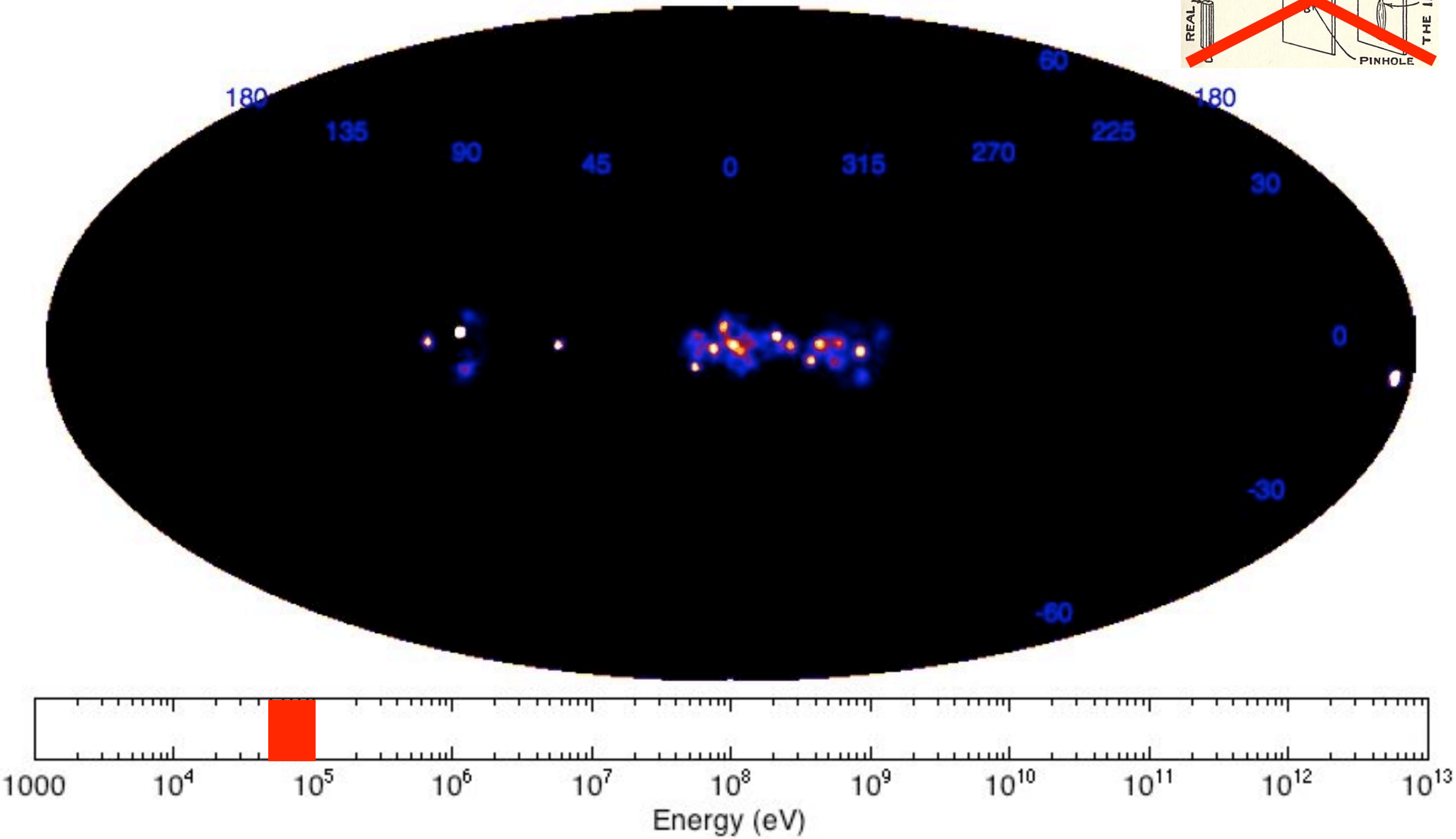




The Hard X-Ray Sky (50 - 100 keV)

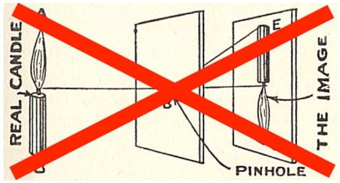
SPI / INTEGRAL (2 yr)

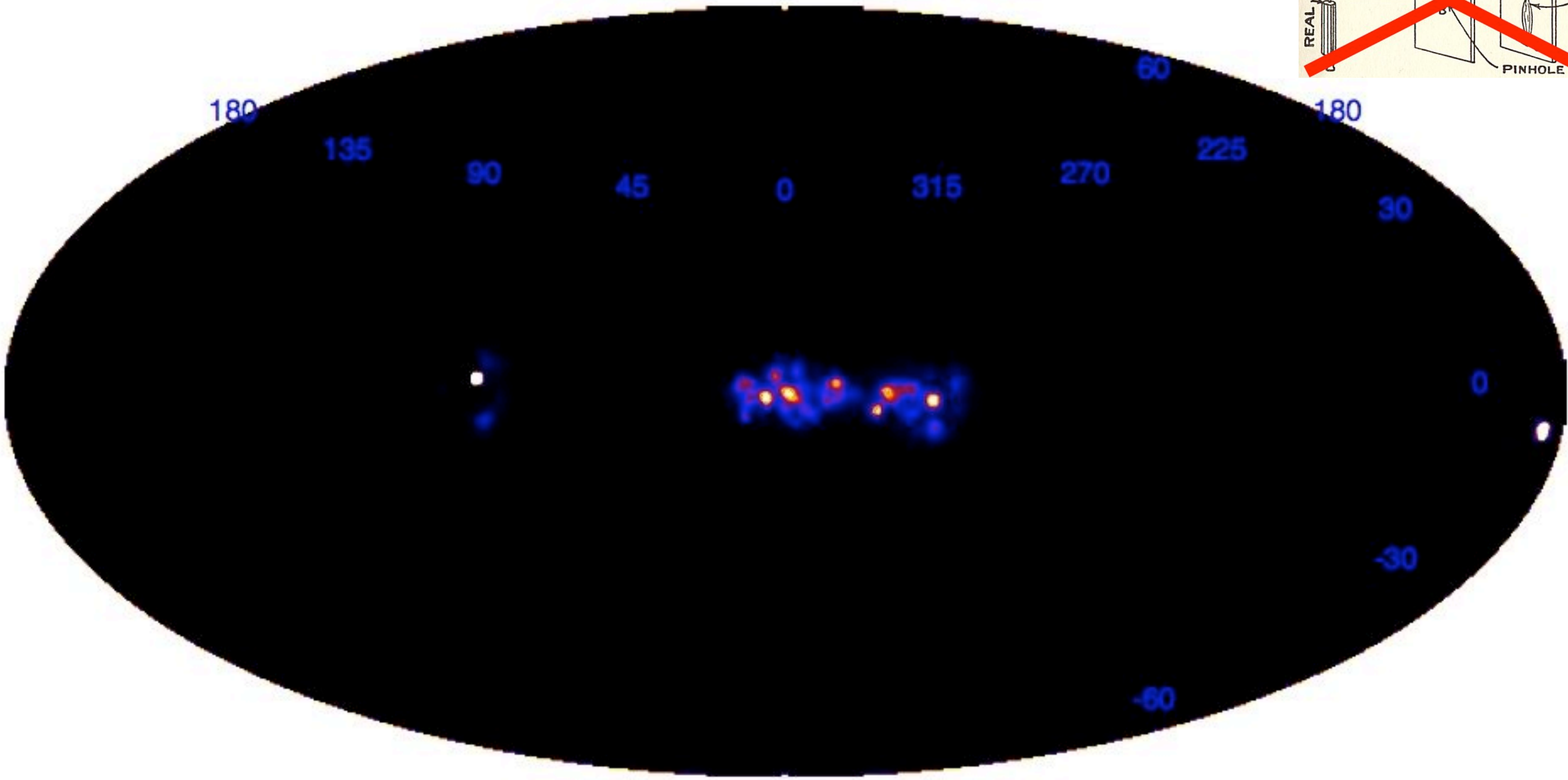


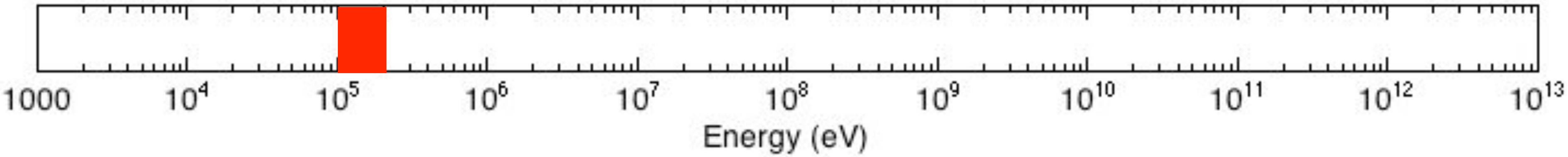


The Hard X-Ray Sky (100 - 200 keV)

SPI / INTEGRAL (2 yr)

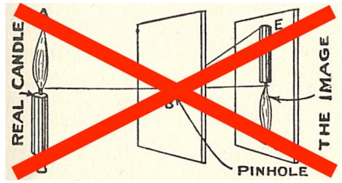


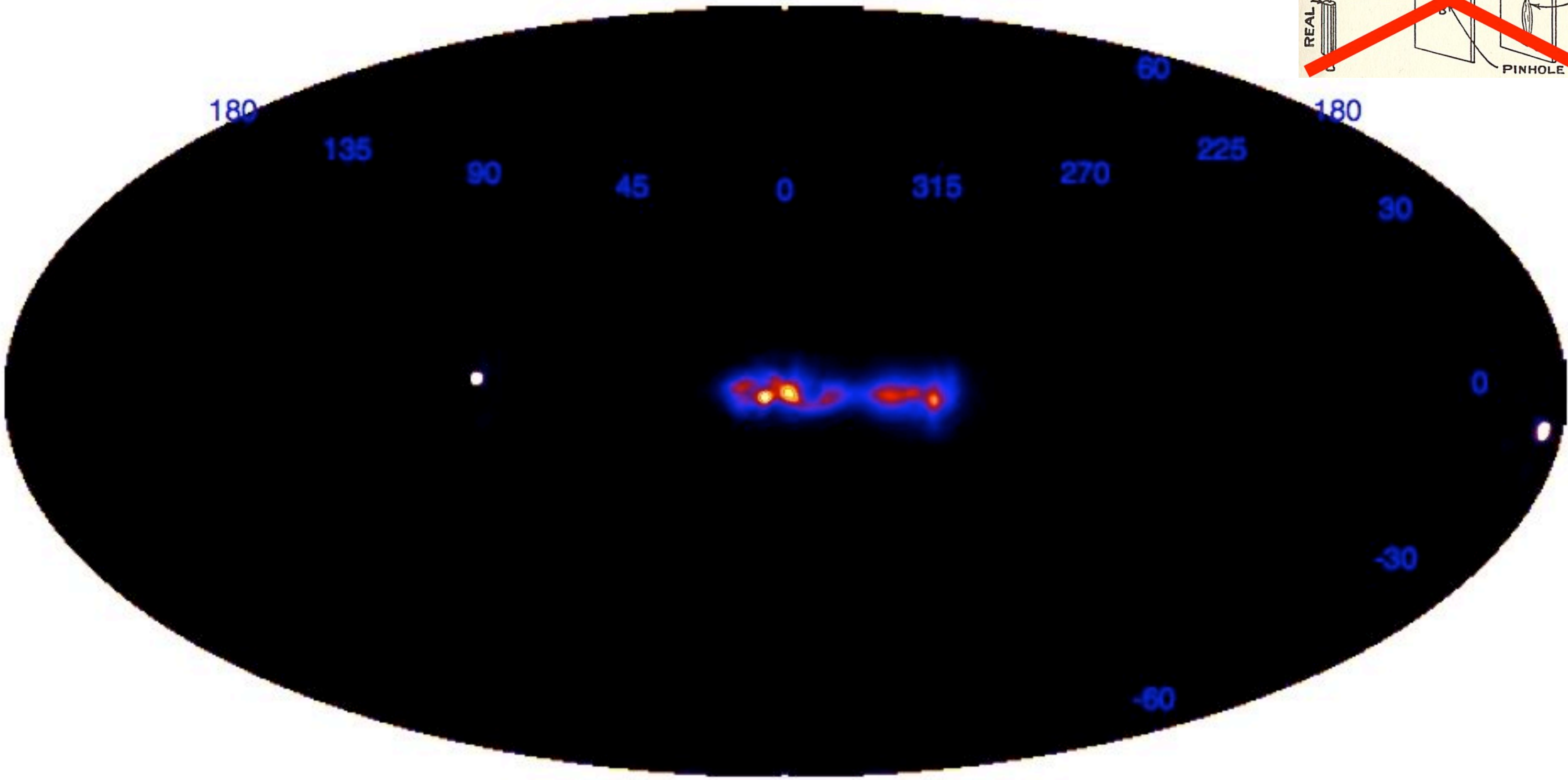


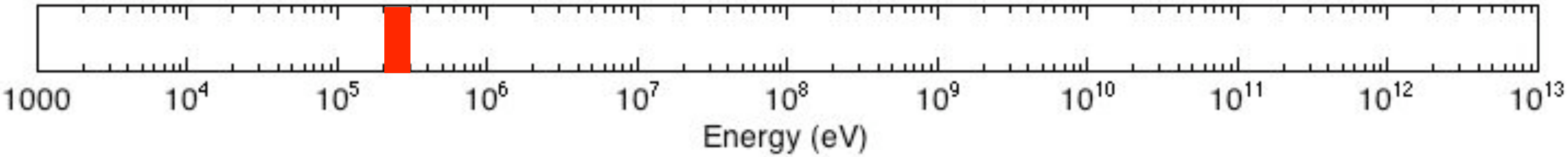


The Hard X-Ray Sky (200 - 300 keV)

SPI / INTEGRAL (2 yr)

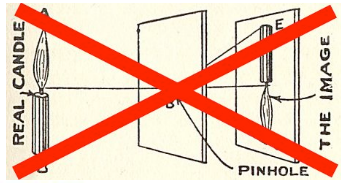


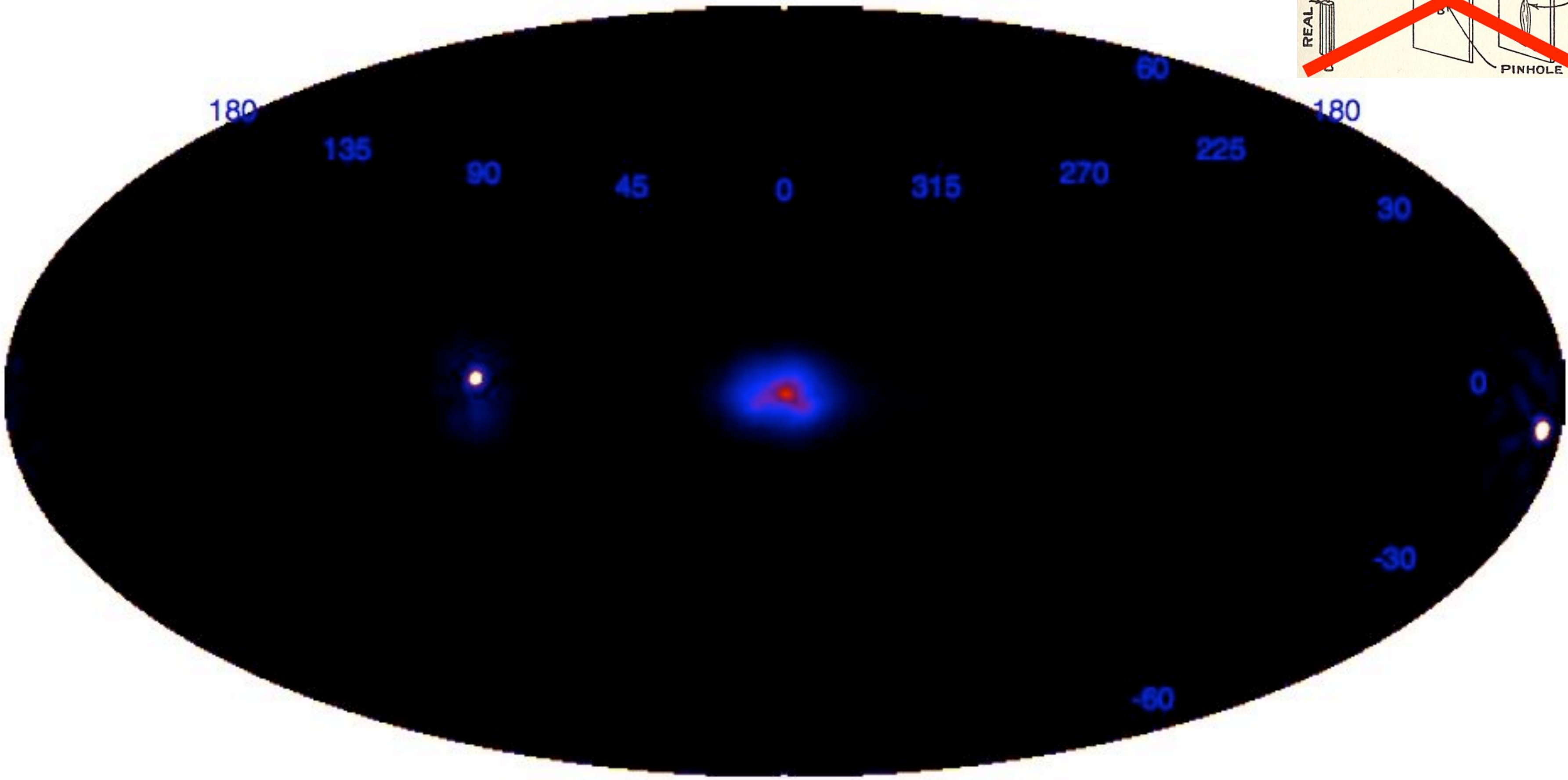


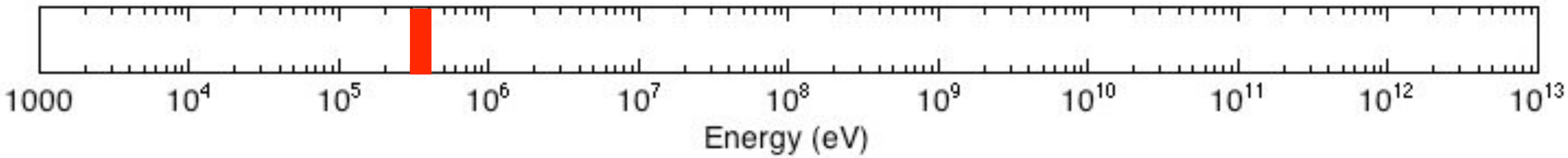


The Gamma-Ray Sky (300 - 400 keV)

SPI / INTEGRAL (2 yr)

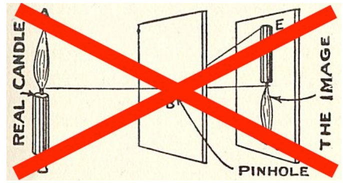


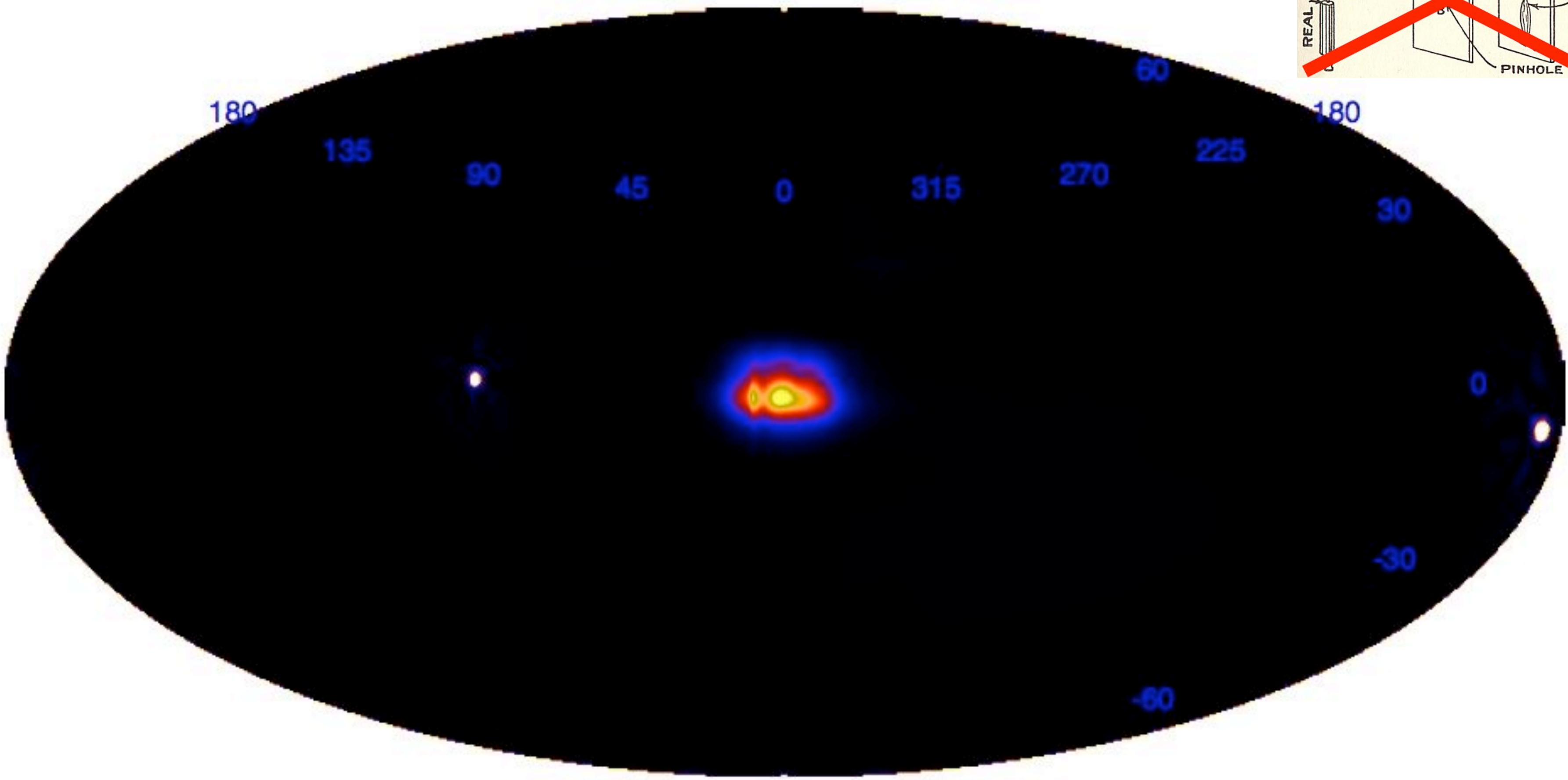


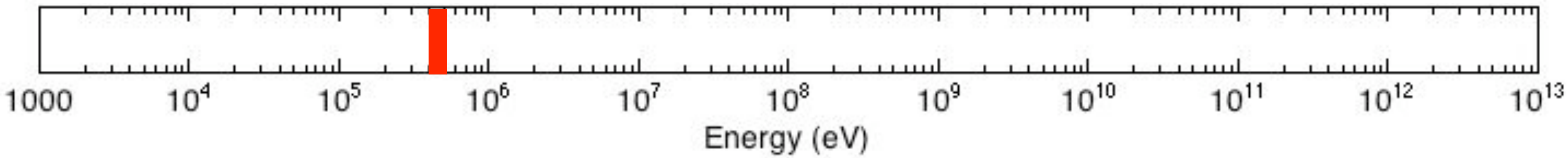


The Gamma-Ray Sky (400 - 500 keV)

SPI / INTEGRAL (2 yr)

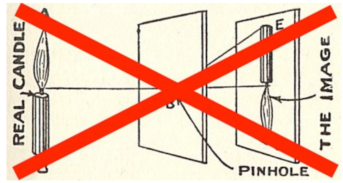


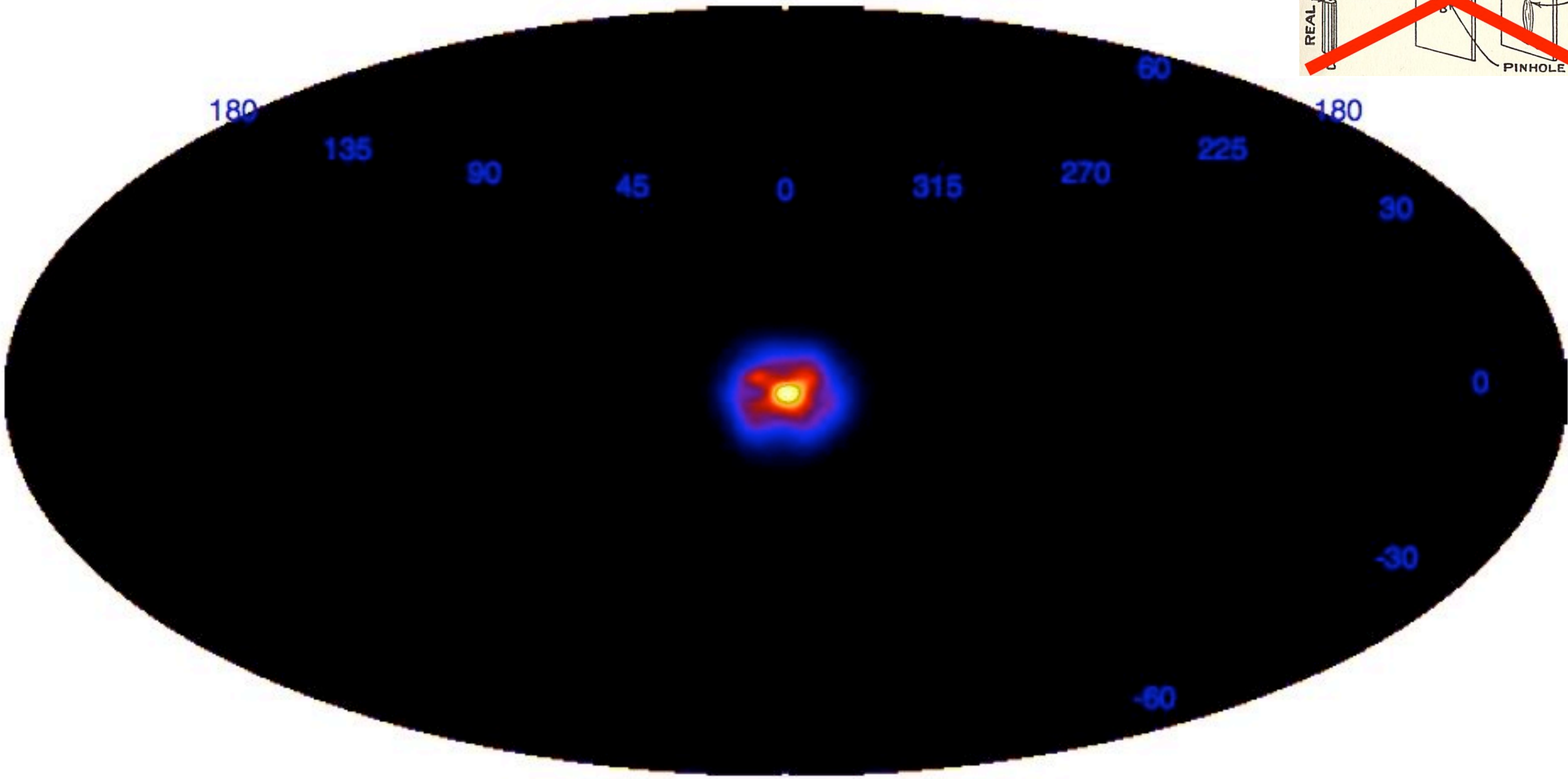


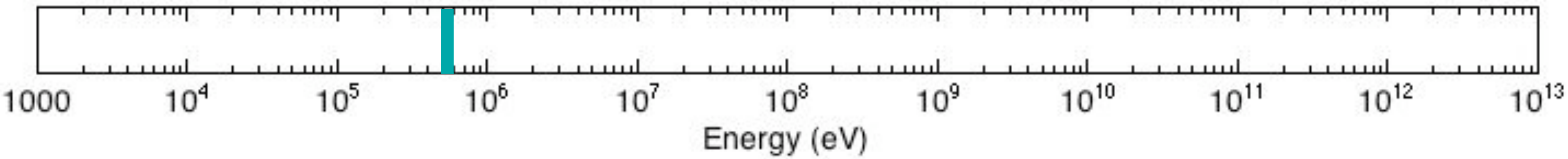


The Gamma-Ray Sky (511 keV line)

SPI / INTEGRAL (2 yr)

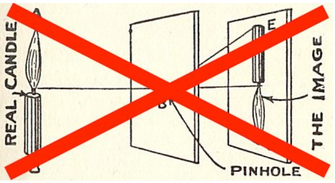


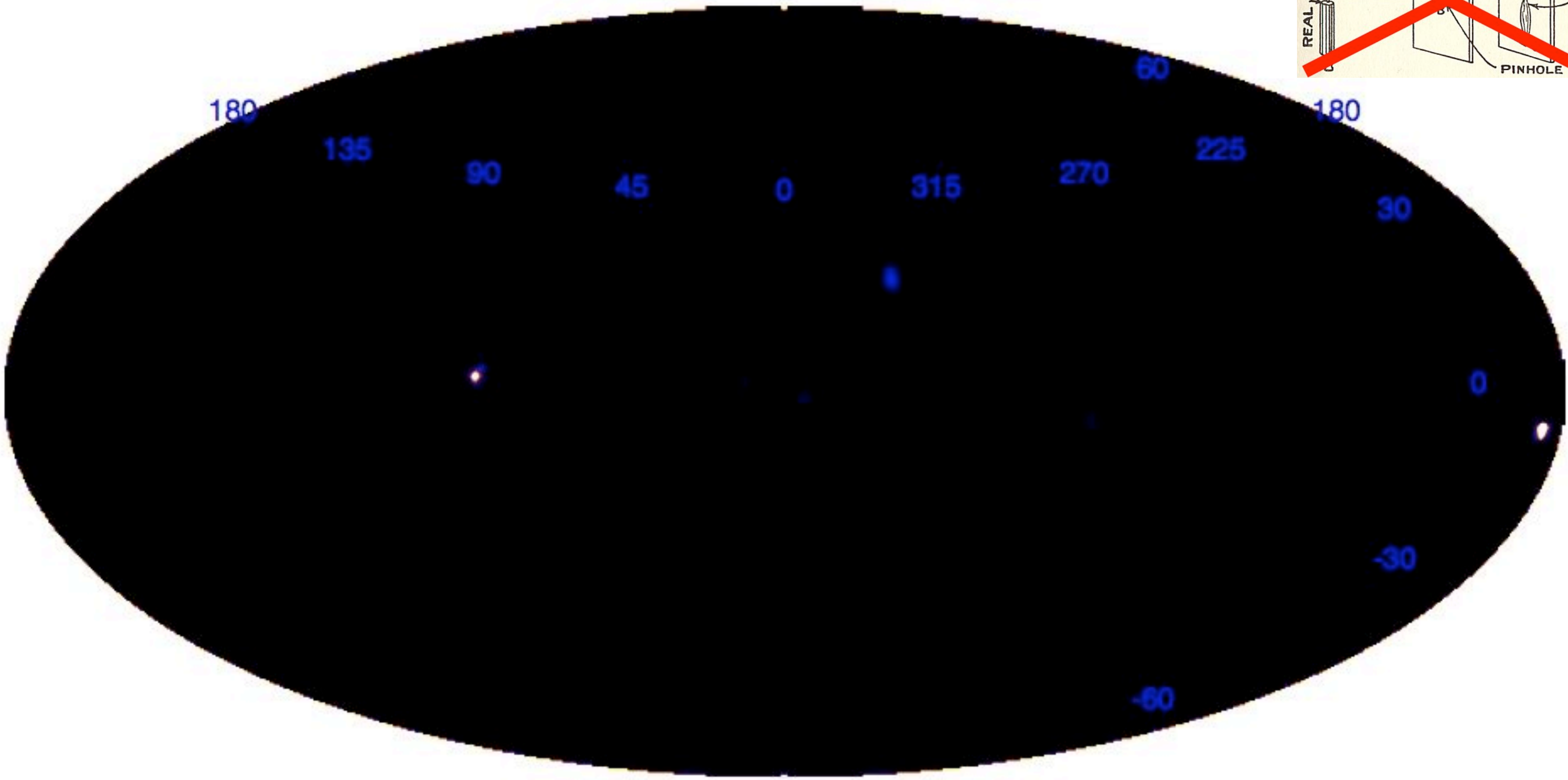


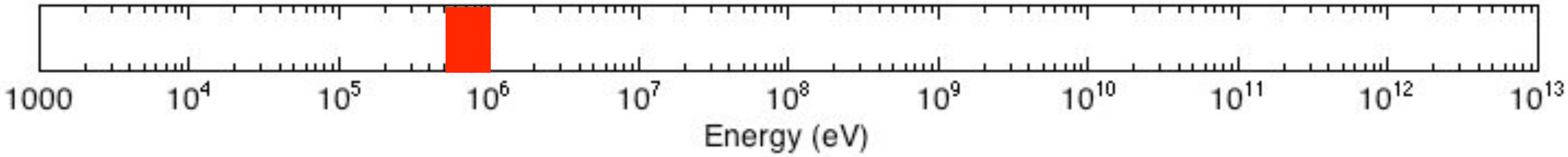


The Gamma-Ray Sky (514 - 1000 keV)

SPI / INTEGRAL (2 yr)

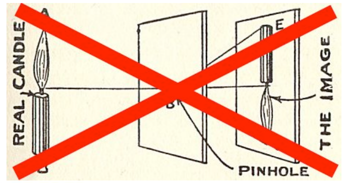


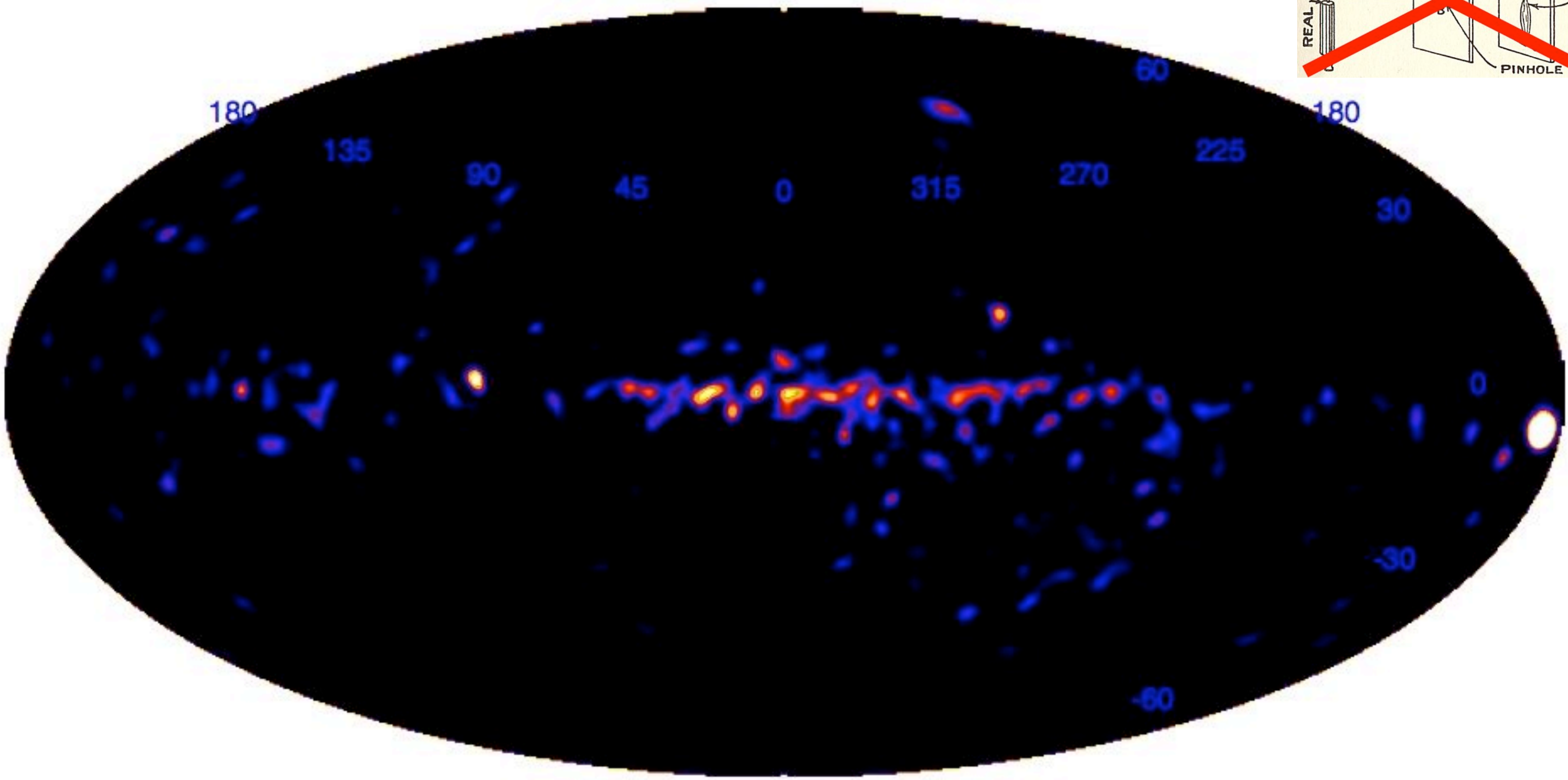


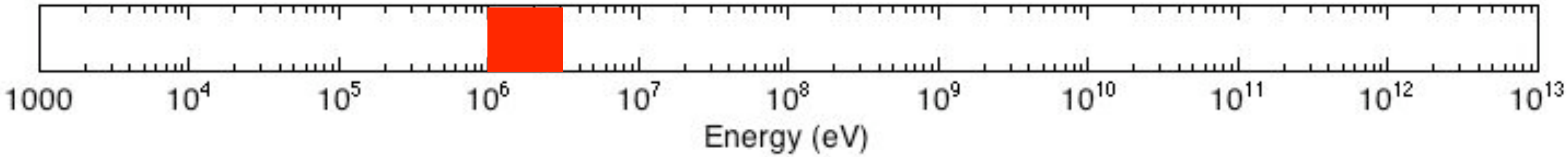


The Gamma-Ray Sky (1 - 3 MeV)

COMPTEL / CGRO (6 yr)

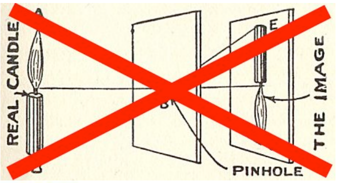


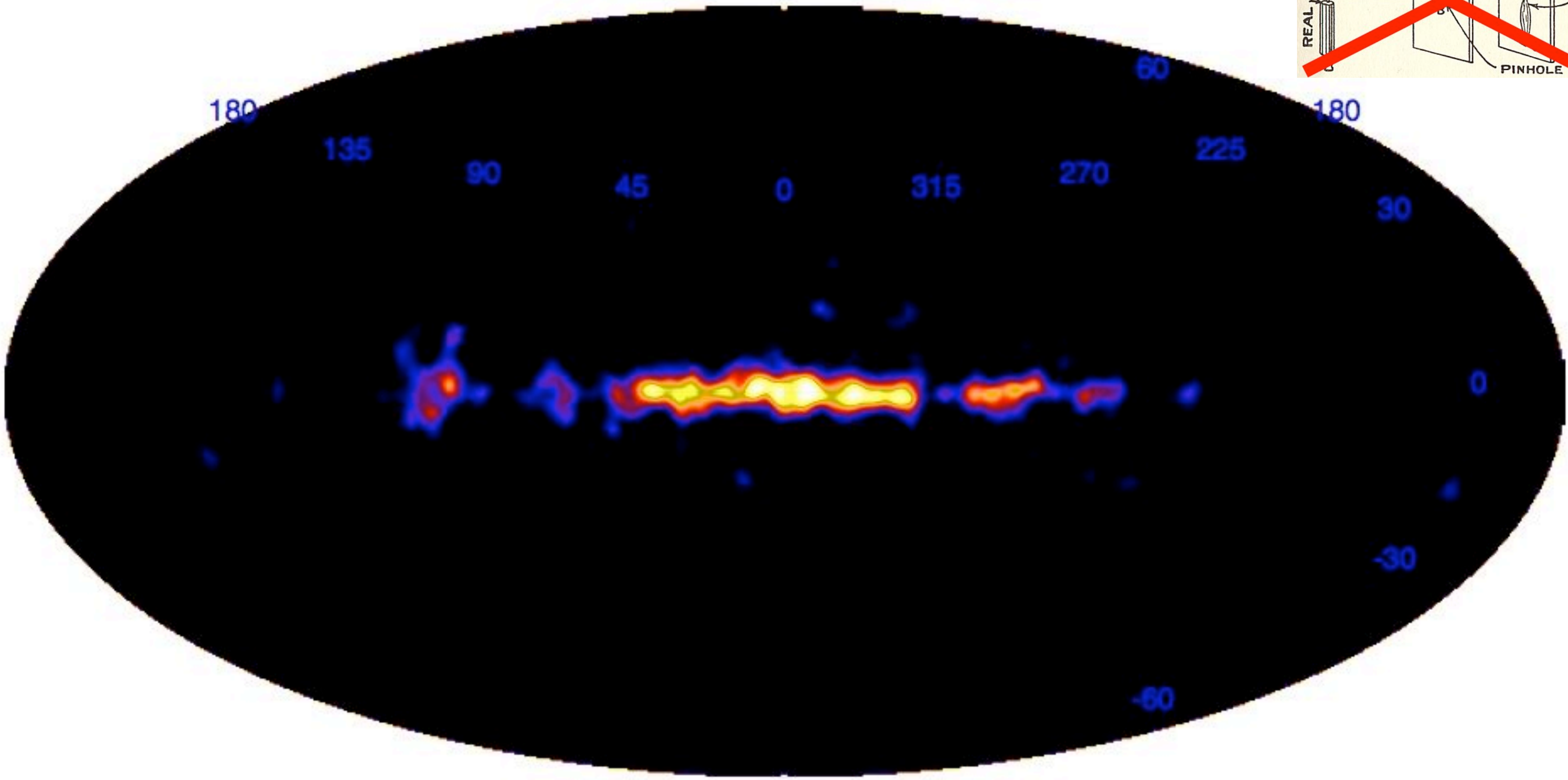


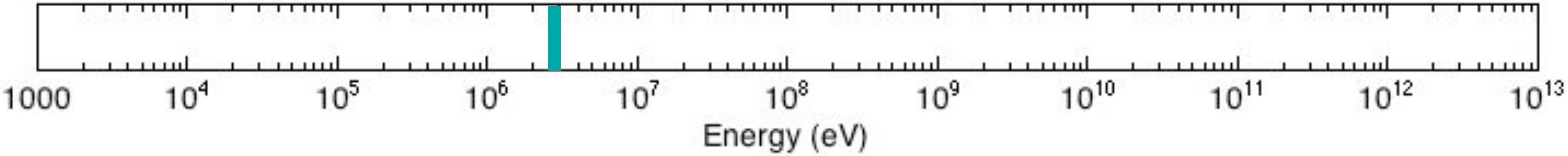


The Gamma-Ray Sky (1809 keV line)

COMPTEL / CGRO (9 yr)

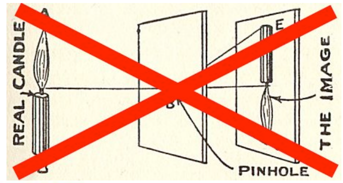


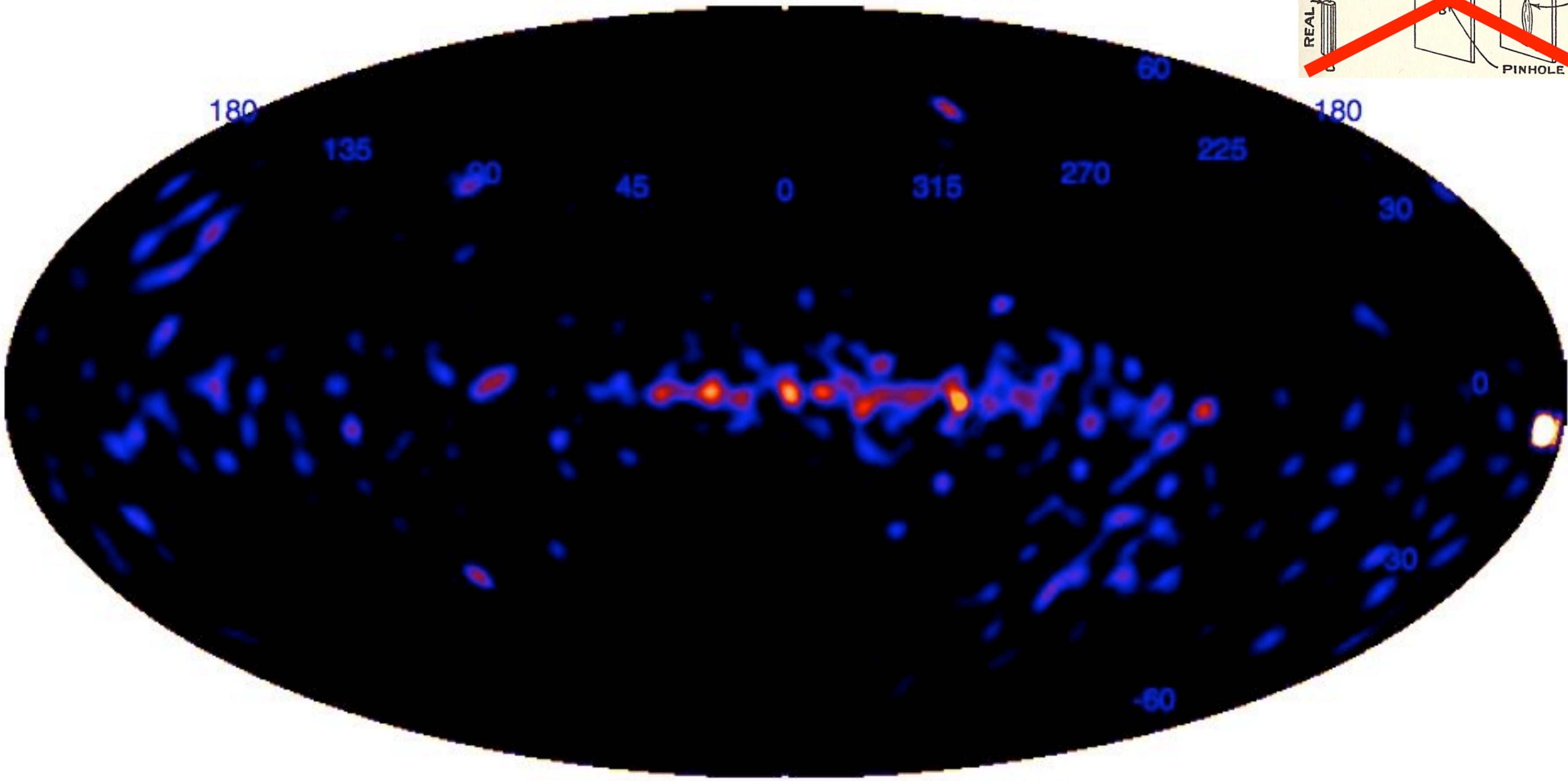


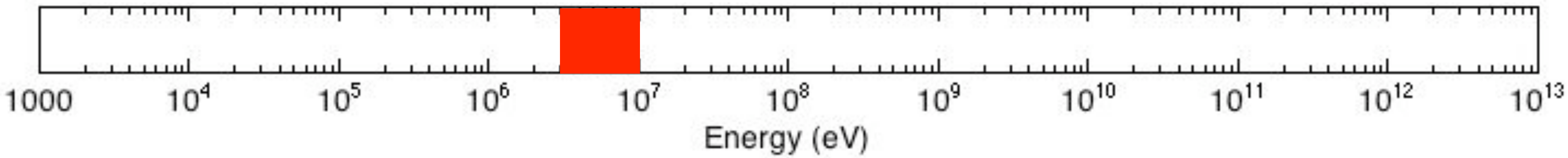


The Gamma-Ray Sky (3 - 10 MeV)

COMPTEL / CGRO (6 yr)

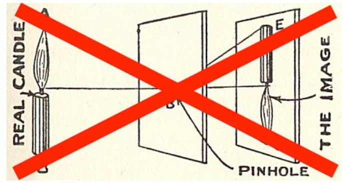


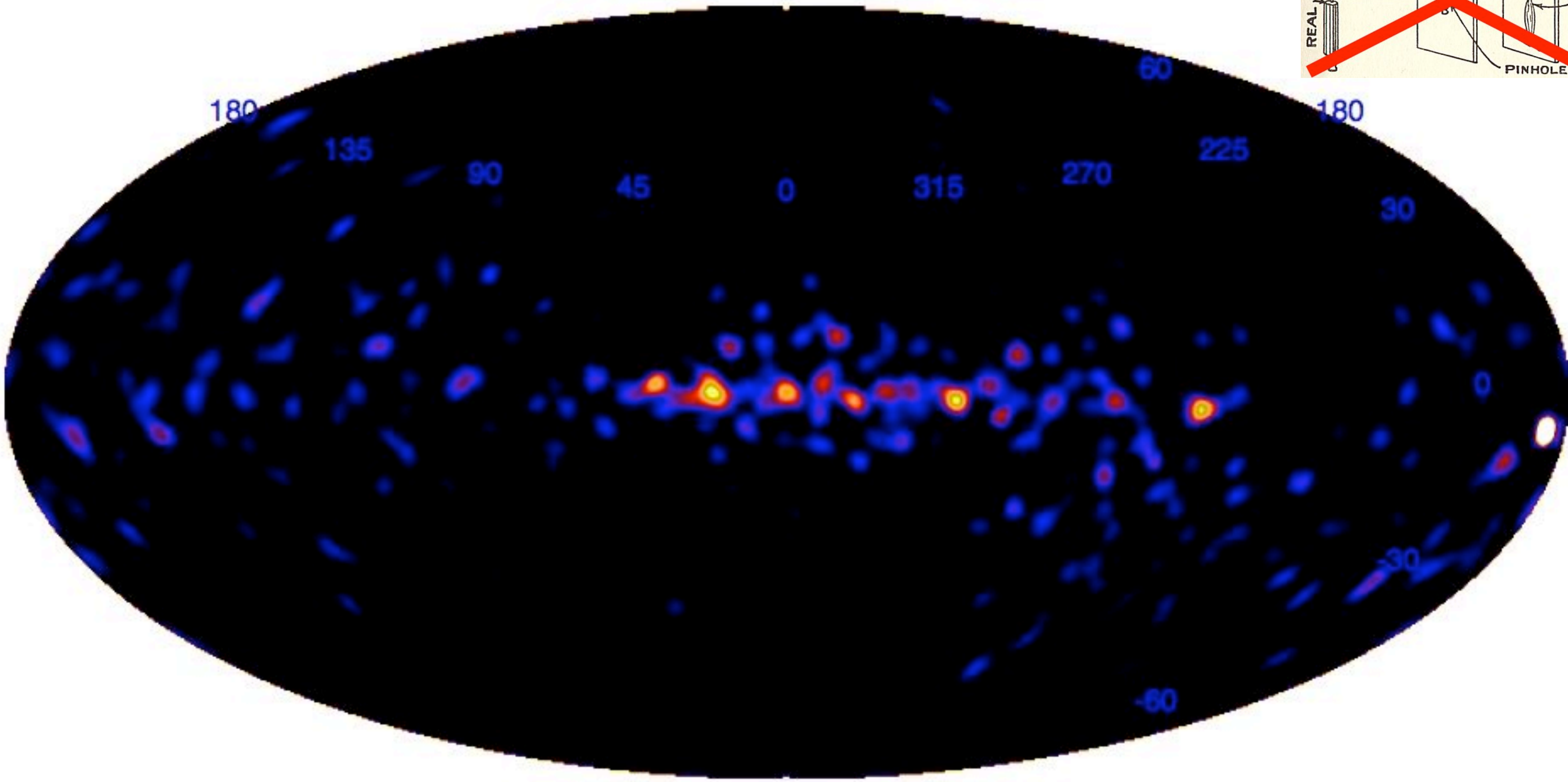


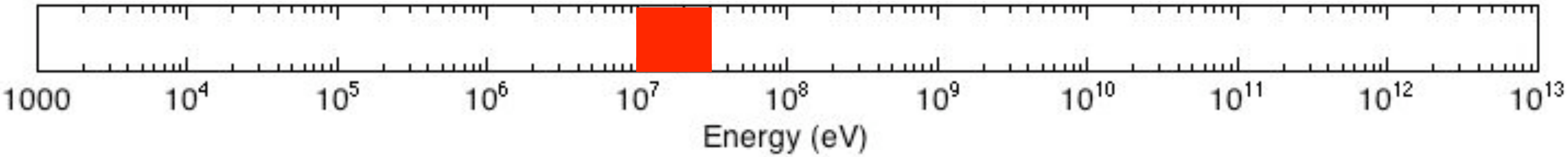


The Gamma-Ray Sky (10 - 30 MeV)

COMPTEL / CGRO (6 yr)

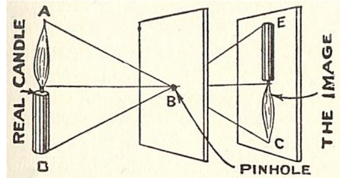


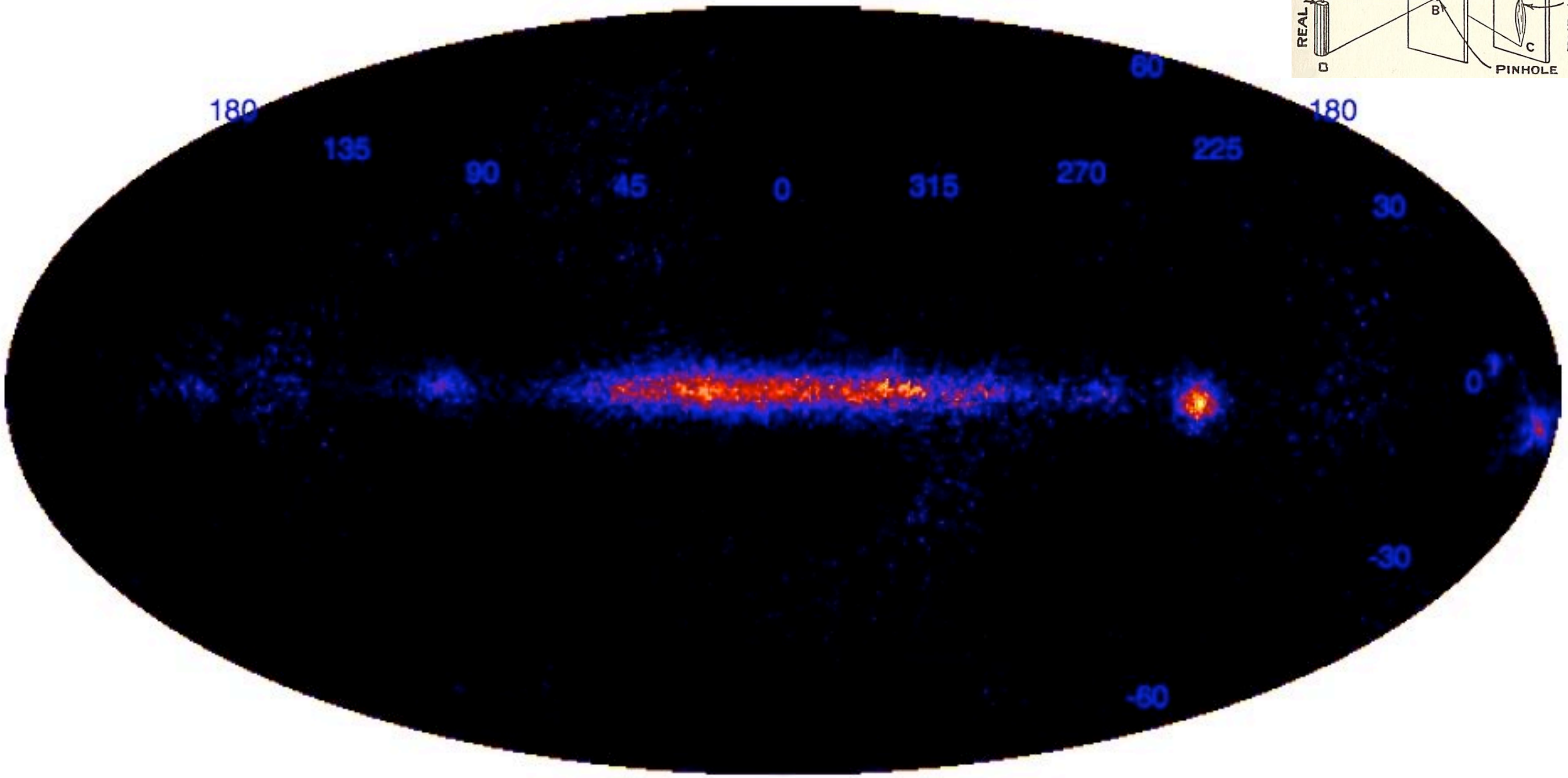


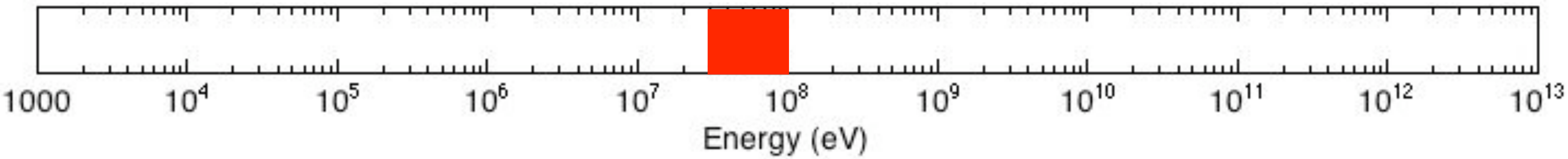


The HE Gamma-Ray Sky (30 - 100 MeV)

EGRET / CGRO (4 yr)

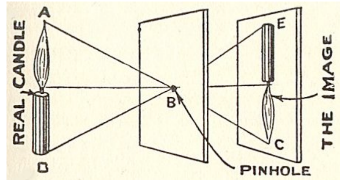


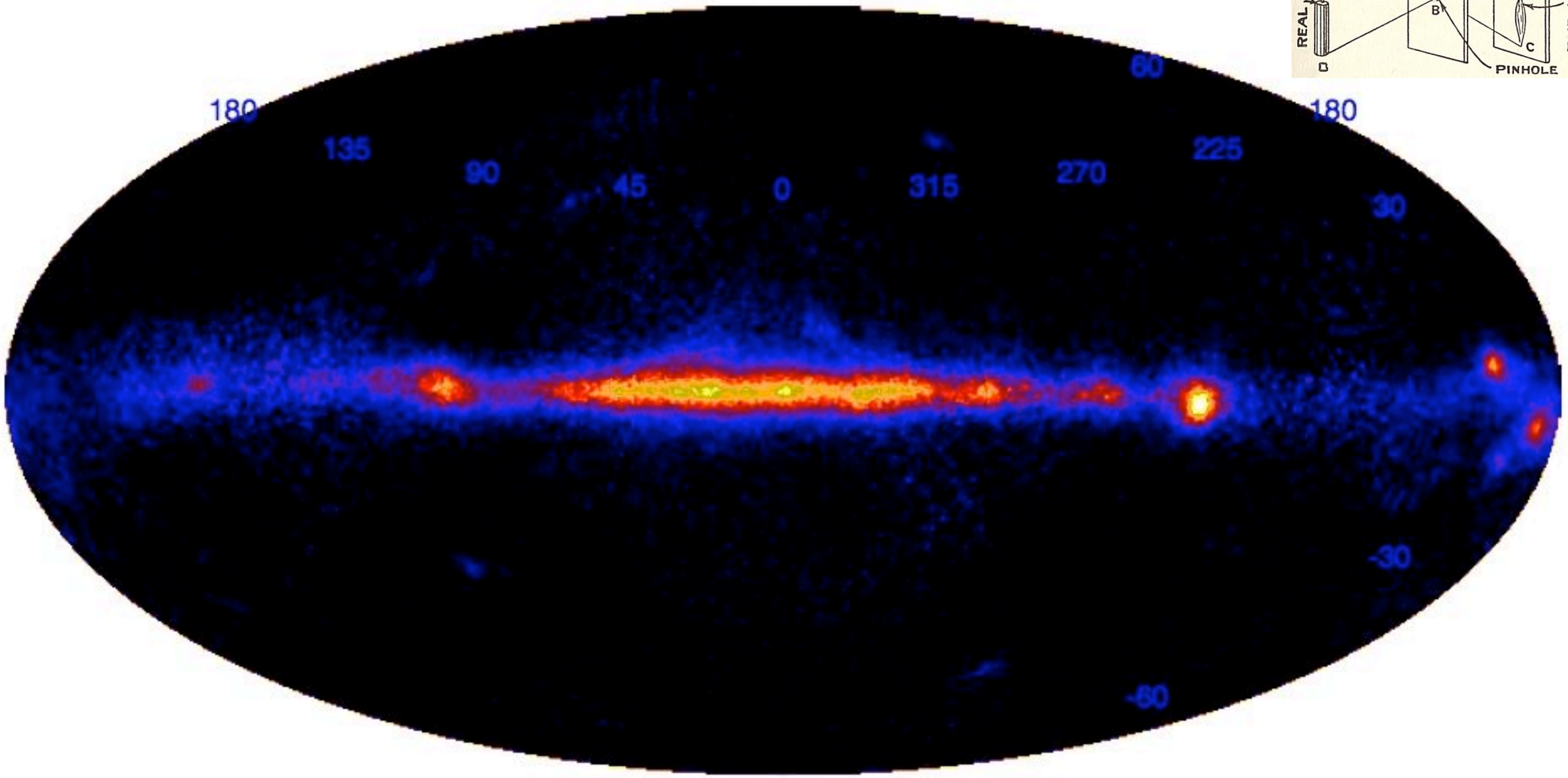


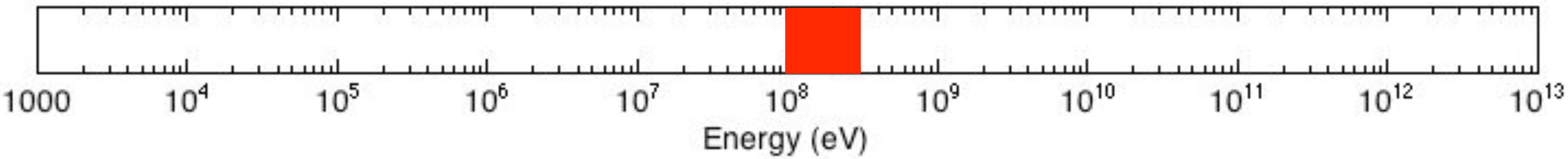


The HE Gamma-Ray Sky (100 - 300 MeV)

EGRET / CGRO (4 yr)

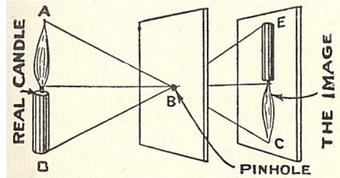


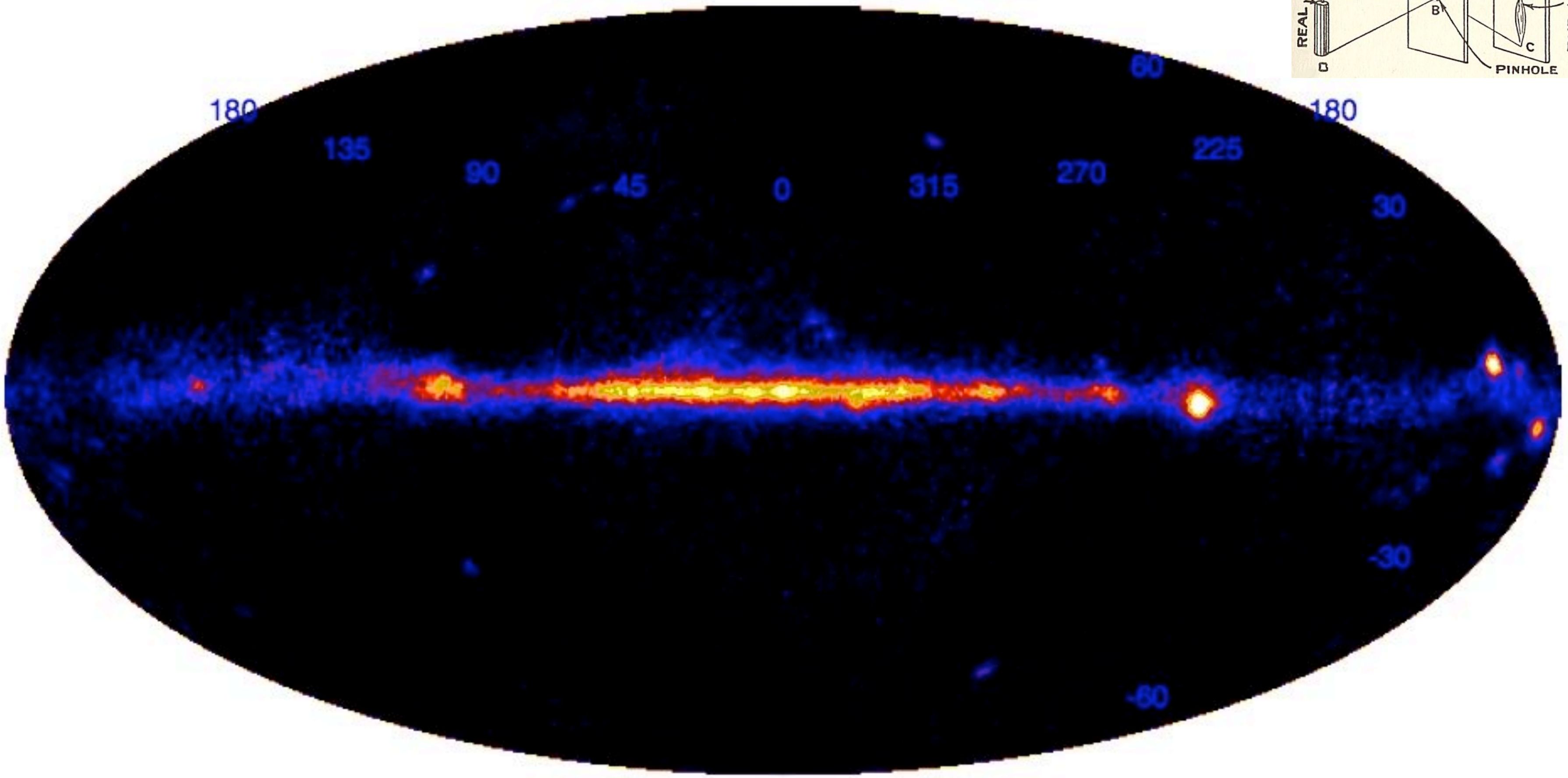


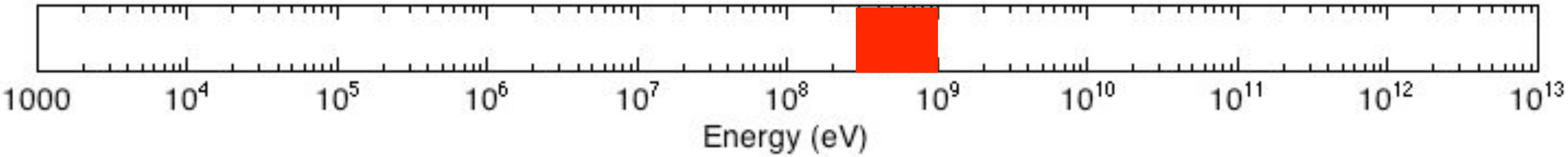


The HE Gamma-Ray Sky (300 - 1000 MeV)

EGRET / CGRO (4 yr)

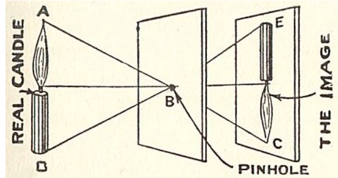


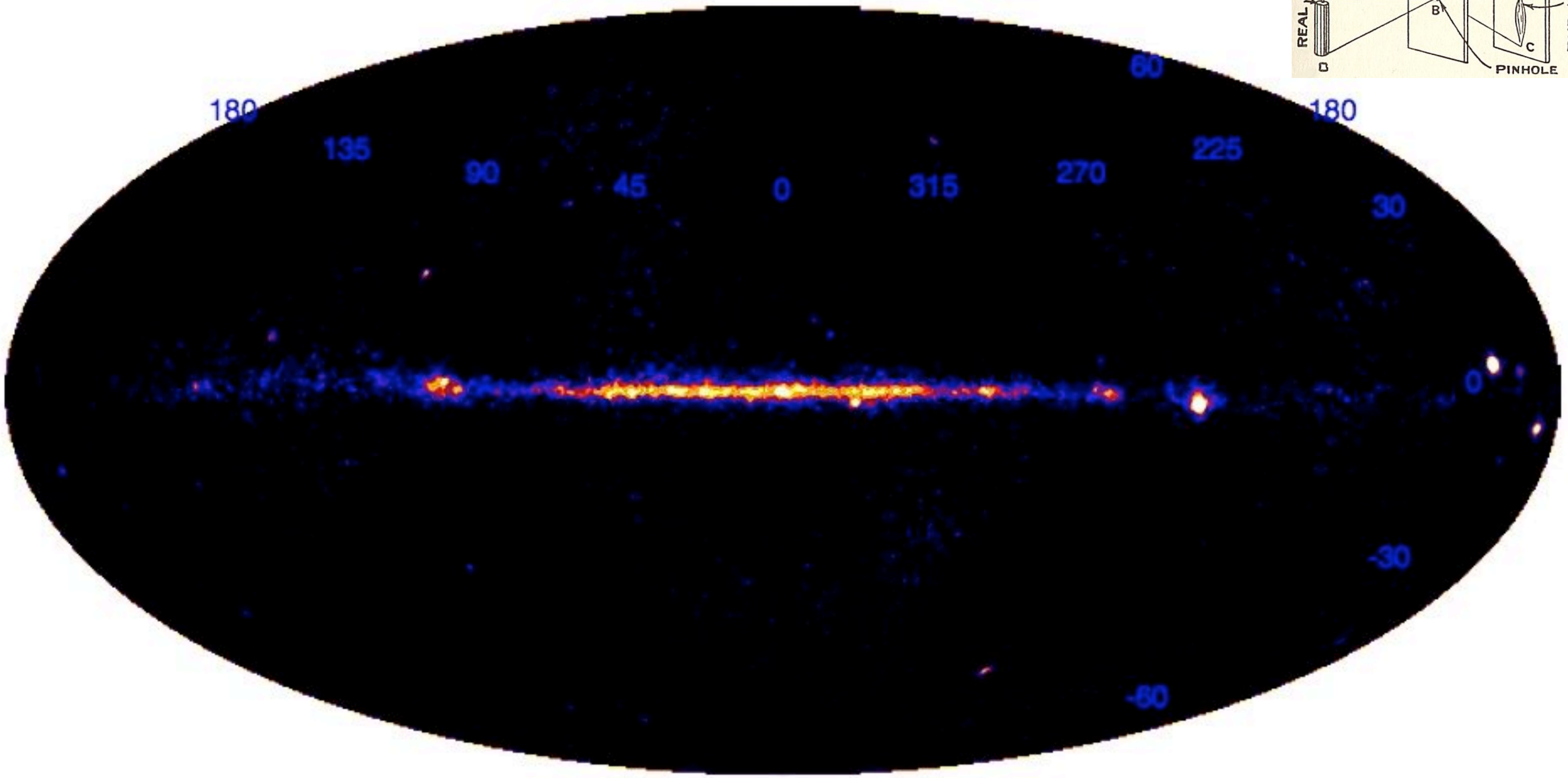


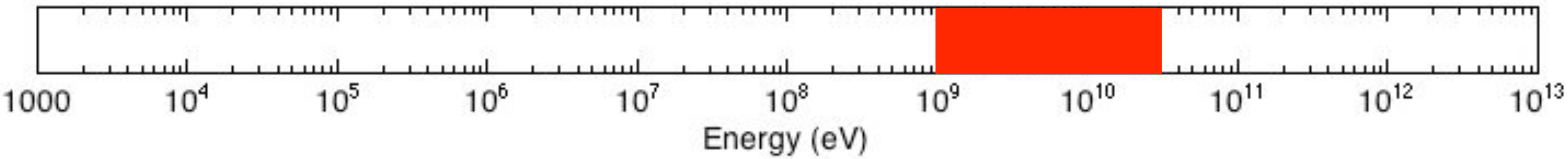


The HE Gamma-Ray Sky (1 - 30 GeV)

EGRET / CGRO (4 yr)

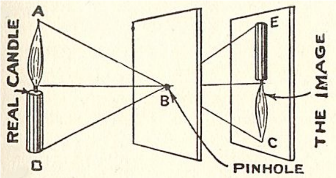


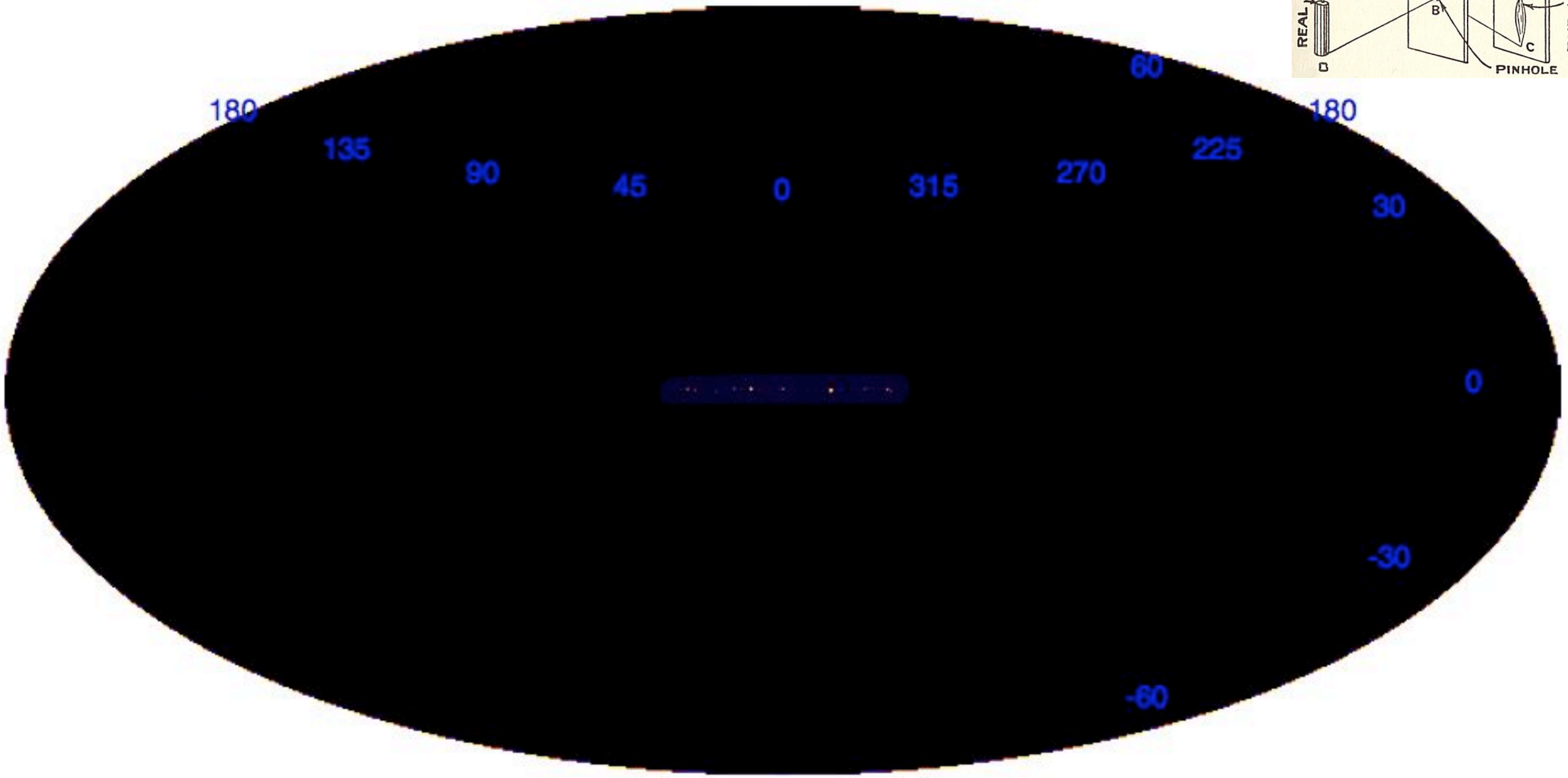


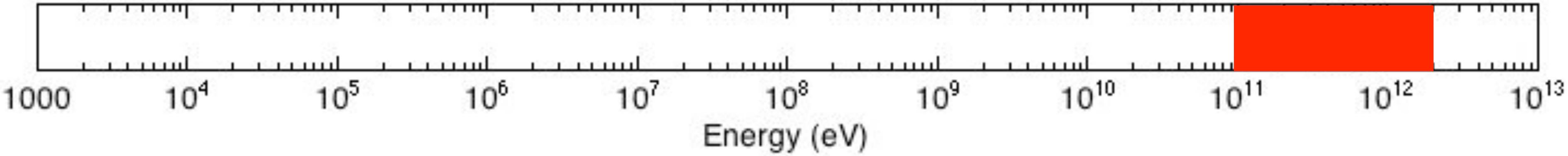


The VHE Gamma-Ray Sky (0.1 - 20 TeV)

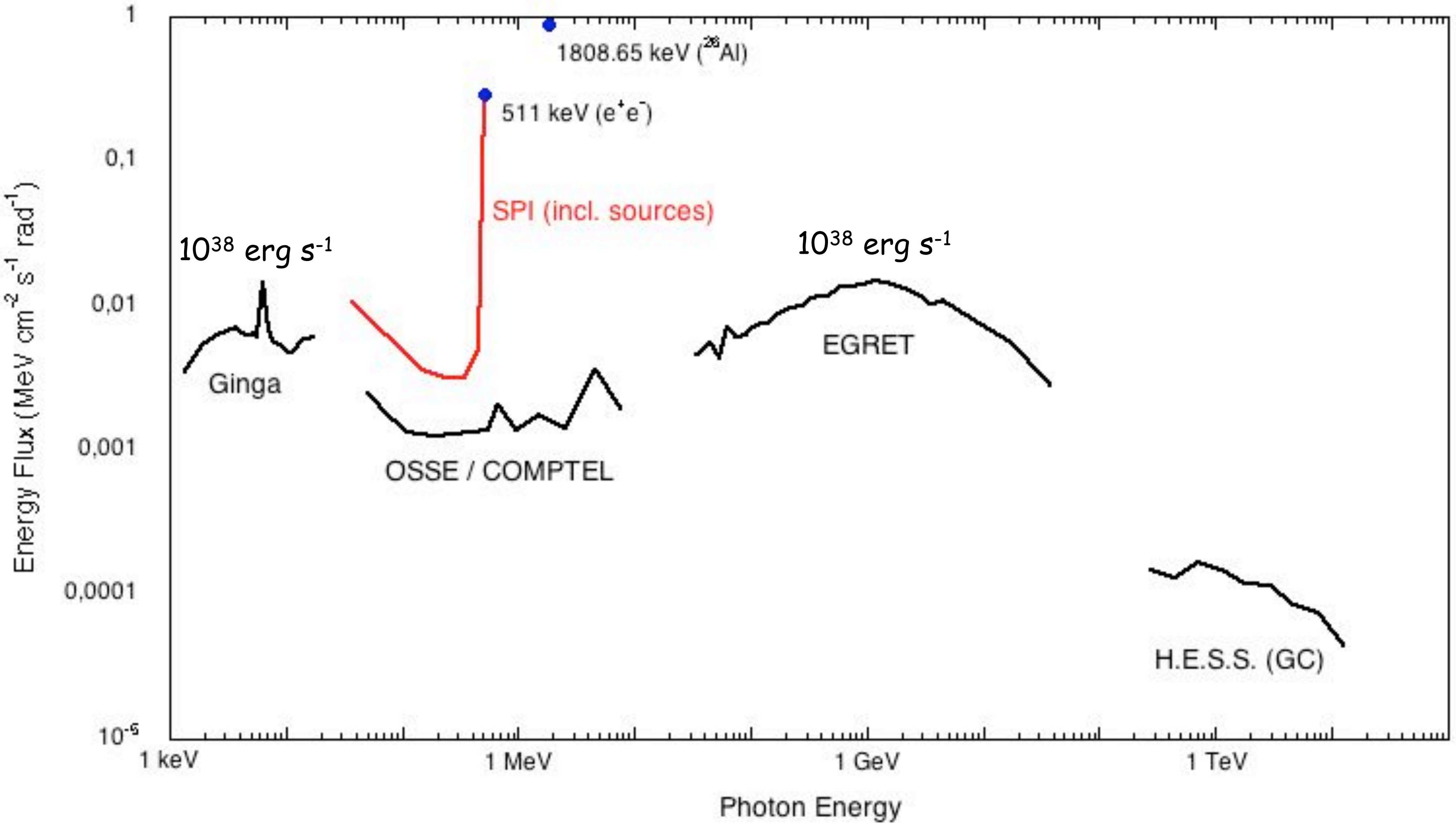
H.E.S.S.





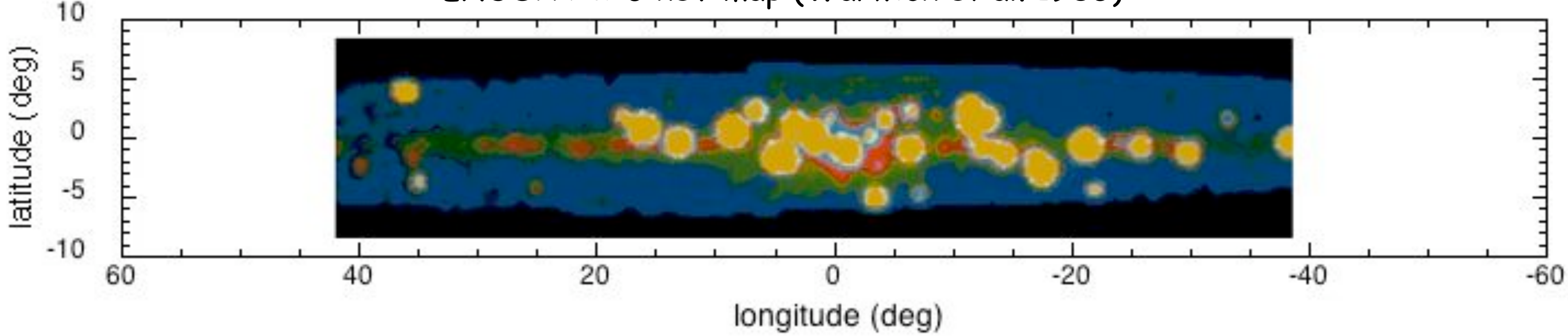


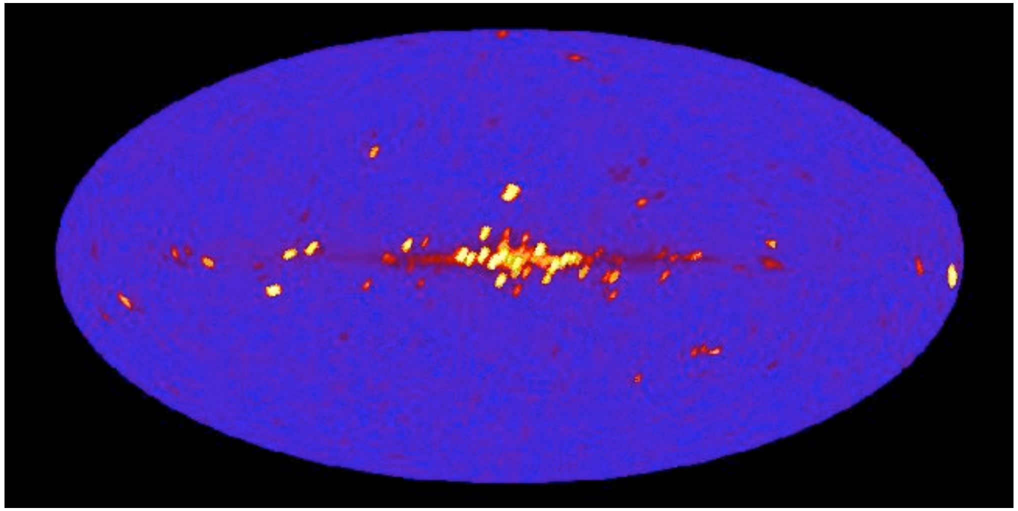
The galactic diffuse emission spectrum



X-ray galactic ridge emission

EXOSAT 2-6 keV map (Warwick et al. 1985)





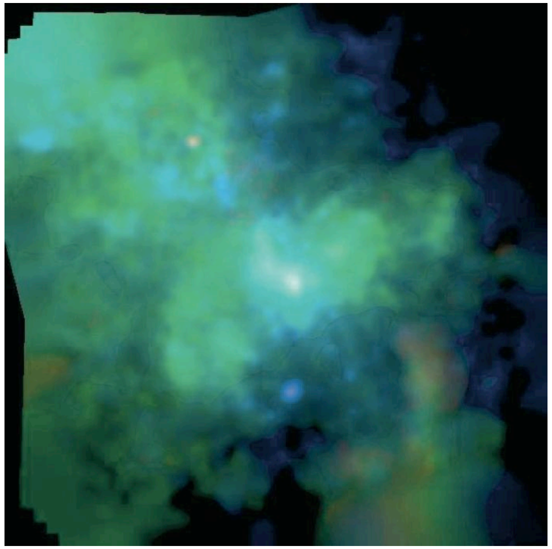
HEAO-1 2-50 keV map (Allen et al. 1994)

X-ray (2-10 keV) emission components
- point sources (X-ray binaries)
- unresolved (or diffuse) emission

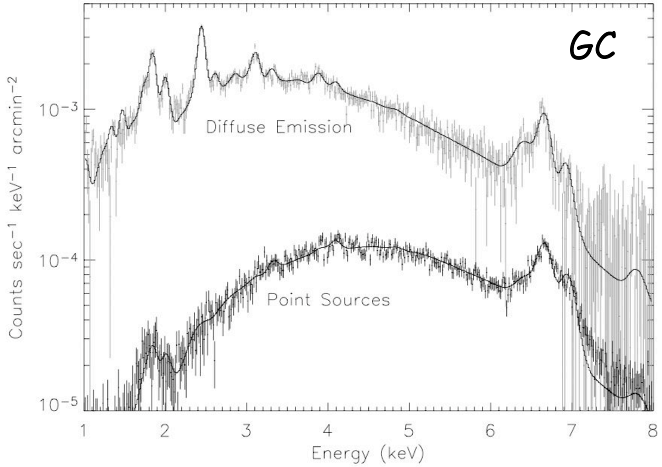
Galactic ridge X-ray emission (GRXE)
- exponential disk & bulge components
- confined to the inner disk ($|l| < 60°$)
- disk scale height z_0 ~ 100 - 300 pc
- luminosity ~ 10^{38} erg s^{-1} (2 - 10 keV) (few % of resolved sources luminosity)

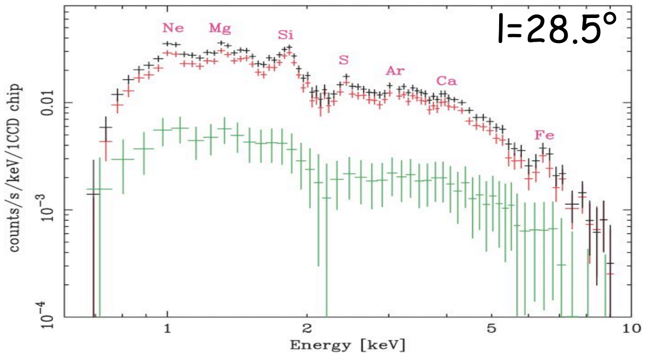
Origin of GRXE
- unresolved point sources?
- truly diffuse emission?

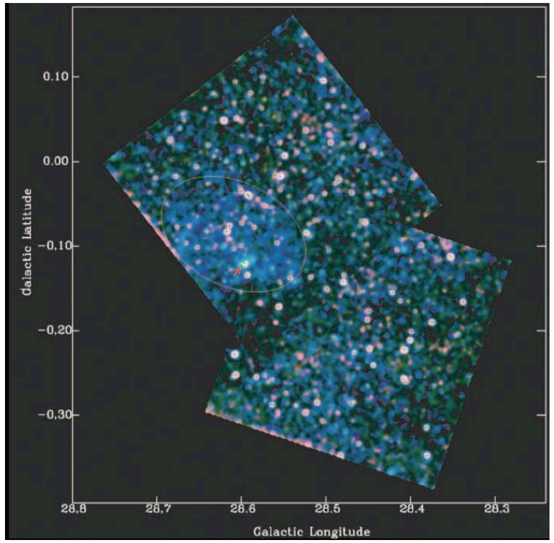
Deep X-ray surveys (XMM & Chandra)



GC (Muno et al. 2004)





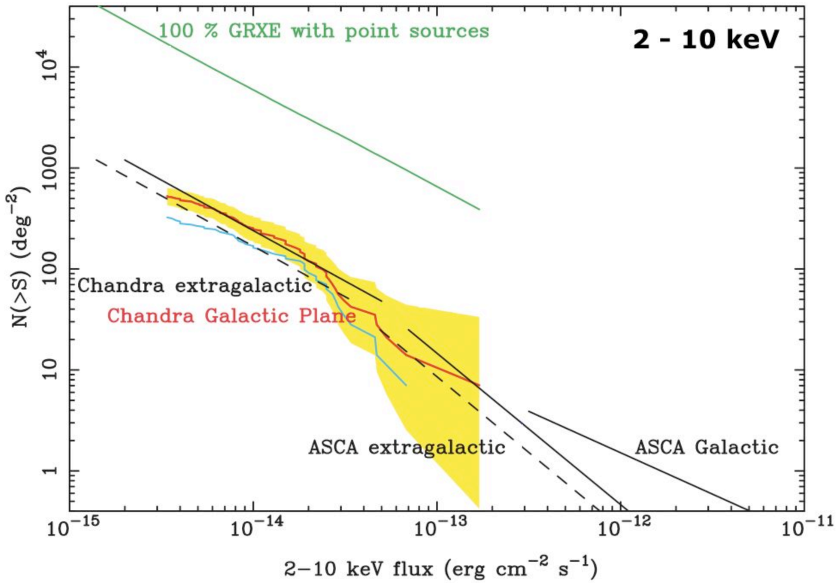


l=28.5° (Ebisawa et al. 2005)

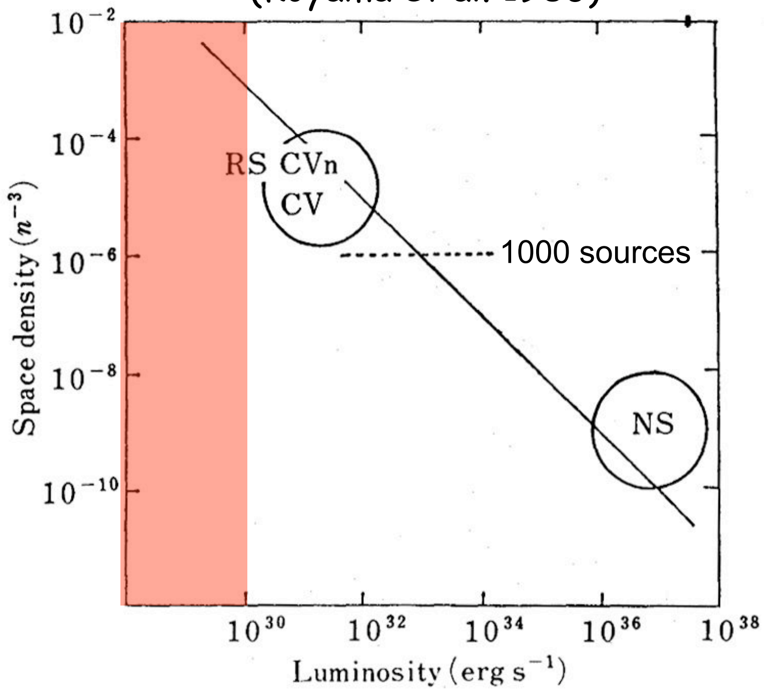
- XMM & Chandra detect new faint point sources and prominent diffuse emission
- Only 10-20% of flux originates from point sources, 80-90% of the emission is diffuse
- Soft (< 2 keV) point sources are of galactic origin
- Hard (2-10 keV) point sources are of extragalactic origin
- Prominent emission lines from highly ionized heavy elements

Point-source origin

(Ebisawa et al. 2005)



(Koyama et al. 1986)



Point source hypothesis

- Candidate must have a thin thermal plasma spectrum with iron line emission
- Candidate population requires rapid steepening of log N-log S at low flux (<3 x 10^{-15} erg s^{-1} cm^{-2})

Candidats

- NS binaries (10^{36-38} erg s^{-1}): **rarely show iron line, most of them are individually resolved**
- RS CVn / CVs (10^{30-32} erg s^{-1}): **resolved by Chandra/XMM, but not numerous enough**
- Low luminosity population (<10^{30} erg s^{-1}): **>10^9 sources required within Galaxy**

Diffuse origin

Inverse Compton scattering of microwave background, FIR photons, starlight

- fall short by 2 orders of magnitudes
- CR scale-height of > 1 kpc does not match the GRXE scale-height

Synchrotron radiation

- requires ~ 10^{14} eV electrons ⇒ unclear whether they exist (solar modulation)
- large energy input required to sustain electron population ⇒ ionisation of ISM

Thermal equilibrium plasma

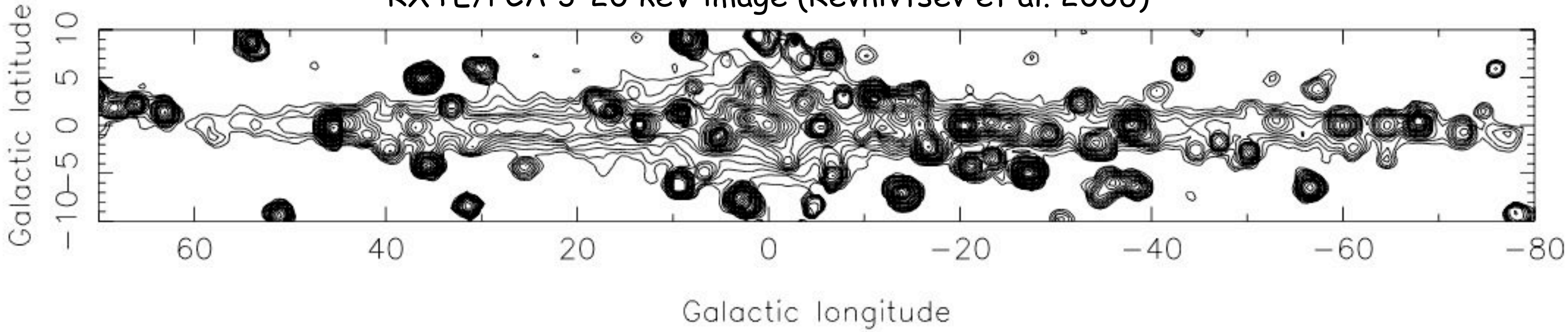
- requires T ~ 10^7 - 10^8 K ⇒ plasma exceeds escape velocity from galactic plane
- requires P/k ~ 10^5 cm^{-3} K ⇒ exceeds pressure of other ISM components
- required energy density ~ 10 eV cm^{-3} ⇒ 1-2 orders of magnitudes higher than CR, B, n

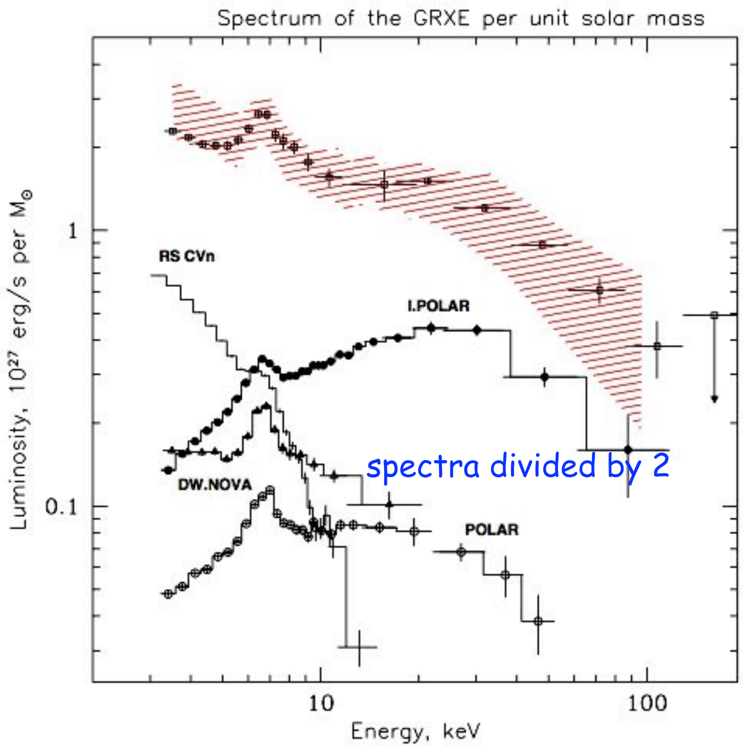
CR interactions with interstellar medium

- interactions of low-energy CR e^-, in-situ accelerated e^-, or heavy ions with ISM
- hard X-ray emitting SNR AX J1843.8-0352: possible link between GRXE and SNRs

Finally point sources?

RXTE/PCA 3-20 keV image (Revnivtsev et al. 2006)





Morphology

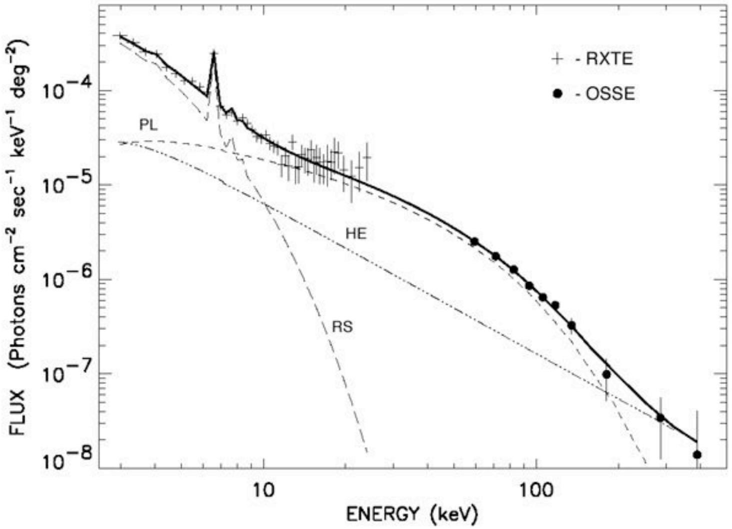
- tri-axial bar/bulge & exponential disk
- distribution very similar to NIR (e.g., COBE 3.5 μm)
- bar tilt angle: 29° ± 6° (COBE NIR data: 20° ± 10°)
- exponential disk scale-height: z = 130 ± 20 pc
- position of Sun above gal. Plane: z_0 = 20 ± 7 pc

Luminosities

- $L_{X,bulge}$ = (3.9 ± 0.5) x 10^{37} erg s^{-1}
- M_{bulge} = (1.0 - 1.3) x 10^{10} $M_\odot$
- $L_X/M_\odot$ = (3.5 ± 0.5) x 10^{27} erg s^{-1}
- **Comparable with cumulative emissivity per unit stellar mass of point X-ray sources in solar neighbourhood (coronally active late-type binaires and CVs)**

INTEGRAL resolves the hard X-ray ridge

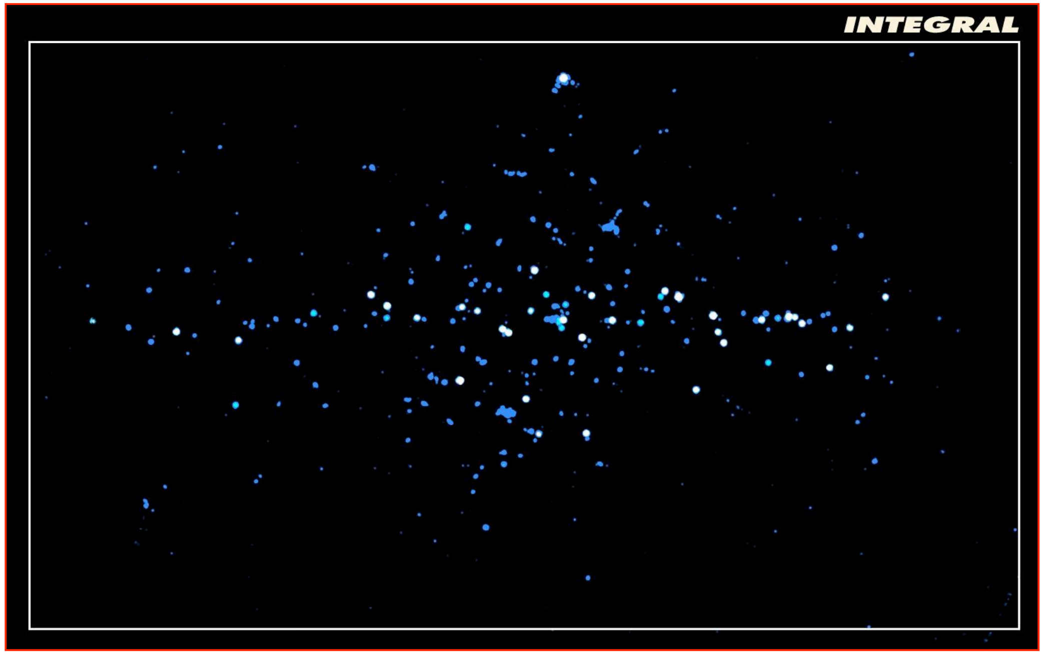
RXTE & OSSE (Valinia & Tatischeff 2001)



Hard X-ray emission components

- **< 10 keV**
  RS (= GXRE)
- **10 - 200 keV**
  PL (exponentially cut-off powerlaw)
- **> 200 keV**
  HE (high-energy flattening)

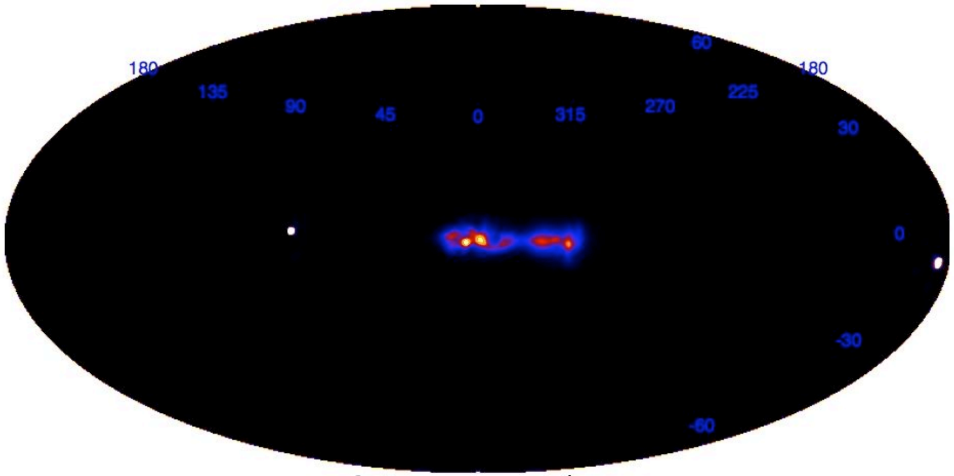
IBIS (Lebrun et al. 2004)



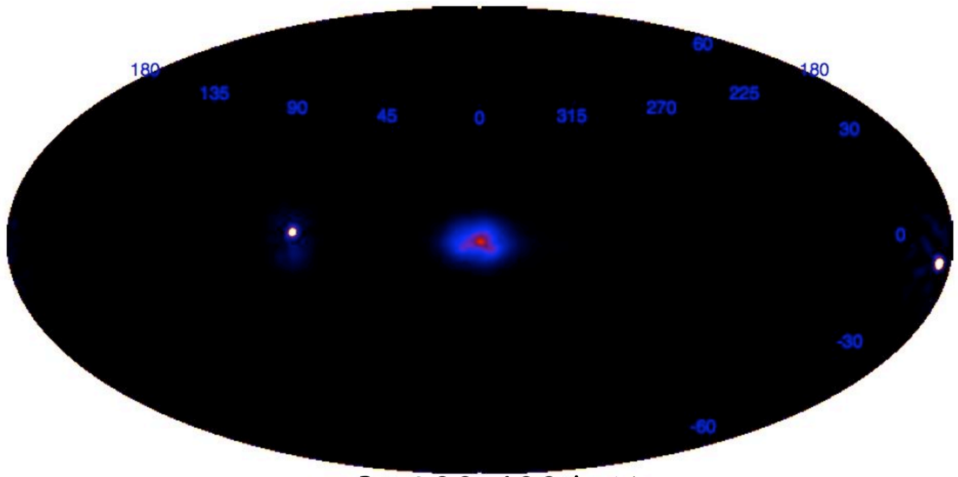
PL (exponentially cut-off powerlaw)

- IBIS detects many point source towards the galactic bulge region
- Most of the total emission is attributed to point sources
  20 - 40 keV: 87% attributed to point sources
- By combining IBIS (point sources) and SPI (total emission)
  100 - 200 keV: 86% attributed to point sources

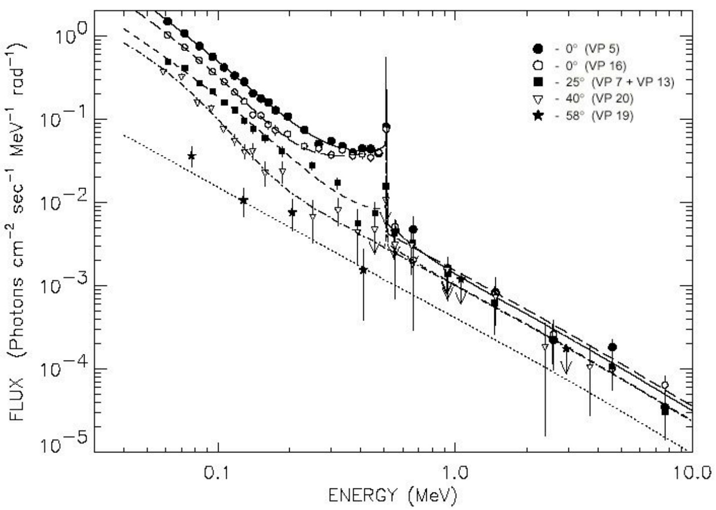
The hard X-ray to soft γ-ray transition



SPI 200-300 keV



SPI 300-400 keV



OSSE spectra (Kinzer et al. 1999)

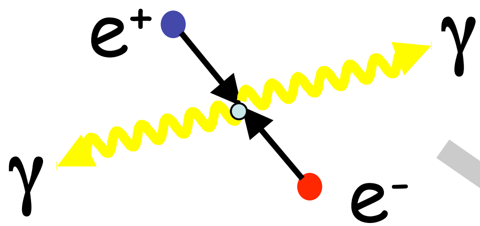
Emission components

- **< 200 keV (hard X-rays)**
  PL (exponentially cut-off powerlaw)
- **200 - 511 keV (soft γ-rays)**
  Pscont (Positronium continuum, towards bulge only)
- **> 511 keV (γ-rays)**
  HE (high-energy power-law tail)

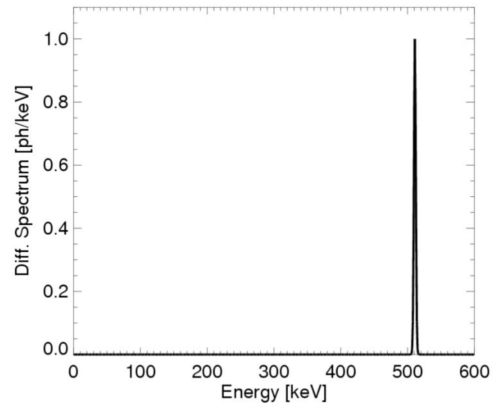
Is the transition hard X-ray $\Rightarrow$ soft γ-ray
a point source $\Rightarrow$ diffuse emission transition?

Antimatter annihilation in the Milky-Way

- Direct annihilation

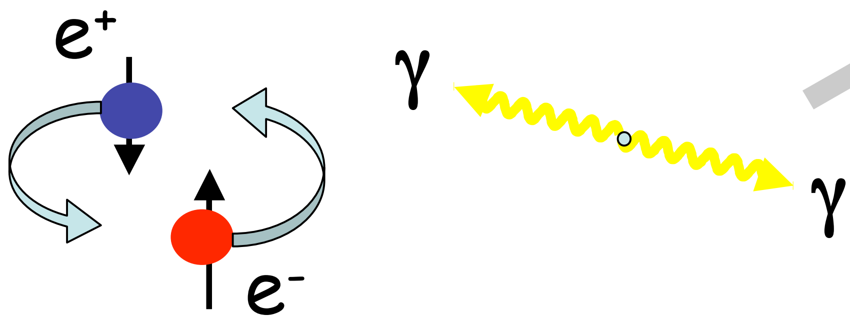


Annihilation line
E = 511 keV



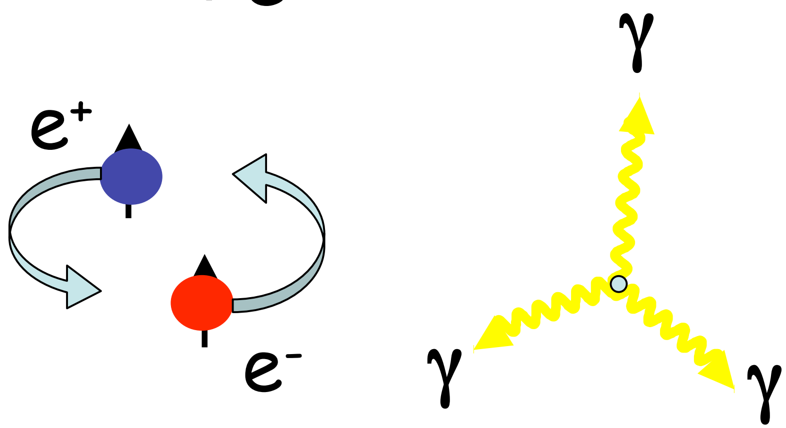
- Annihilation via positronium (Ps) formation

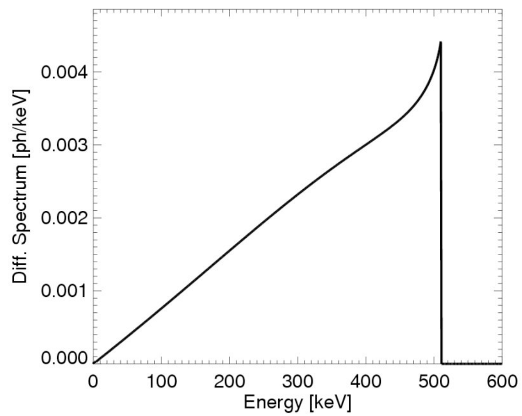
para-positronium
1/4



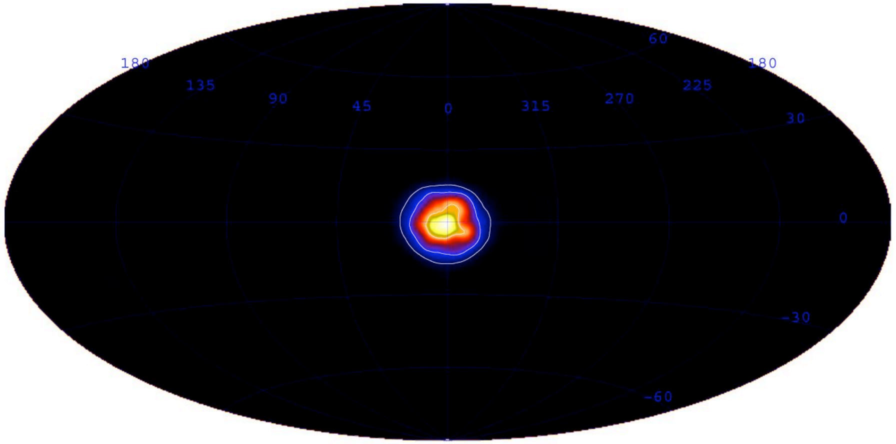
Positronium continuum
E < 511 keV

ortho-positronium
3/4

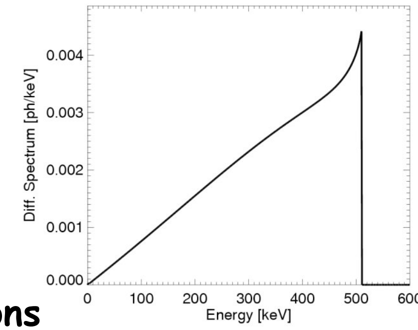




Positron annihilation: spatial distribution

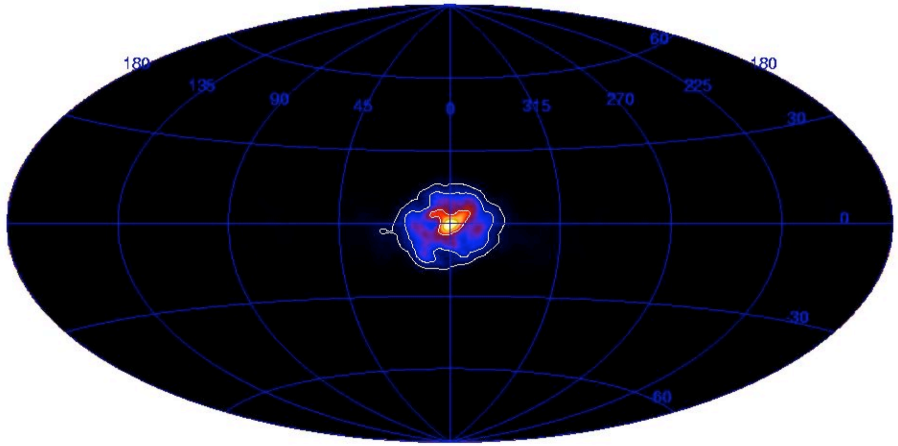


SPI Pscont image (Weidenspointner et al. 2006)

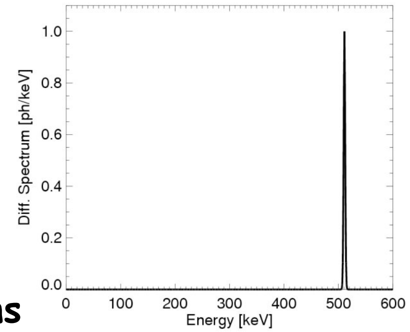


Observations

- No point sources seen (SPI & IBIS)
- Continuum and line are spatially consistent
- Galactic bulge dominates emission
- Only small signal from galactic disk (~3σ)
- B/D luminosity ~ 3 - 9



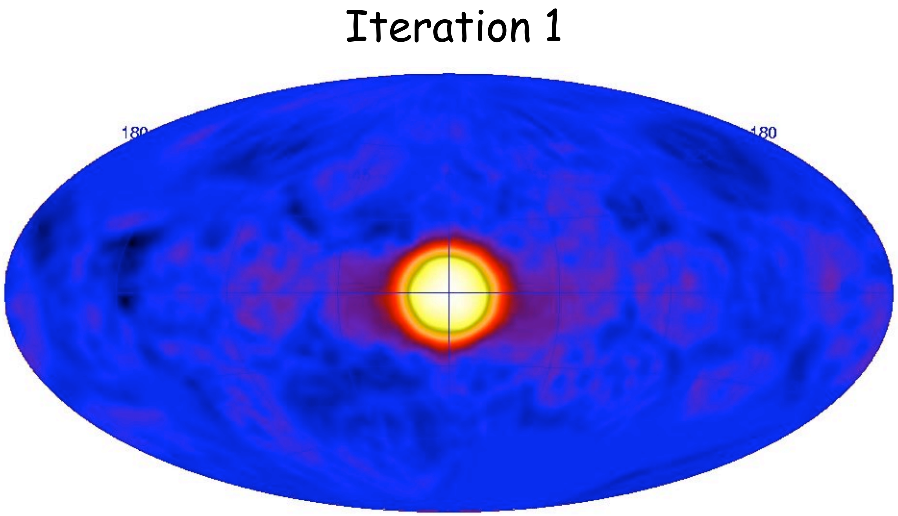
SPI 511 keV image (Knödlseder et al. 2005)

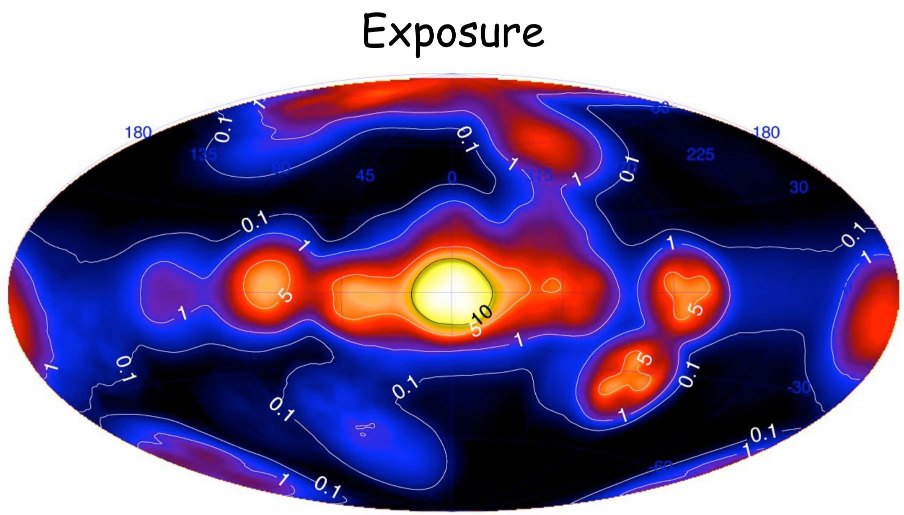


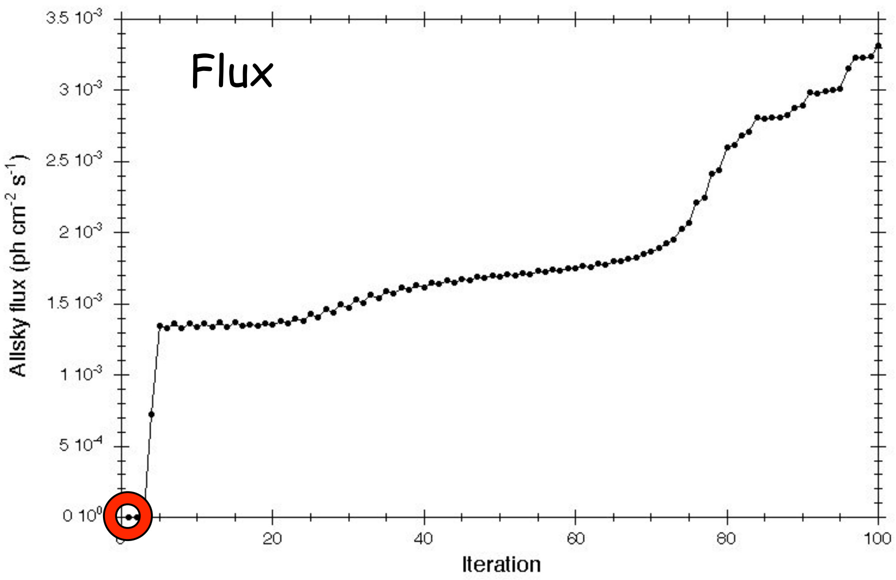
Implications

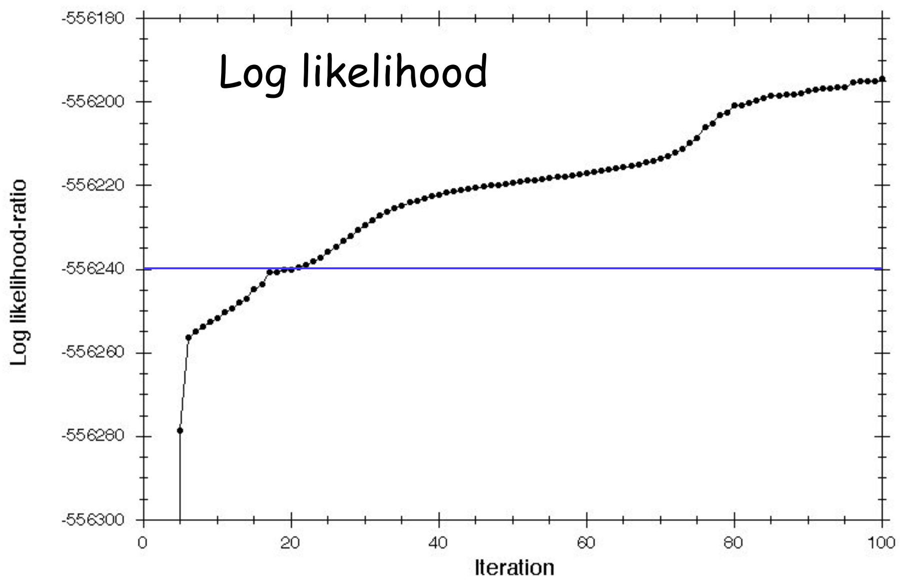
- Positron annihilation distribution is unique
  Once we identify the source we certainly learn something new! (new population, new mecanism, new physics, …)
- Weak galactic disk signal compatible with ^{26}Al decay

Indirect imaging: deconvolving SPI data

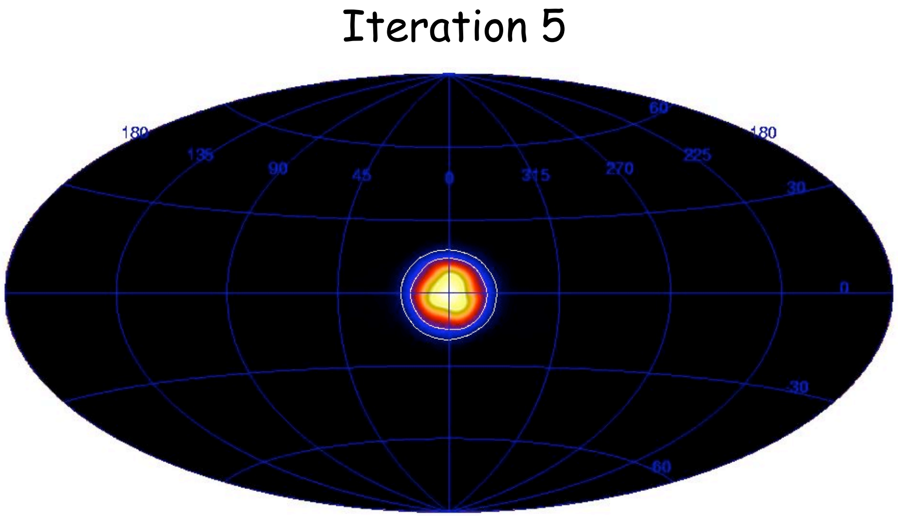


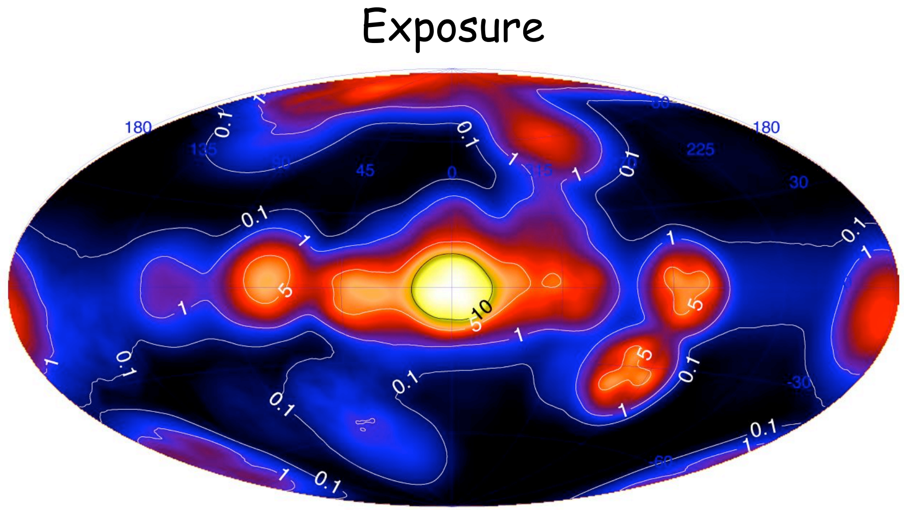


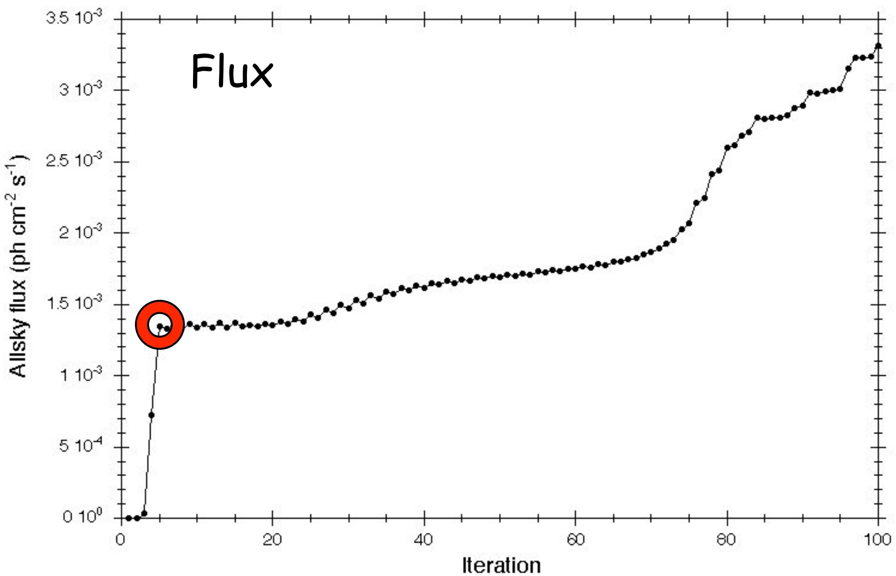


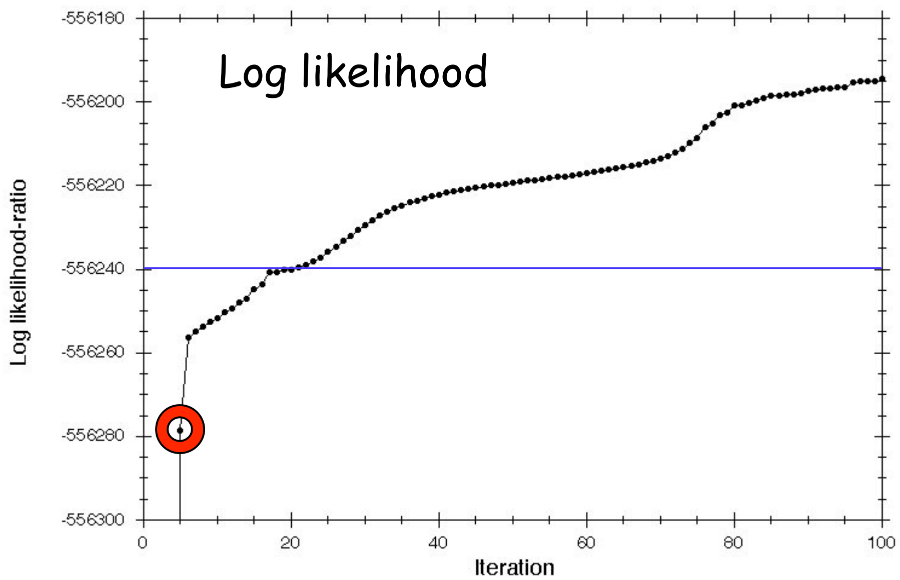


Indirect imaging: deconvolving SPI data



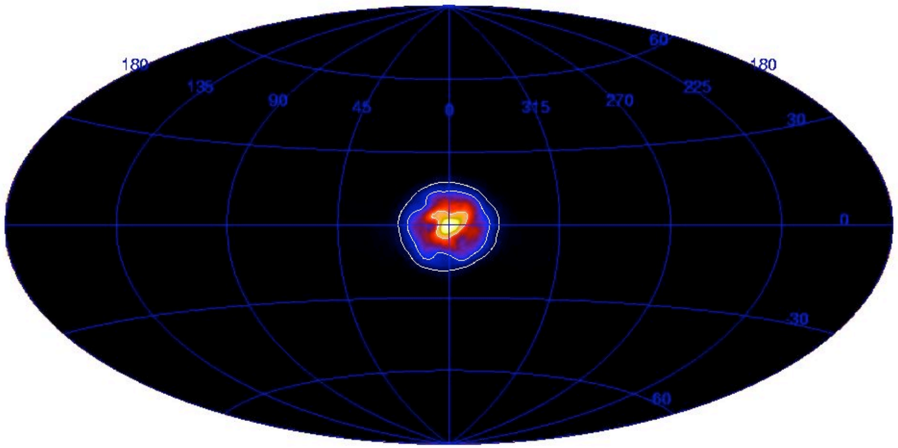




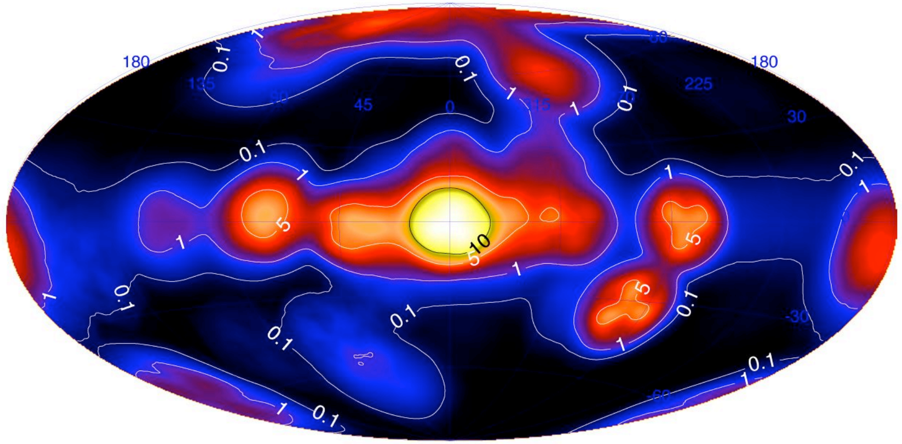


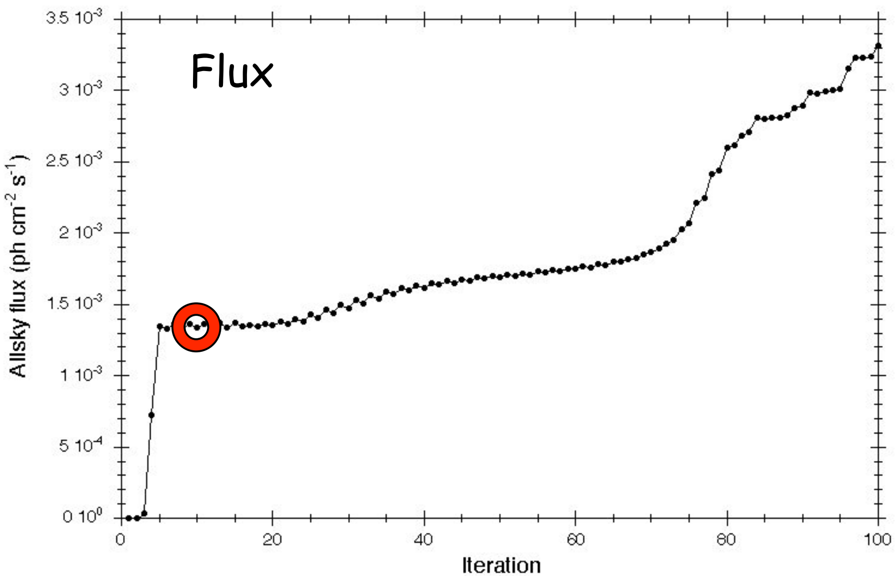
Indirect imaging: deconvolving SPI data

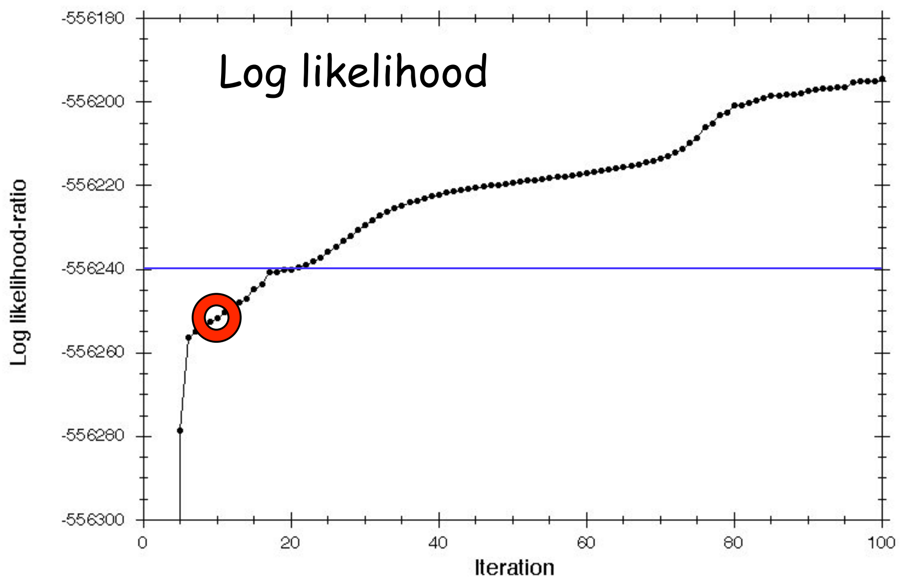
Iteration 10



Exposure

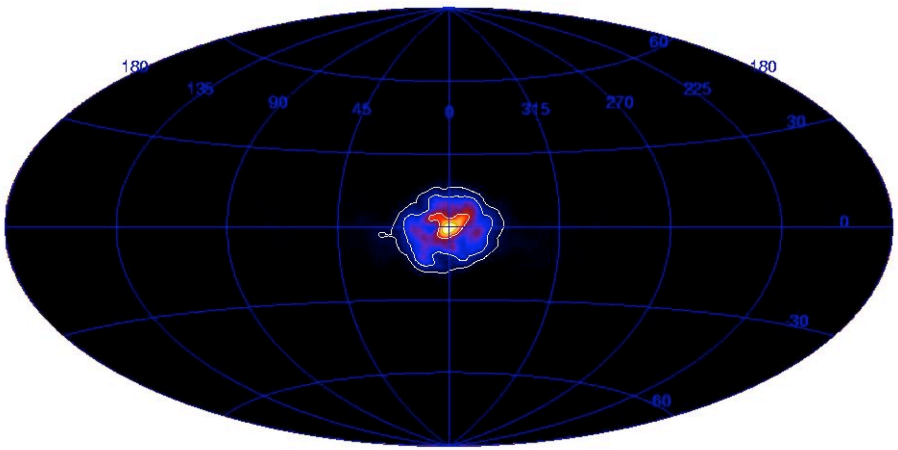




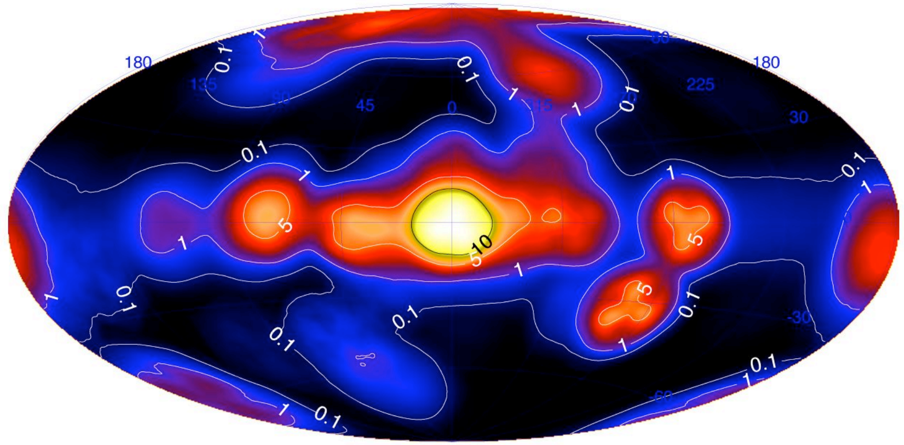


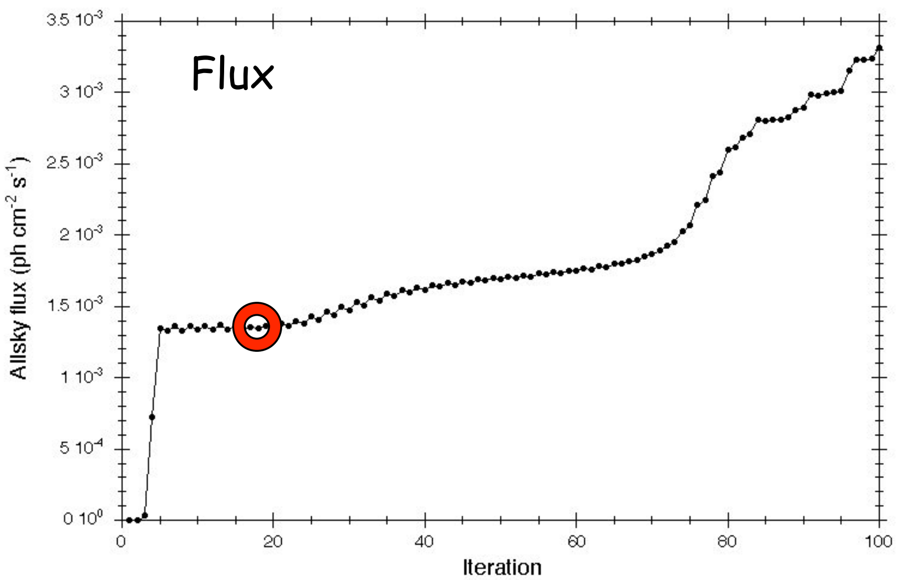
Indirect imaging: deconvolving SPI data

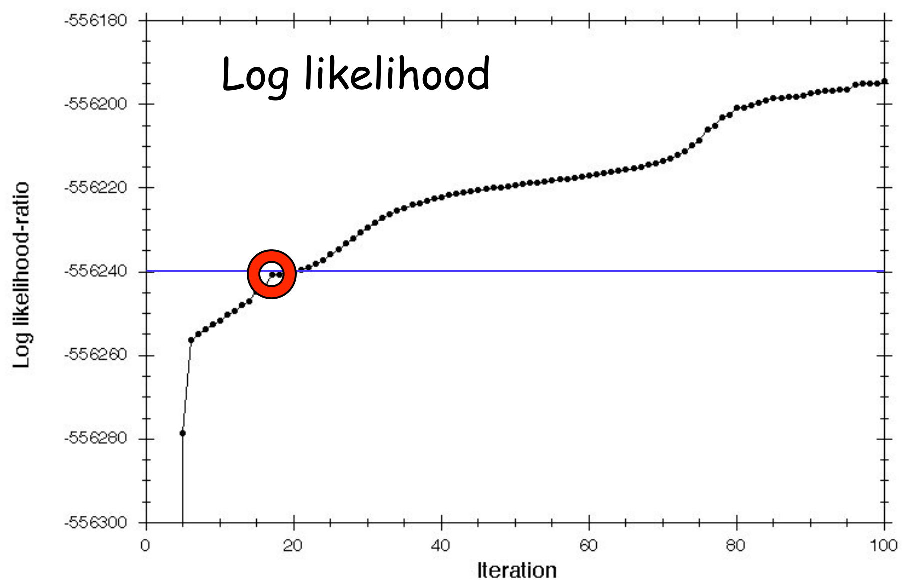
Iteration 17



Exposure

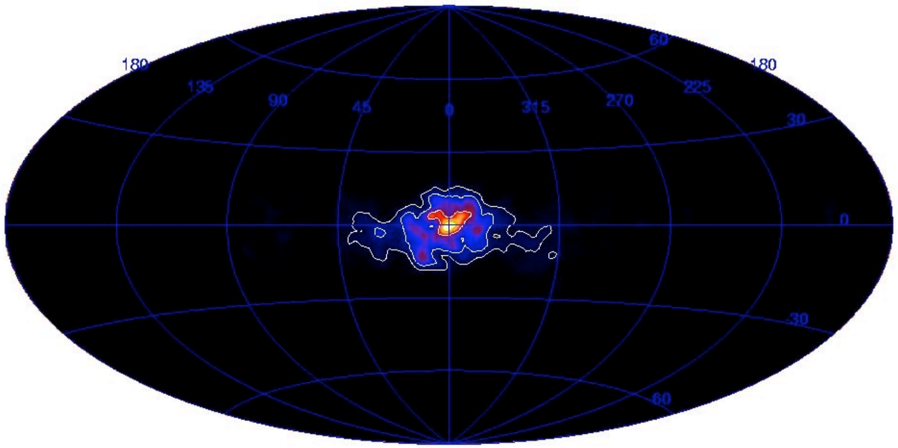




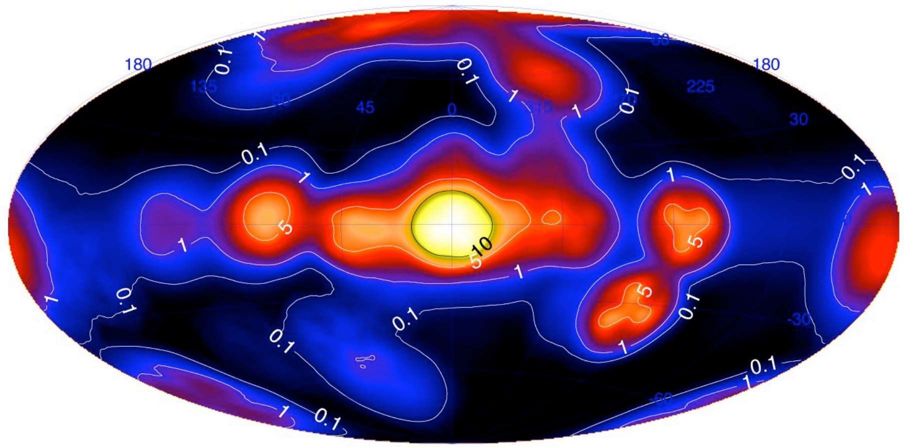


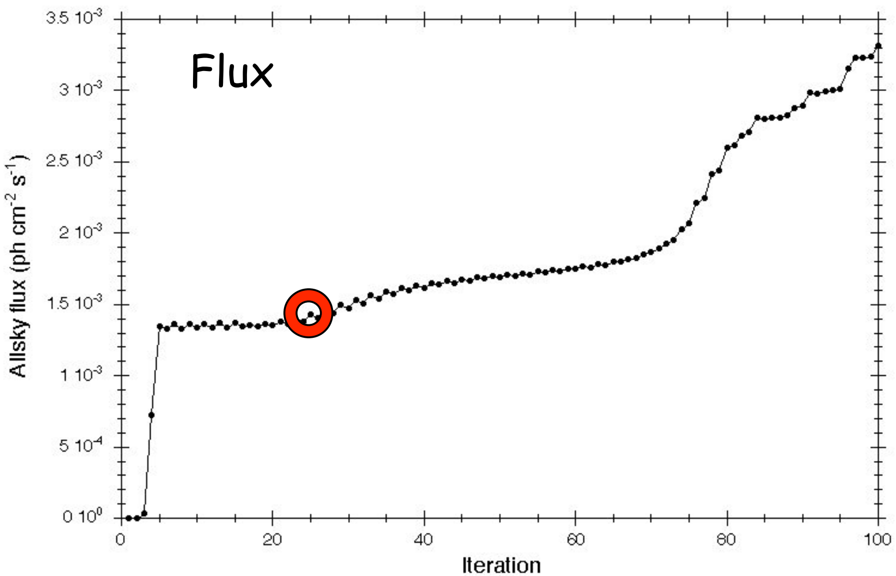
Indirect imaging: deconvolving SPI data

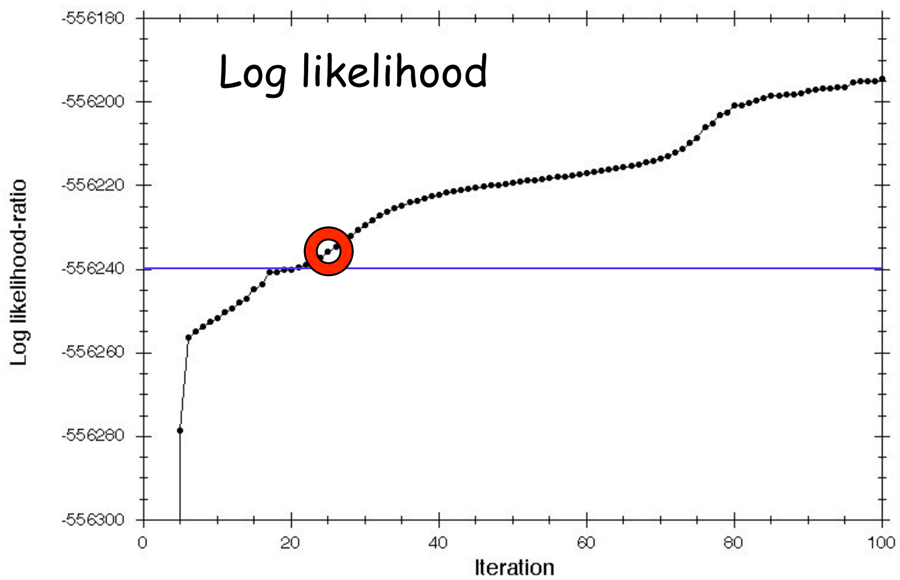
Iteration 25



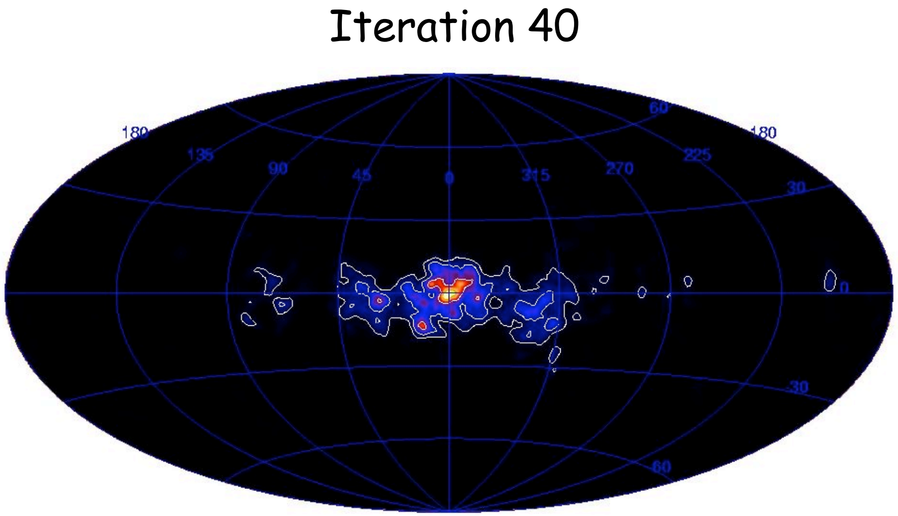
Exposure

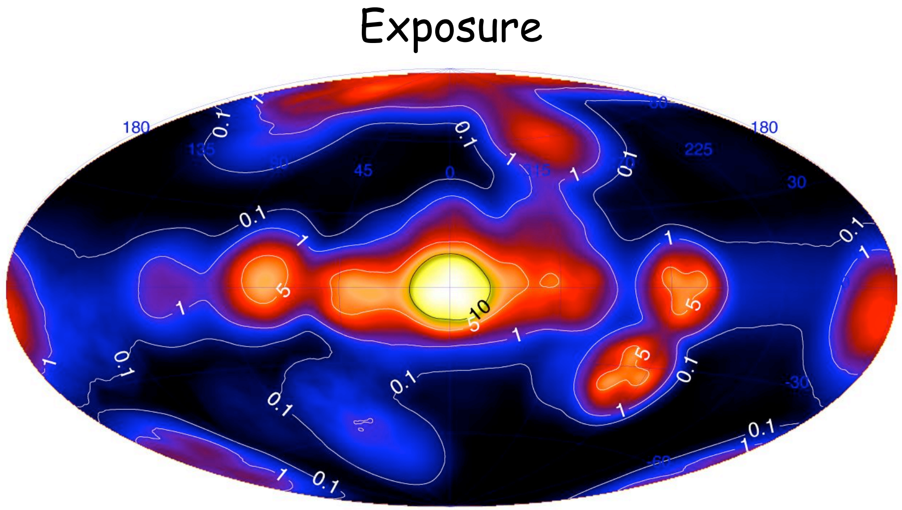


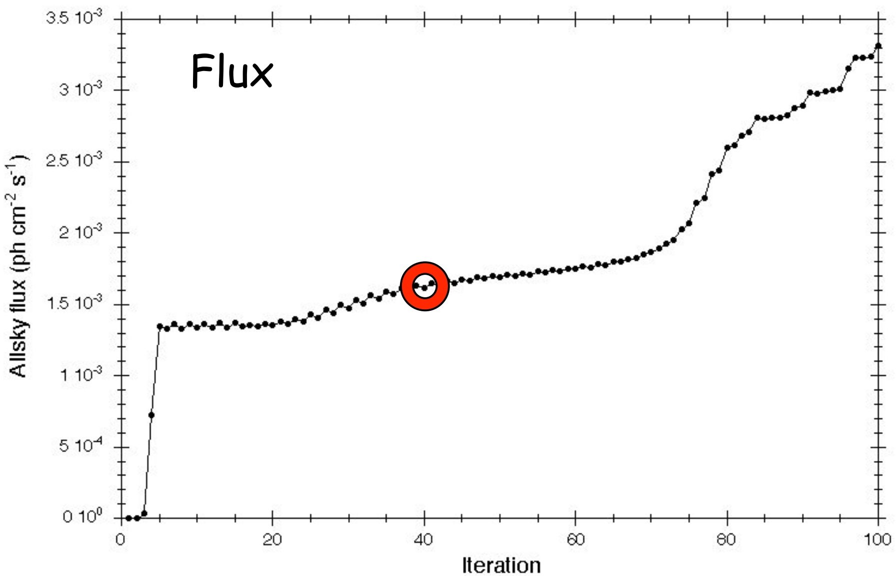


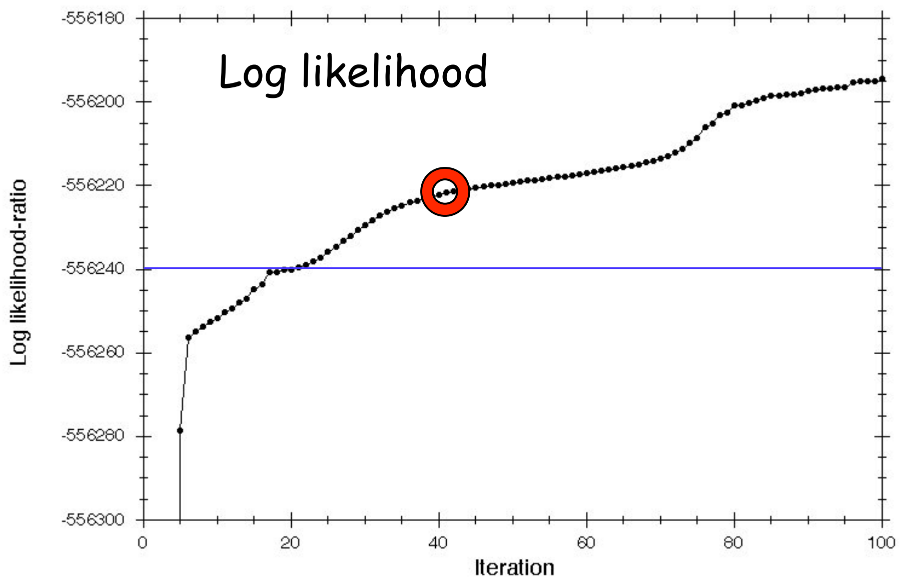


Indirect imaging: deconvolving SPI data



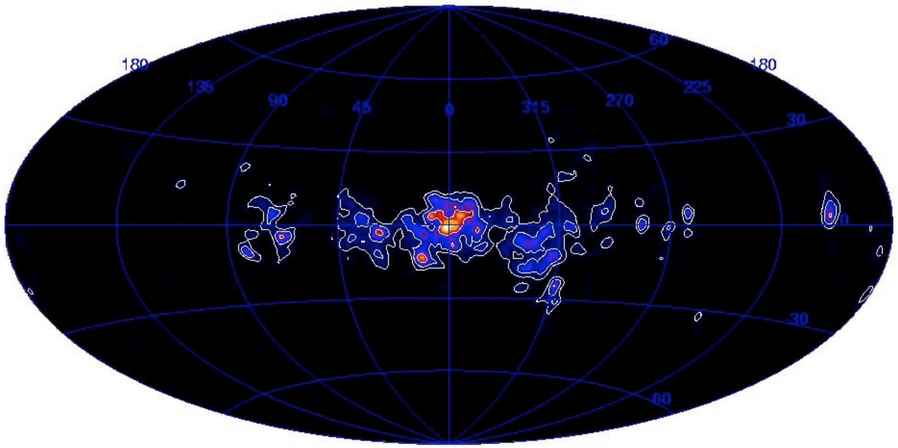




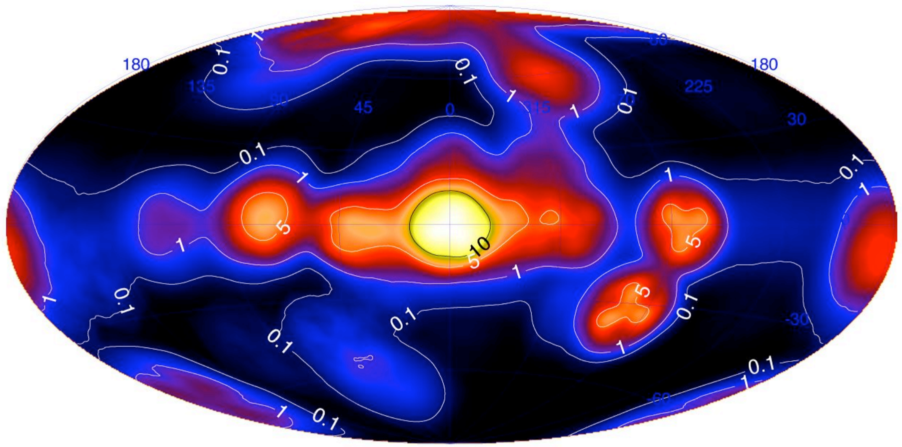


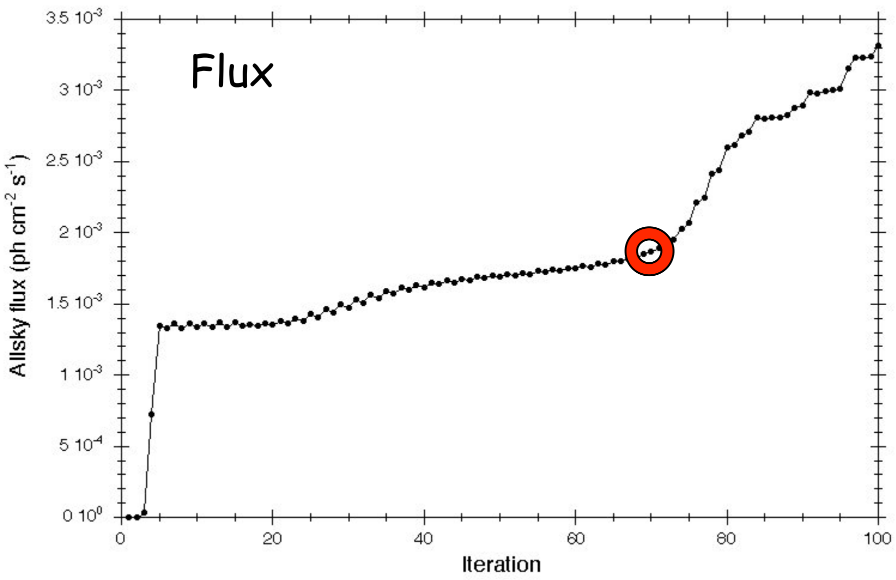
Indirect imaging: deconvolving SPI data

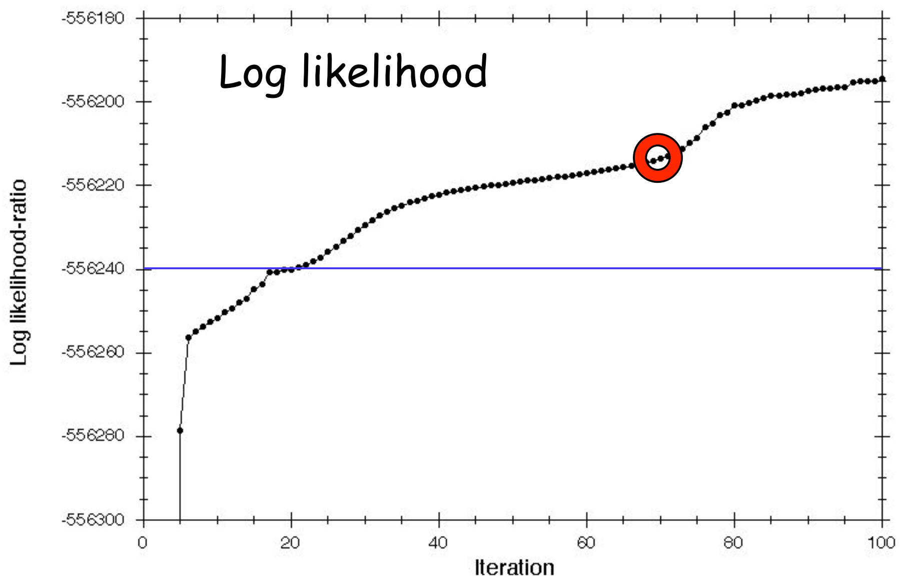
Iteration 70



Exposure

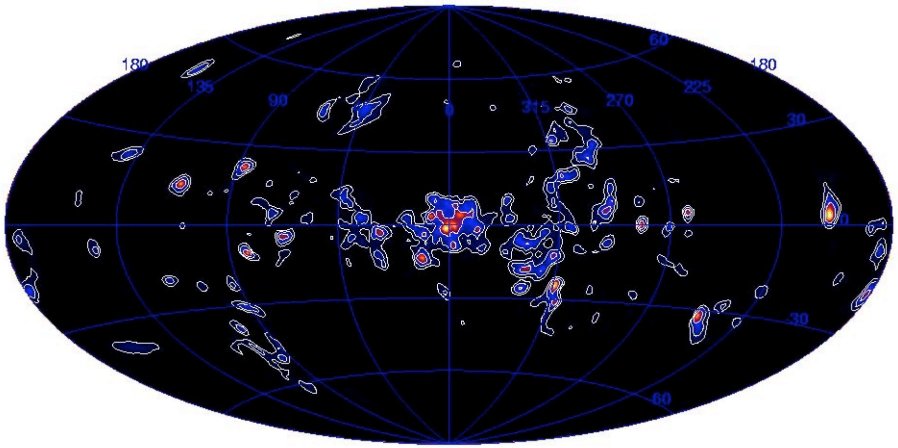




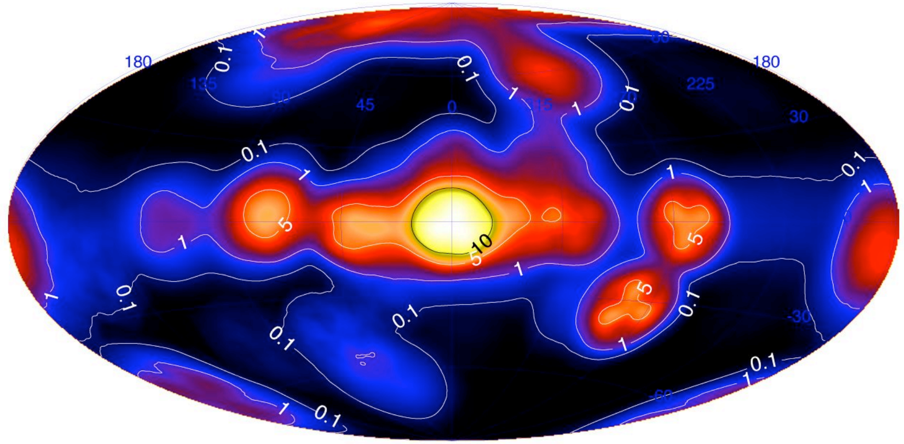


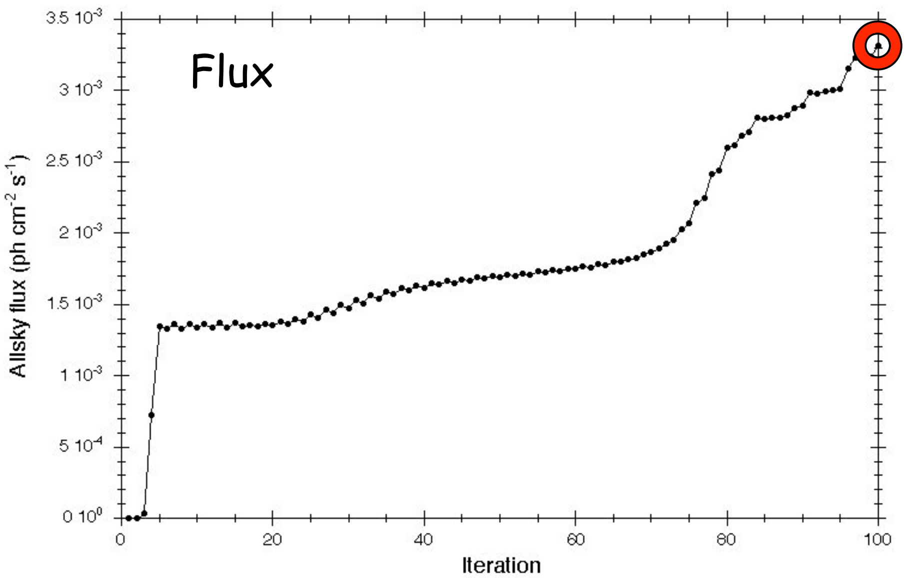
Indirect imaging: deconvolving SPI data

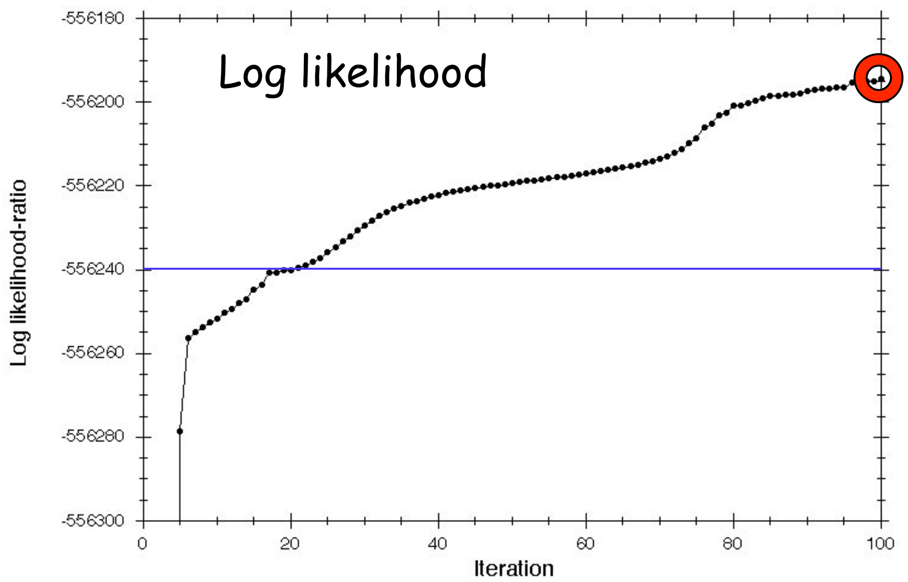
Iteration 100



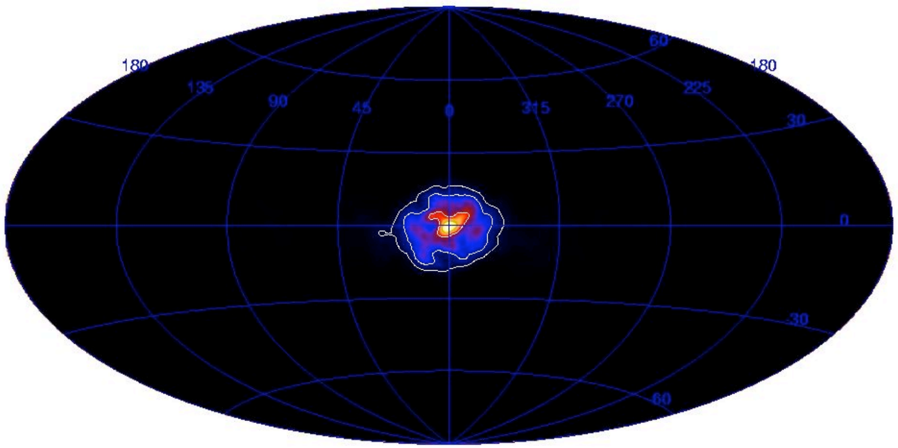
Exposure



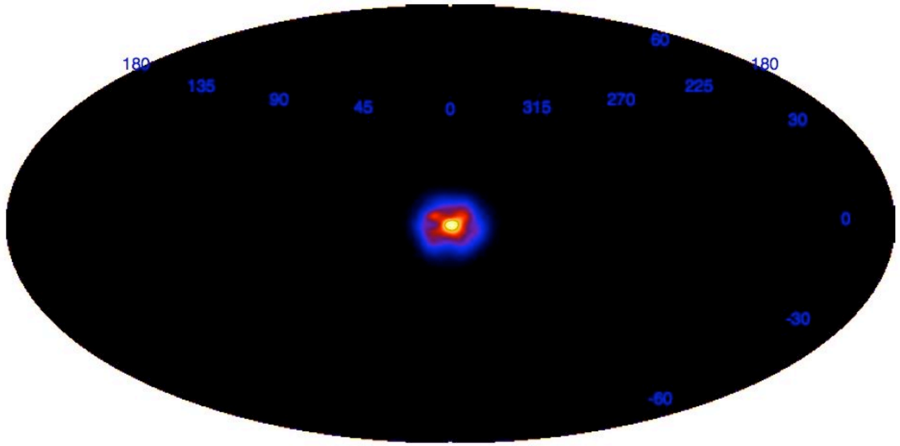




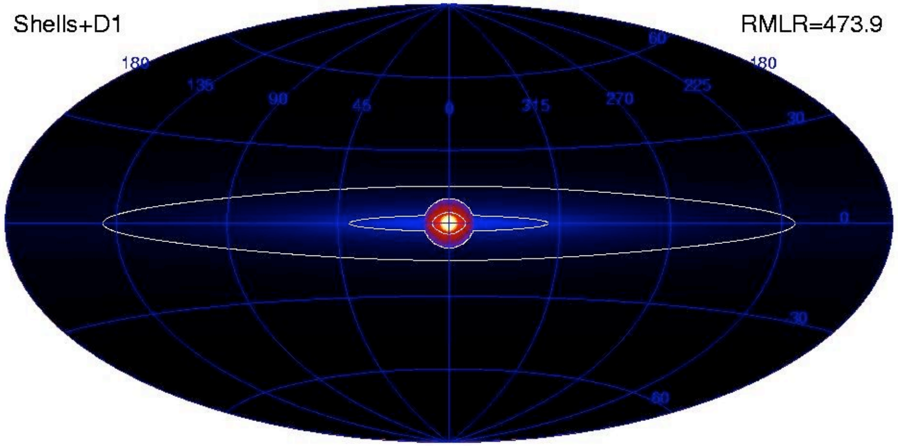
Suppressing noise



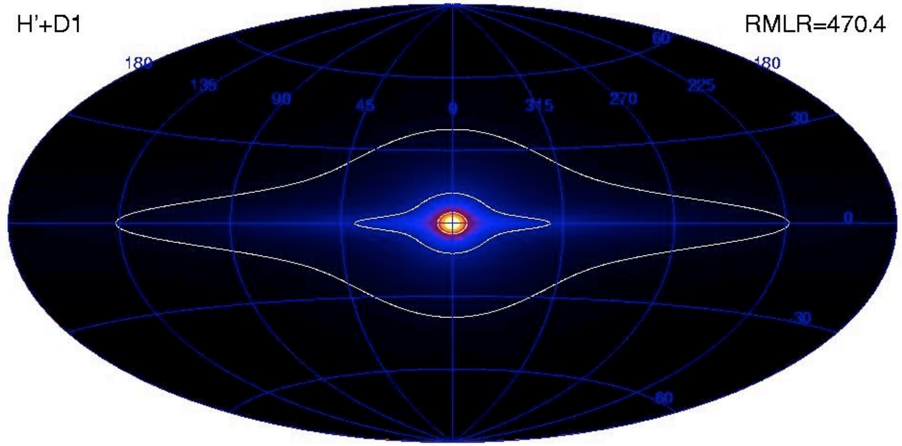
Richardson-Lucy (iteration 17)



MREM (Knödlseder et al. 1999)

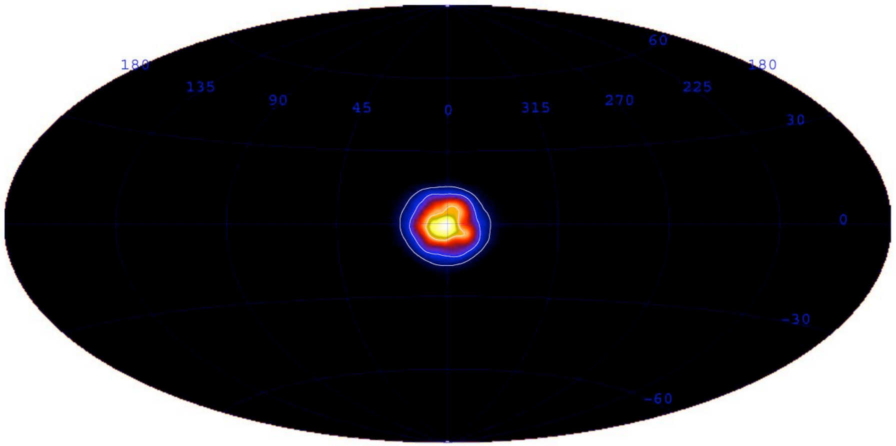


Model fitting (bulge + old disk)

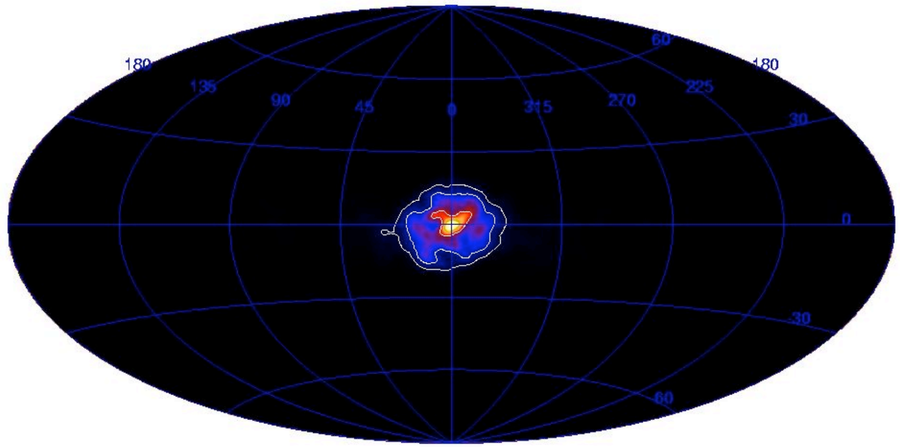


Model fitting (halo + old disk)

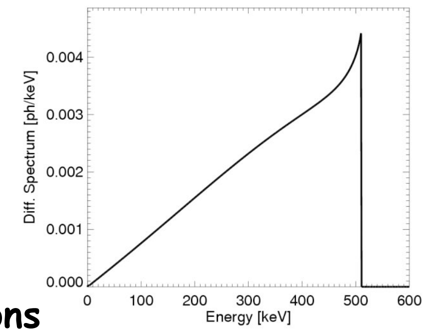
Positron annihilation: spatial distribution

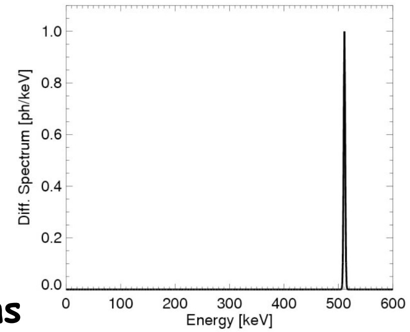


SPI Pscont image (Weidenspointner et al. 2006)



SPI 511 keV image (Knödlseder et al. 2005)





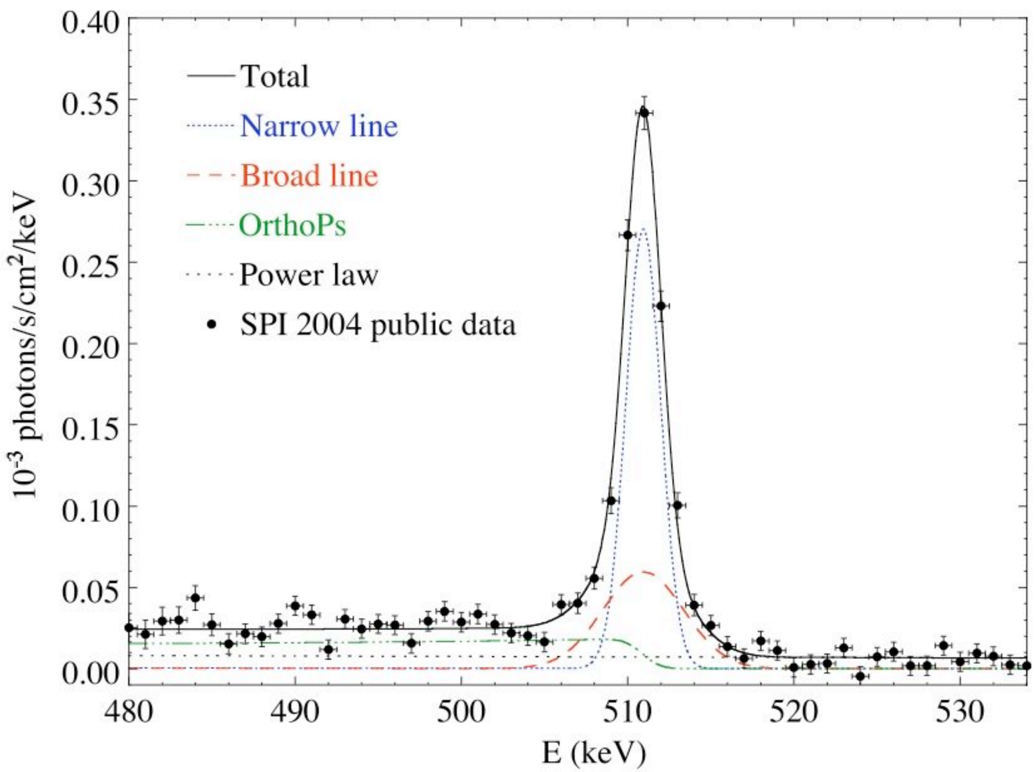
Observations

- No point sources seen (SPI & IBIS)
- Continuum and line are spatially consistent
- Galactic bulge dominates emission
- Only small signal from galactic disk (~3σ)
- B/D luminosity ~ 3 - 9

Implications

- Positron annihilation distribution is unique
  Once we identify the source we certainly learn something new! (new population, new mecanism, new physics, …)
- Weak galactic disk signal compatible with ^{26}Al decay

Positron annihilation: spectral distribution



SPI spectrum (Jean et al. 2006)

SPI spectral fitting

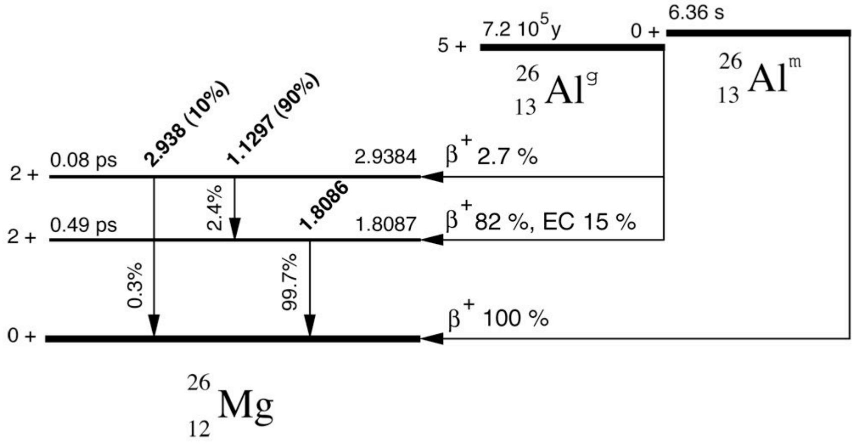
- Energy 510.98 ± 0.03 keV
- $FWHM_n$ 1.3 ± 0.4 keV
- $FWHM_b$ 5.4 ± 1.2 keV
- $Flux_n$ 7.2×10^{-4} ph cm^{-2} s^{-1}
- $Flux_b$ 3.5×10^{-4} ph cm^{-2} s^{-1}

Interpretation

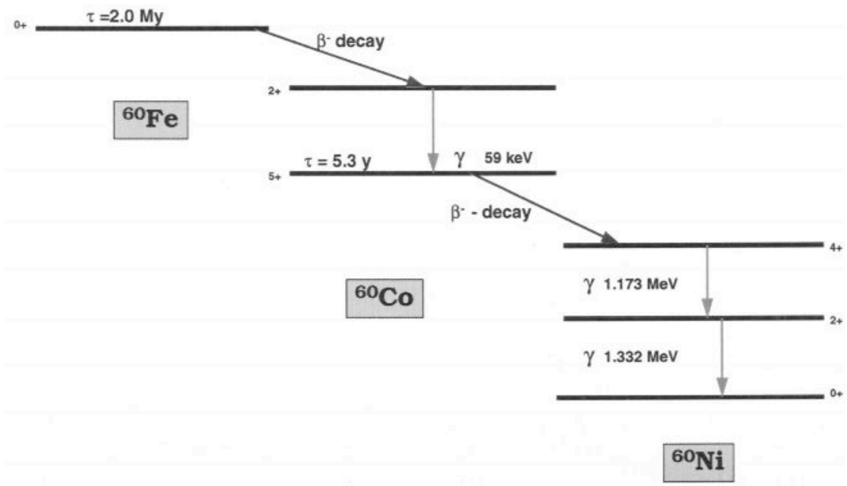
- Narrow line (1.1 keV)
  - thermalised positrons
  - consistent with 8000 K warm ISM (neutral & ionised)
- Broad line (5.1 keV)
  - inflight positronium formation
  - consistent with 8000 K warm ISM (only neutral, quenched if gaz is fully ionised)
- Narrow / broad line fraction ~ 2
  consistent with 8000 K warm ISM (50% ionised)

Radioactive decay in the Milky-Way

^{26}Al decay scheme



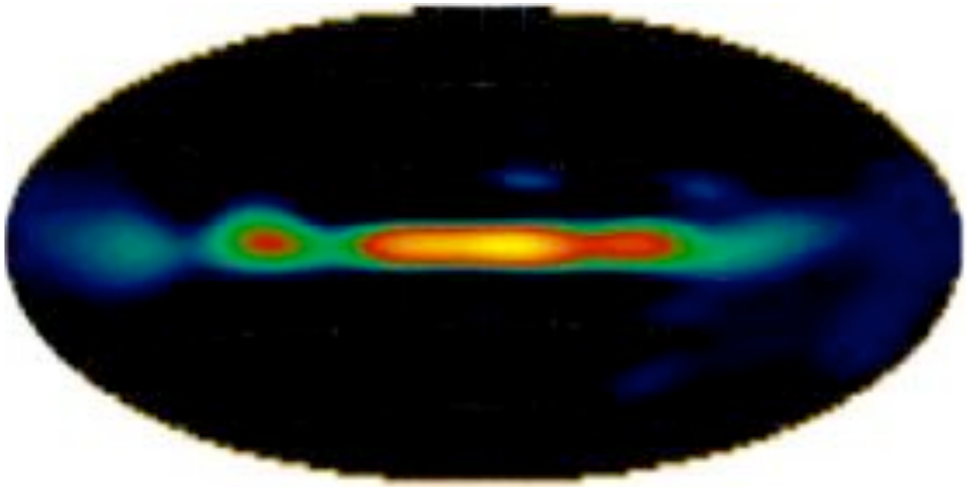
^{60}Fe decay scheme



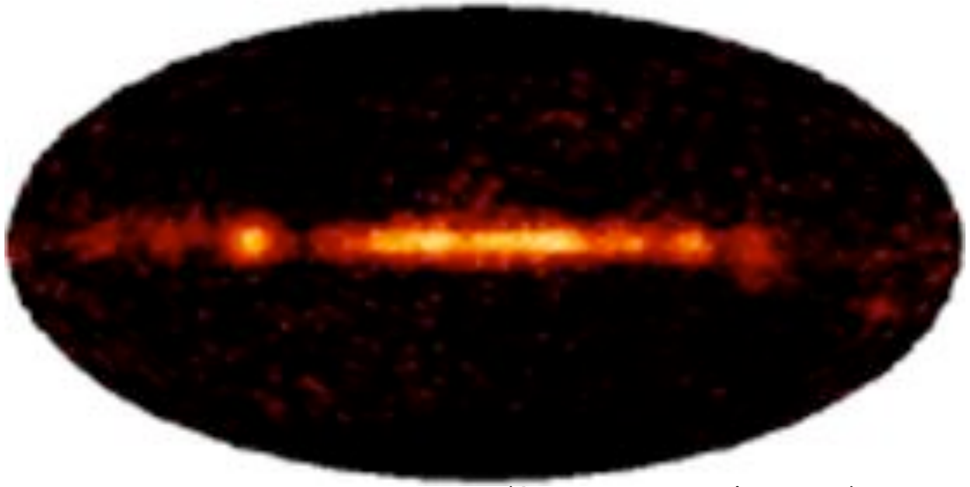
Distribution of ^{26}Al and ^{60}Fe in the ISM

- velocity of 1 km/s corresponds to a distance of 1 pc with 1 Myr
- SN ejection velocities: 1000 - 10000 km s^{-1} (but slow down)
- WR wind velocities: several 1000 km s^{-1}
- SN or wind blown bubbles: 10 - 100 pc
- **^{26}Al and ^{60}Fe should lead to diffuse emission, nuclei probably thermalised**
- Short livetime isotopes (<100 yr, such as ^{44}Ti, ^{7}Be, ^{22}Na, ^{56,57}Co): point-like emission (<pc)

^{26}Al decay 1809 keV line emission



COMPTEL image (Knödlseder et al. 1999)



DMR microwave image (Bennett et al. 1992)

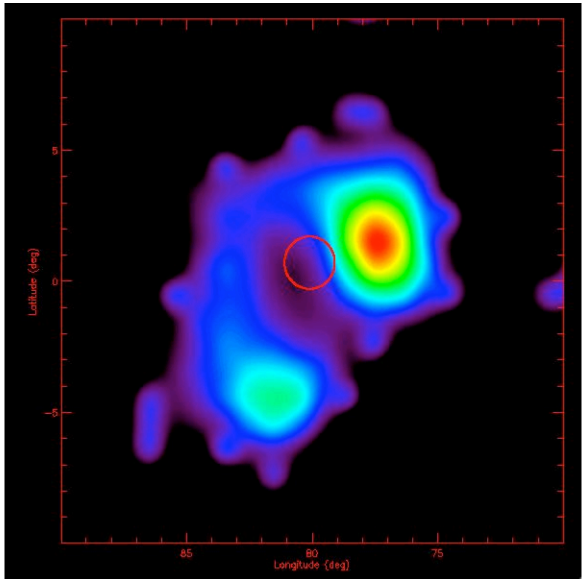
1809 keV line: radioactive ^{26}Al production

- H and C-burning nucleosynthesis
- Hydrodynamic and explosive
- Stellar wind ejection (O, LBV, WR)
- Supernovae ejection (type II, Ib/c)
- Probe stellar mixing processes
- Traces massive stars

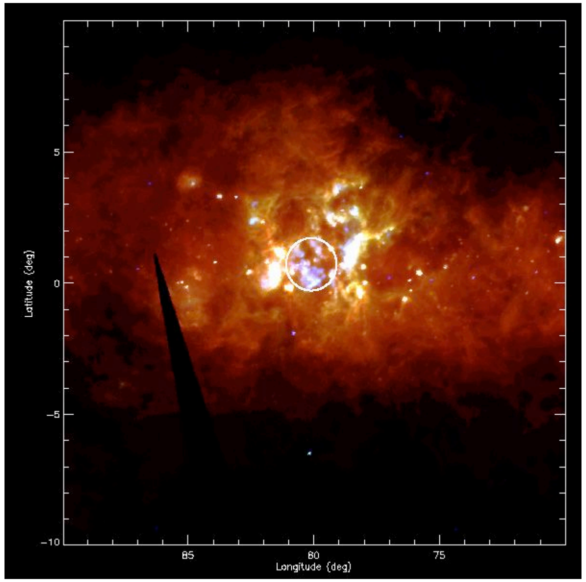
^{26}Al production and massive stars

- 1809 keV emission correlates to microwave free-free emission
- Free-free: ionised ISM (O stars, $M>20\ M_\odot$)
- $Y_{26} = 10^{-4}\ M_\odot$ /O7V

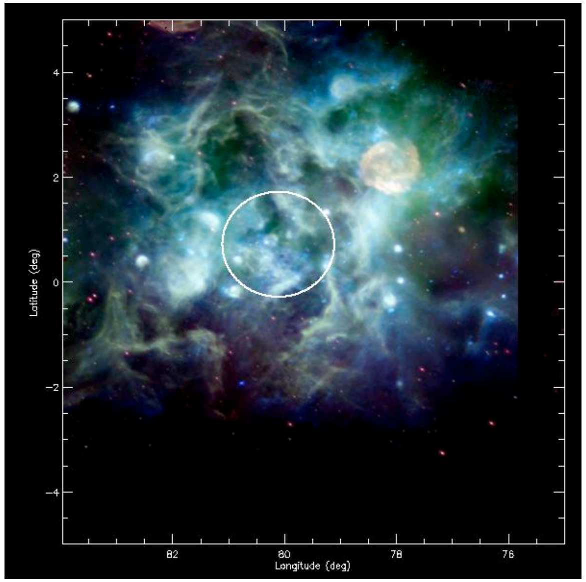
Calibrating stellar models



1809 keV γ-rays (COMPTEL)



Infrared (IRAS)

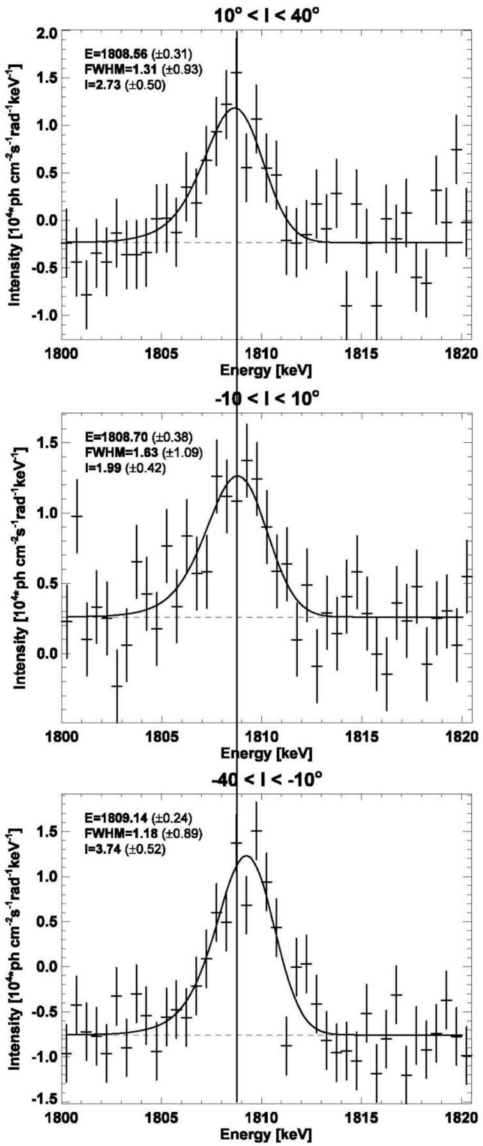


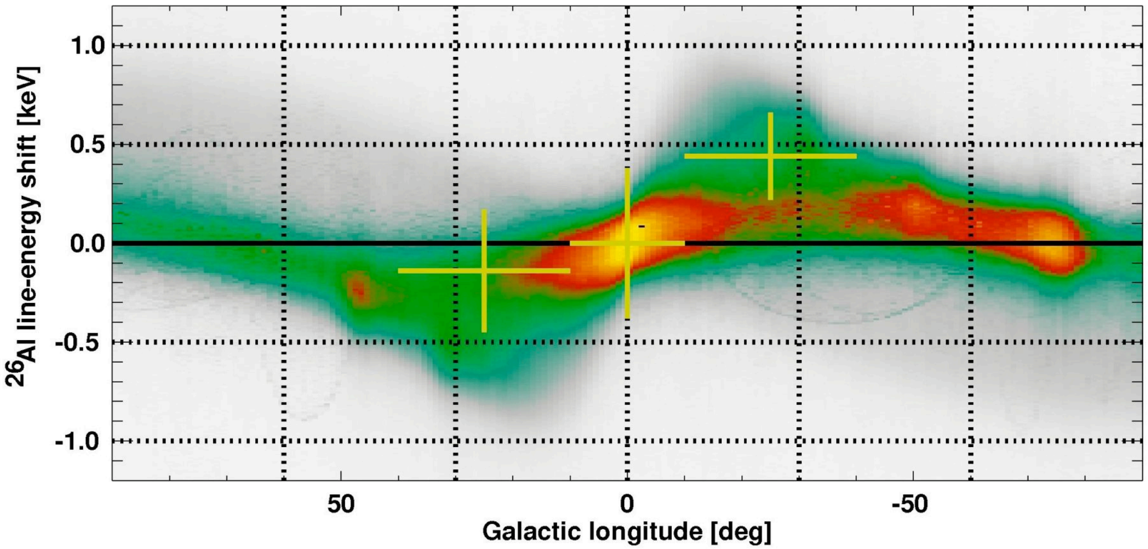
Radio (DRAO)

Understanding ^{26}Al nucleosynthesis in Cygnus

- Bright 1809 keV line feature
- Massive star population of Cygnus region is known (IR surveys)
- Estimate expected 1809 keV line flux using nucleosynthesis models and stellar population models (Cerviño et al. 2000; Knödlseder et al. 2002)
- Validate model using multi-wavelength properties (e.g. ionizing flux)
- **1809 keV flux underestimated by at least a factor of 2** (mixing?, stellar rotation?)

1809 keV line emission traces galactic rotation



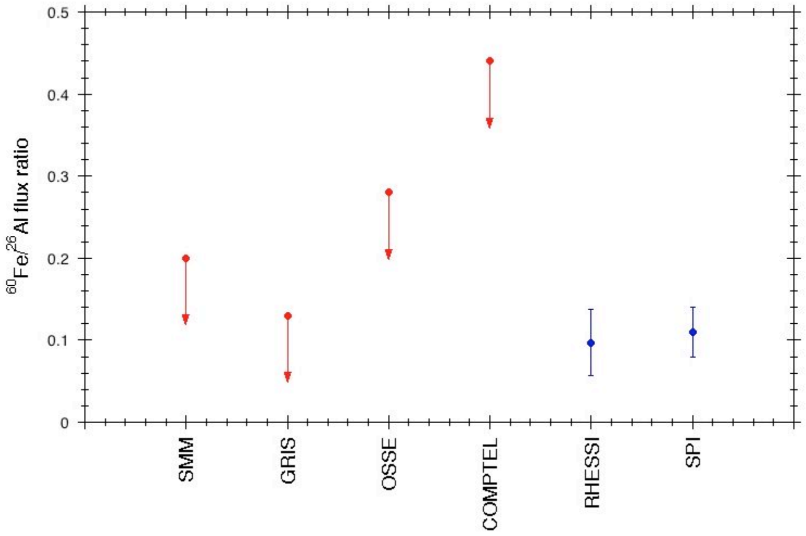


^{26}Al kinematics

- Galactic rotation (v ~ 200 km s^{-1}) leads to Dopples shifts (~ 1 keV)
- Expected average line shifts ± 0.3 keV (from CO)
- Measured line shifts ± 0.3 keV (SPI/INTEGRAL)
- Confirmation of galaxy-wide ^{26}Al production (2.8 ± 0.8 $M_\odot$)
- Using yield estimates (theory) this converts into **SFR of 4 $M_\odot$ yr^{-1}**

INTEGRAL spectra (Diehl et al. 2006)

^{60}Fe: A long way to a faint radioactivity

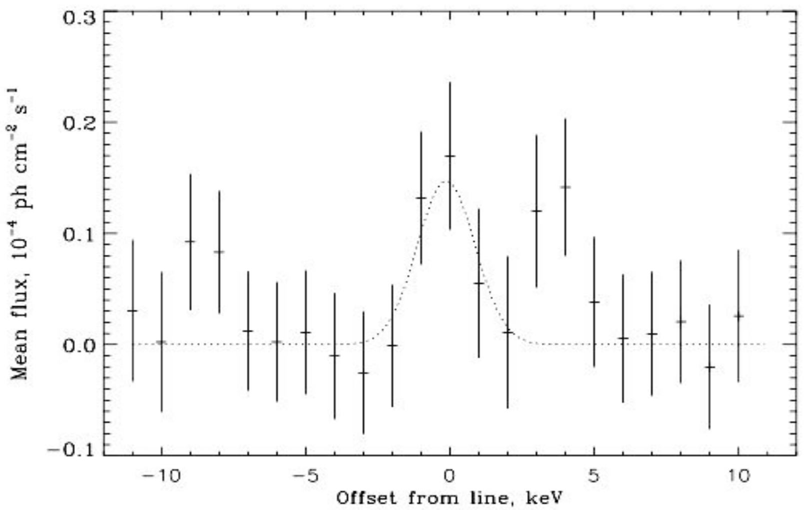


SPI/INTEGRAL and RHESSI measurements

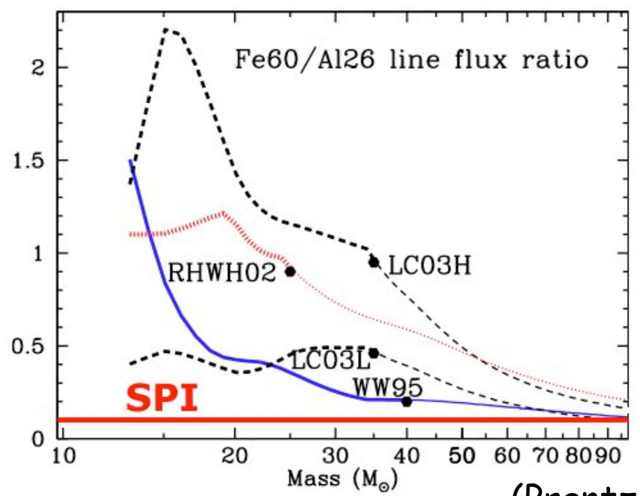
- ^{60}Fe / ^{26}Al flux ratio ~ 10%
- ^{60}Fe / ^{26}Al abundance ratio ~ 0.23

Interpretation

- ^{60}Fe only produced in core-collapse evens
- ^{26}Al produced in core-collapse and WR winds
- Expected core-collapse ^{60}Fe / ^{26}Al ratio too large
- **WR winds contribute significantly to galactic ^{26}Al nucleosynthesis**

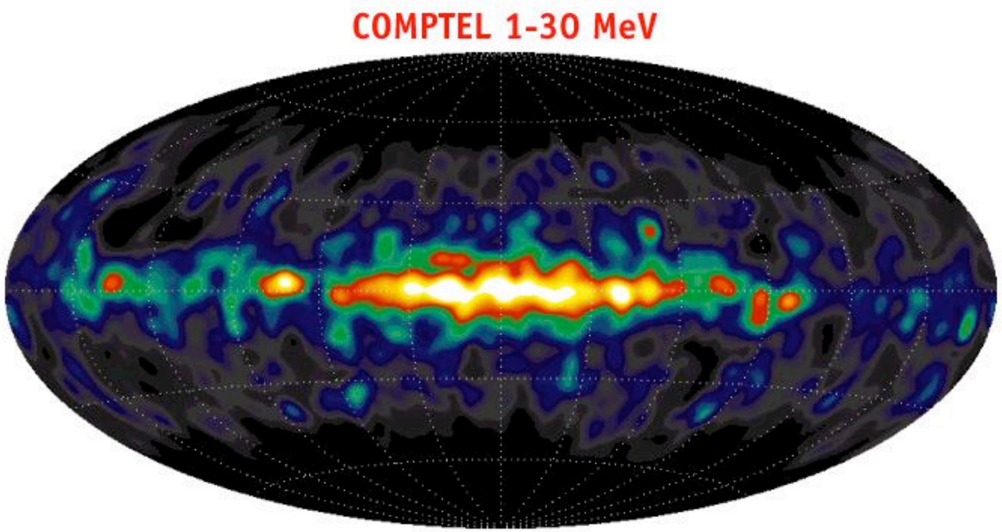


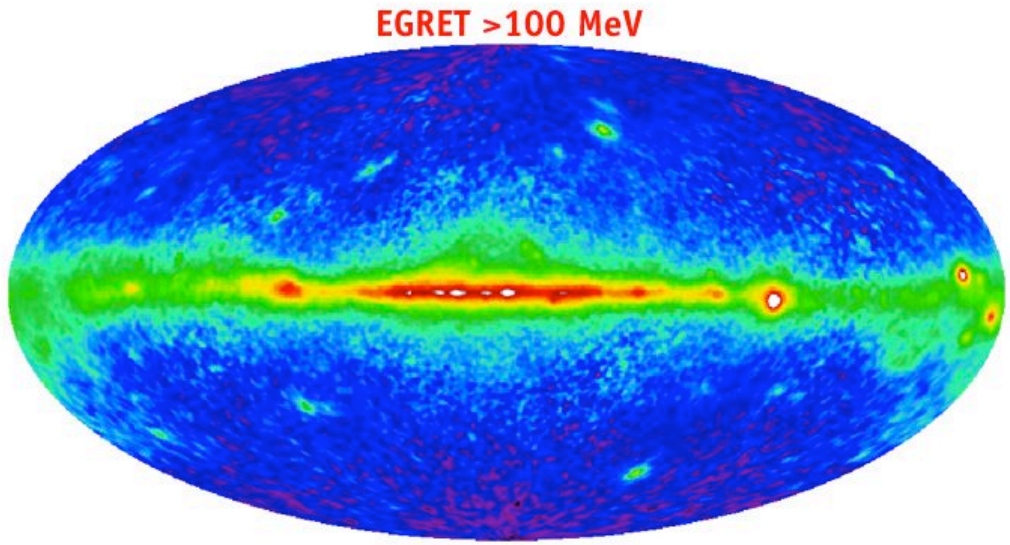
SPI spectrum (Harris et al. 2005)



(Prantzos 2004)

Diffuse MeV and GeV Gamma-Ray emission



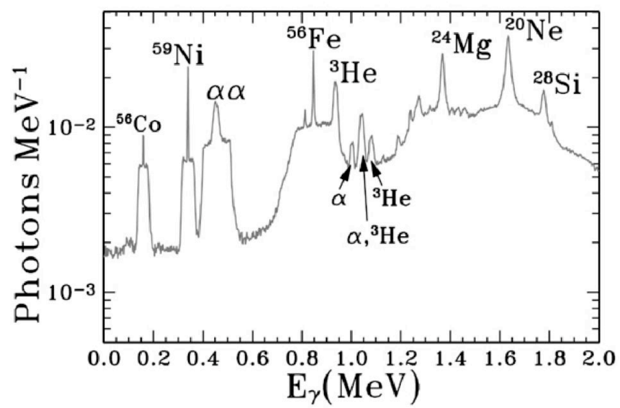


Point sources

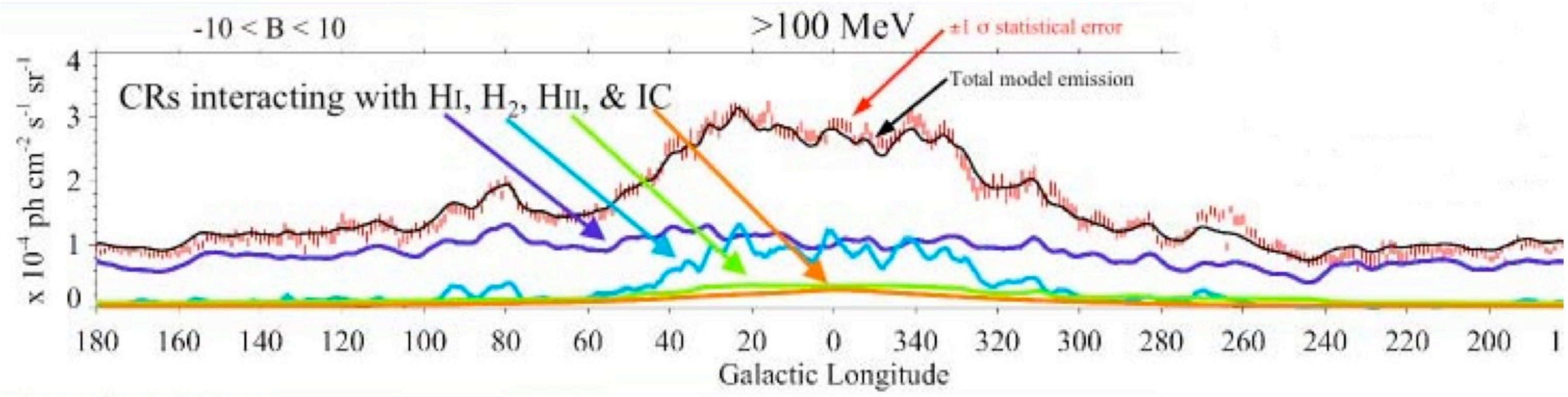
- Pulsars
- Supernova remnants
- AGN (extragalactic)
- unidentified sources

Diffuse emission processes

- inverse Compton
- Bremsstrahlung
- nuclear interactions lines
- π^0 decay (> 300 MeV)



Spatial correlation between gaz and γ-rays



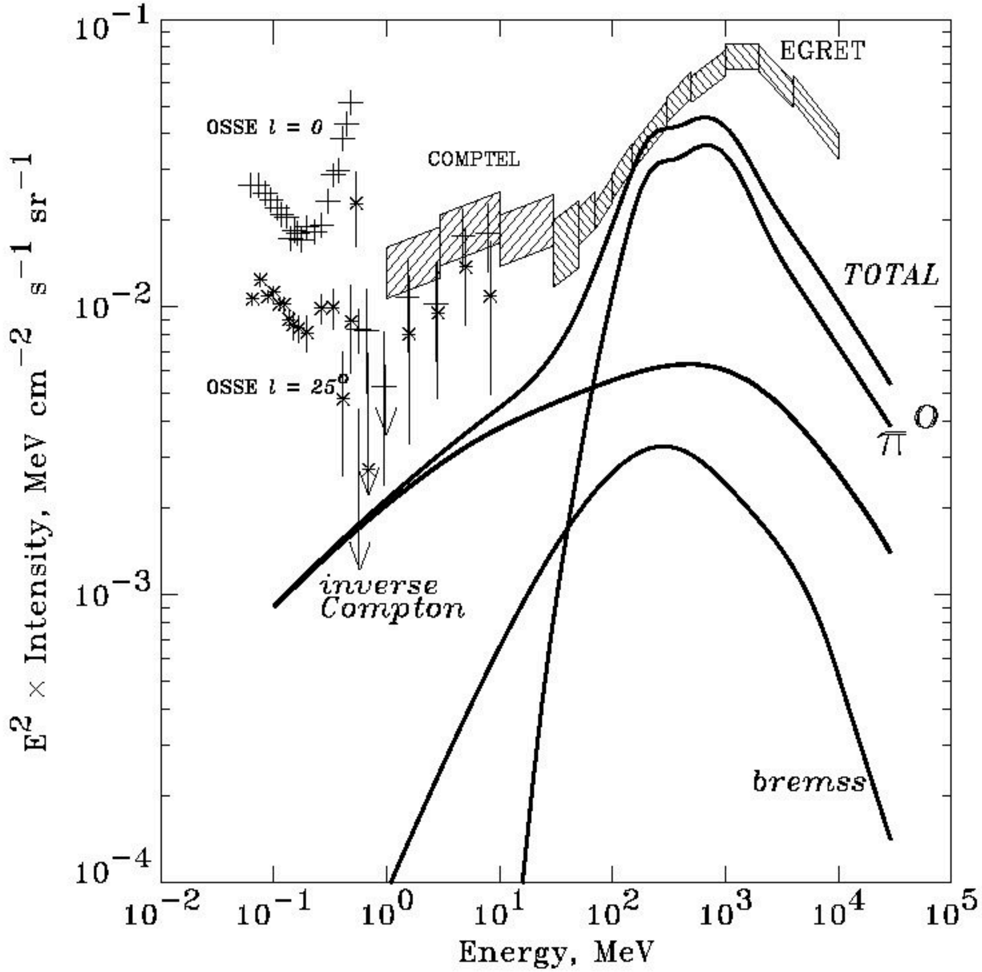
Observations (EGRET):

- large scale spatial distribution well modelled by combination of ISM phases (assuming $I \propto \rho^2$)
- fraction of unresolved point sources is small (unless distributed like the interstellar gas)
- spectrum does not vary (within relatively small uncertainties) in the Galaxy
- deviations from perfect fit

Implications:

- Gamma-Rays probe galactic CR and ISM distributions
- CR electron-to-proton ratio roughly constant throughout Galaxy
- assumption of dynamic balance ($I \propto \rho^2$) between ISM and CR is reasonably correct
  (large matter density implies larger magnetic fields, allowing for larger CR energy density)

Spectral modelling: The conventional model



C model (Strong et al. 2000)

Model

- based on non γ-ray data only
- **fits only between 30 - 500 MeV**

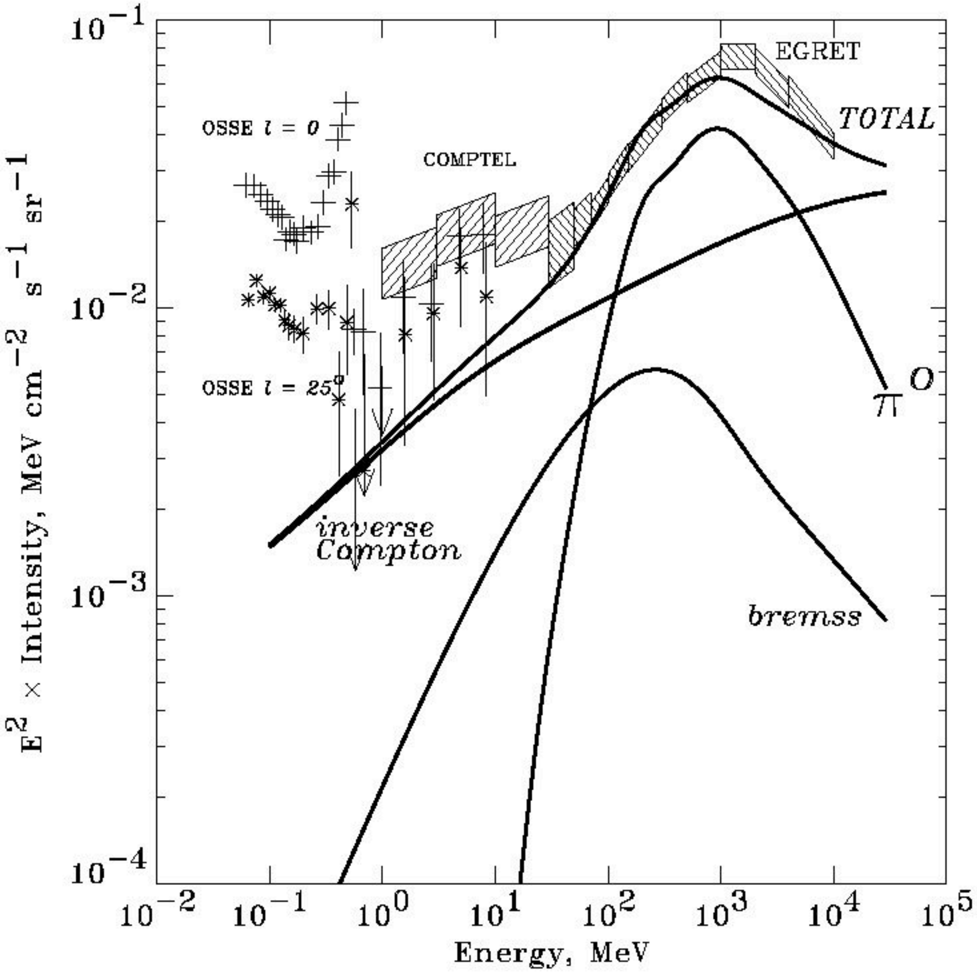
Electron spectrum

- E $^{-1.6}$: E < 10 GeV
- E $^{-2.6}$: E > 10 GeV
- agrees with locally measured spectrum
- satisfies synchrontron spectrum

Proton spectrum

- E $^{-2.25}$
- agrees with locally measured spectrum

Spectral modelling: Hard CR spectrum model



HEMN model (Strong et al. 2000)

Model

- allow for harder e^- and p specturm
- **does not fit <30 MeV (& GeV bump)**

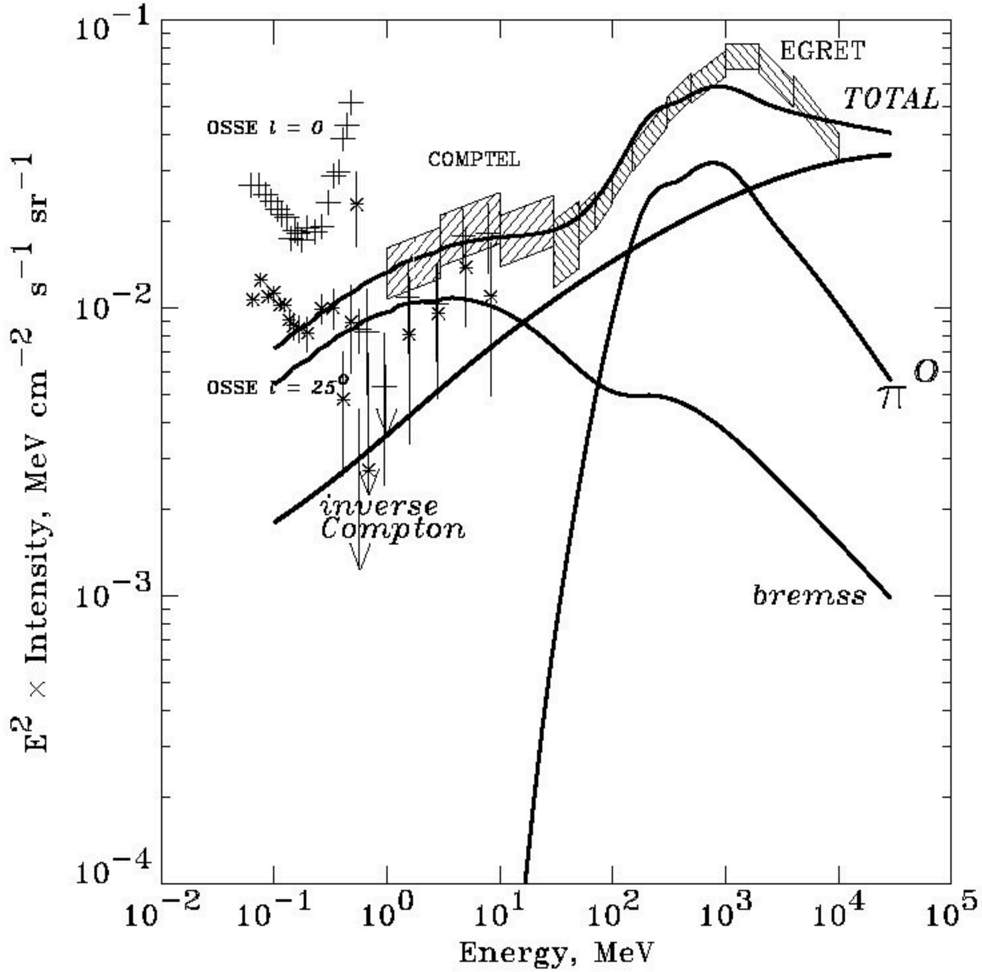
Electron spectrum

- $E^{-1.8}$ (harder w/r C-model above 10 GeV)
- differs from locally measured spectrum (high-energy e^- undergo rapid E-loss)
- satisfies synchrontron spectrum (> 10 GeV spectrum unconstrained)

Proton spectrum

- $E^{-1.8}$: E < 20 GeV (harder w/r C-model)
- $E^{-2.5}$: E > 20 GeV
- agrees with locally measured spectrum (solar modulation allows for some freedom at low energies)

Spectral modelling: Steep low-energy e⁻ model



SE model (Strong et al. 2000)

Model

- allows for more low-energy e^-
- **ad hoc (no observational evidence)**
- **large power input into ISM (ionisation)**

Electron spectrum

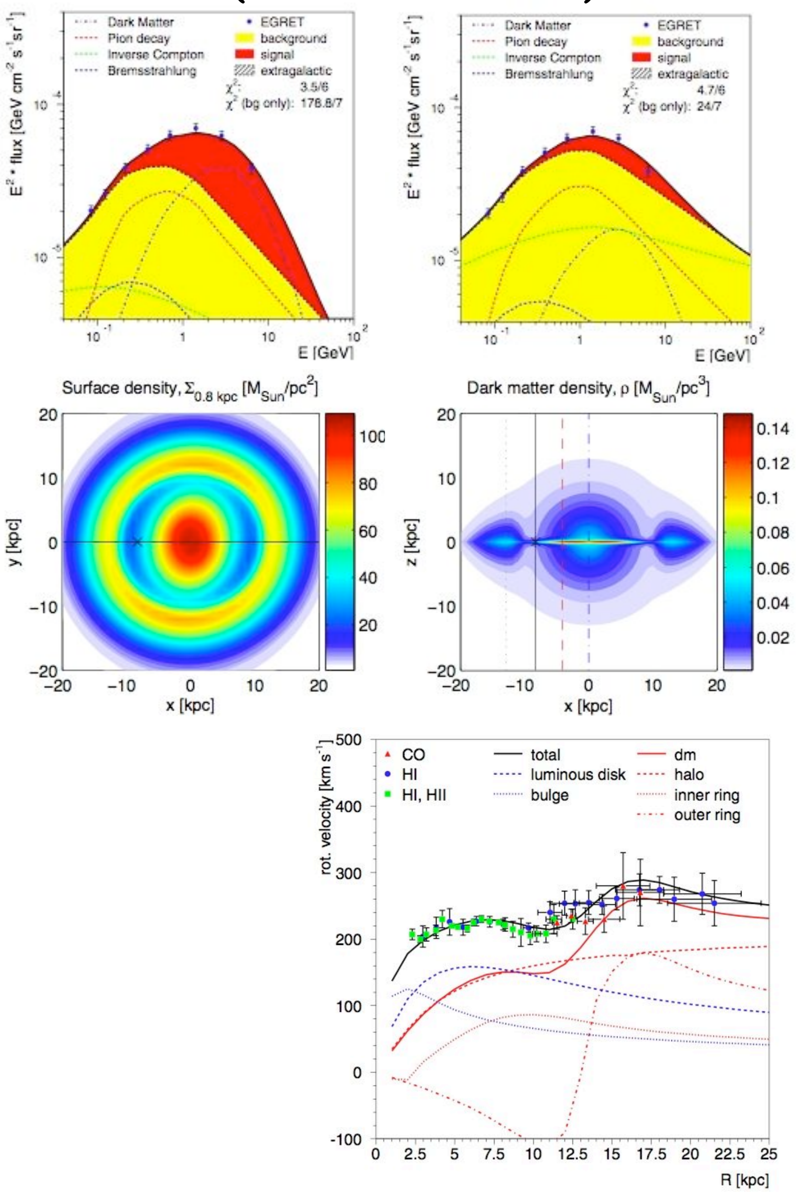
- $E^{-3.2}$: E < 200 MeV (steeped w/r C-model)
- $E^{-1.8}$: E > 200 MeV (like HEMN model)
- differs from locally measured spectrum (high-energy e^- undergo rapid E-loss)
- satisfies synchrontron spectrum (< 1 GeV spectrum unconstrained)

Proton spectrum

- $E^{-2.25}$ (C-model)
- agrees with locally measured spectrum

A dark-matter scenario

(de Boer et al. 2005)



Possible explanations of GeV excess

- different CR spectrum than local
- unresolved point-sources
- EGRET calibration error
- Dark Matter

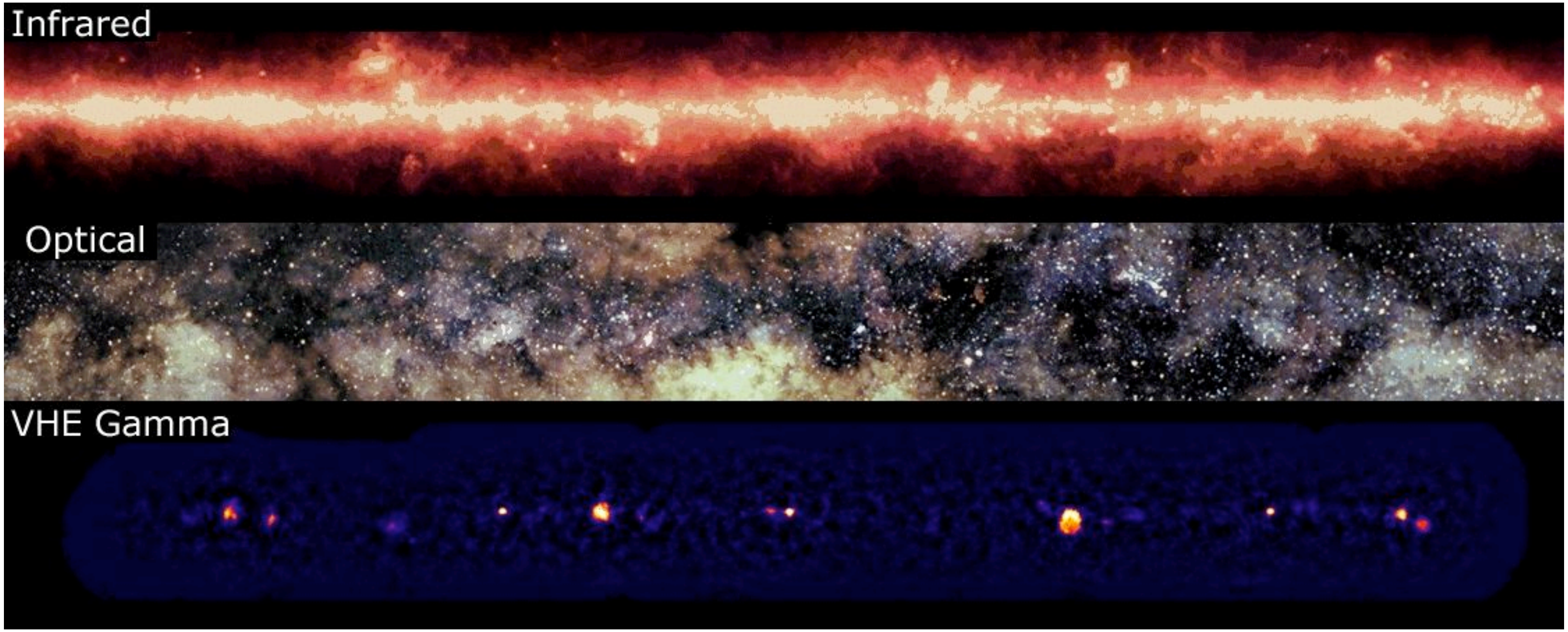
Dark Matter Model

- WIMP annihilation: $\chi + \chi \rightarrow q + \bar{q} \rightarrow \pi^0 \rightarrow \gamma$
- WIMP mass 50 - 100 GeV best fits the EGRET data
- Derive WIMP distribution from γ-ray distribution
- DM in halo and 2 elliptical rings (R = 4 & 14 kpc)
- DM distribution can explain rotation curve

But … (Bergström et al. 2006)

- WIMP annihilation should also produce antiprotons
- Observed antiproton flux much too low w/r model
- Strange DM distribution (ressemblence to baryon distribution with bulge, thin and thick disk)

The first VHE survey of the Galaxy



H.E.S.S. image (Aharonian et al. 2005)

H.E.S.S. survey

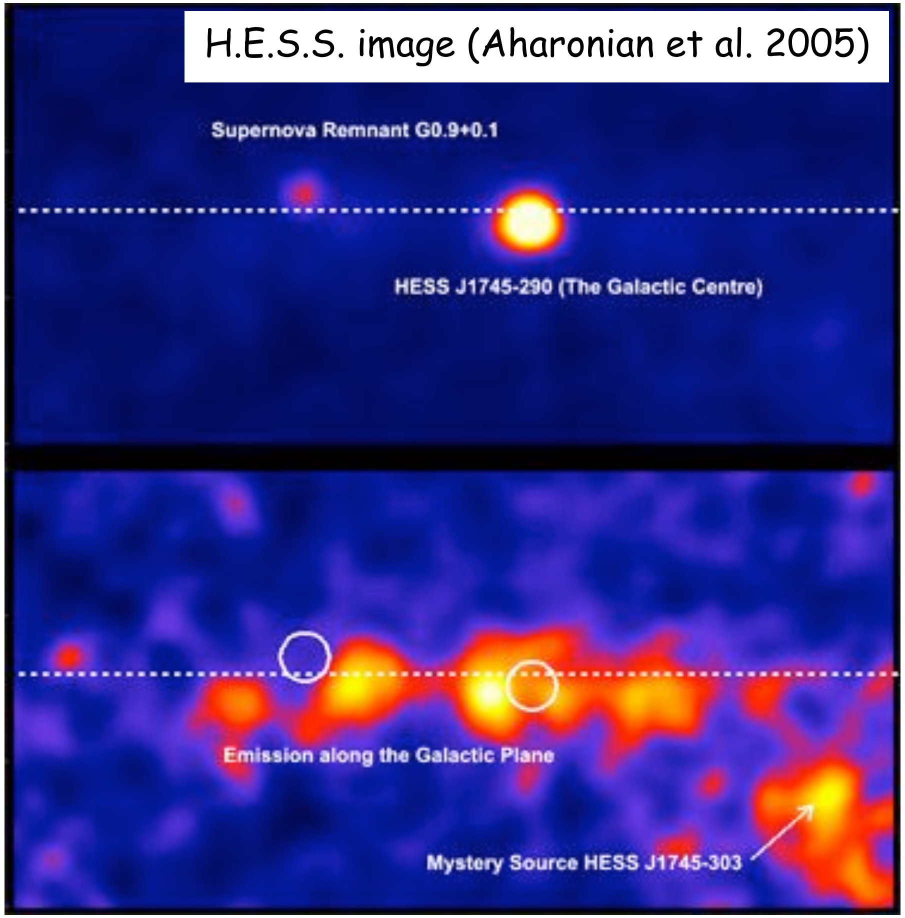
• longitudes ±35°, latitiudes ±4°

• 10 sources from which 8 are new (all spatially resolved ⇒ extended emission)

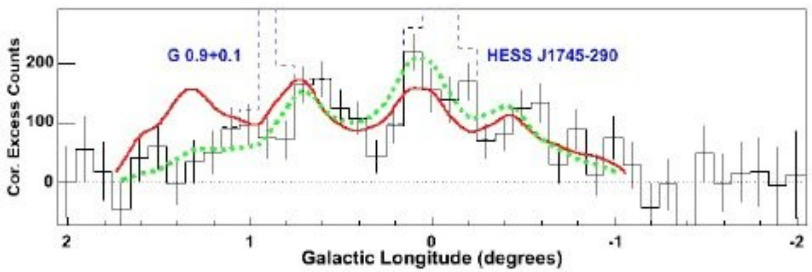
• clustering of sources along the galactic plane (young population)

• some plausible associations with SNRs and pulsars

VHE diffuse emission



H.E.S.S. image (Aharonian et al. 2005)

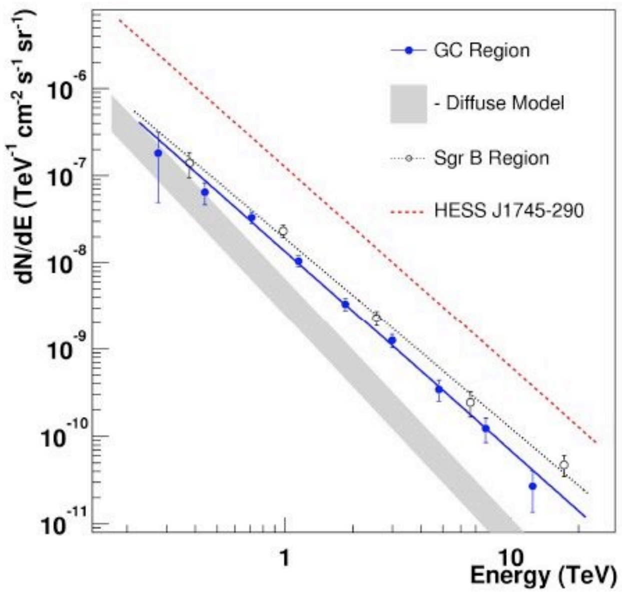


H.E.S.S. discovery of diffuse emission

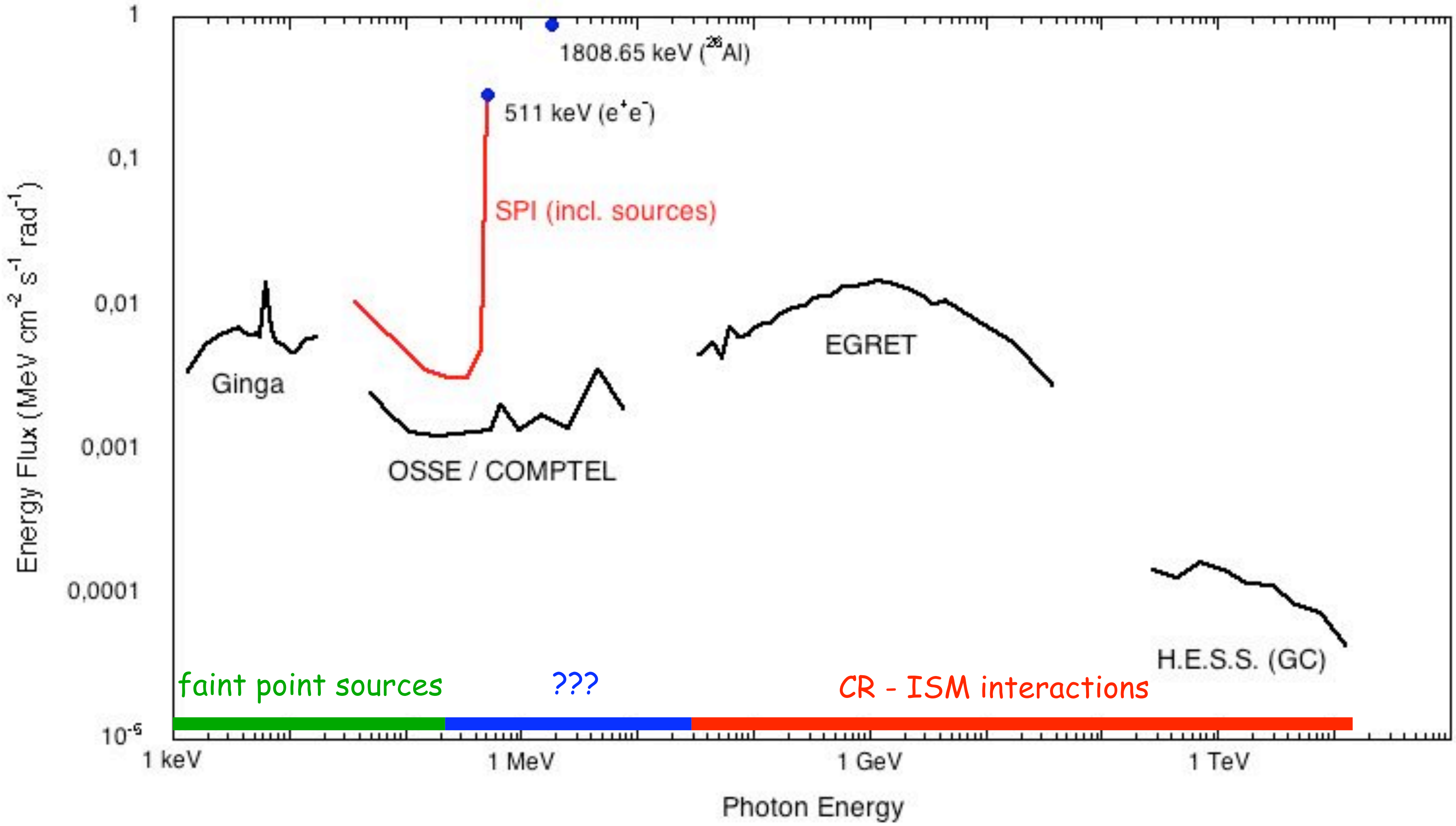
- Subtract point-like emission from sources
- Extended emission (in l and b) along gal. Plane
- Correlates with molecular gas (CS)
- Power law spectrum: Γ = 2.3 ± 0.3

Interpretation

- π^0 decay following CR interaction with ISM
- Flux higher and harder than expected $\Rightarrow$ recent (~10,000 yr) CR acceleration at GC and diffusion



The nature of galactic X-/γ-ray emission



Summary

Hard X-ray emission - GRXE ($E < 200$ keV)

- observationally, a diffuse (unresolved) component remains
- theoretically, diffuse emission is difficult to understand (pressure, gravitational binding)
- spatial distribution and spectrum consistent with **population of weak X-ray point sources**

Soft γ-ray regime ($200 \text{ keV} < E < 511$ keV)

- **diffuse positronium annihilation** dominates (bulge region)
- still no e^+ point sources detected (but diffusion make annihilation probably inherently diffuse process)

MeV domain ($1 \text{ MeV} < E < 30$ MeV)

- ^{26}Al and ^{60}Fe radioactive decays lead to **diffuse line emission**
- **source of continuum emission unclear** (unresolved MeV point sources?)

GeV domain ($30 \text{ MeV} < E < 30$ GeV)

- **diffuse emission** explained by CR interaction with ISM
- spectrum leaves room for additional components (Dark Matter?, point sources?)

TeV domain ($E > 30$ GeV)

- individual point sources identified (SNRs, pulsars)
- **diffuse emission** component that correlates with molecular clouds

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  - Harris et al. 2005, A&A, 433, L49
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  - Strong et al. 2000, ApJ, 537, 763
  - deBoer et al. 2005, A&A, 444, 51
- TeV galactic diffuse emission
  - Aharonian et al. 2006, Nature, 439, 695