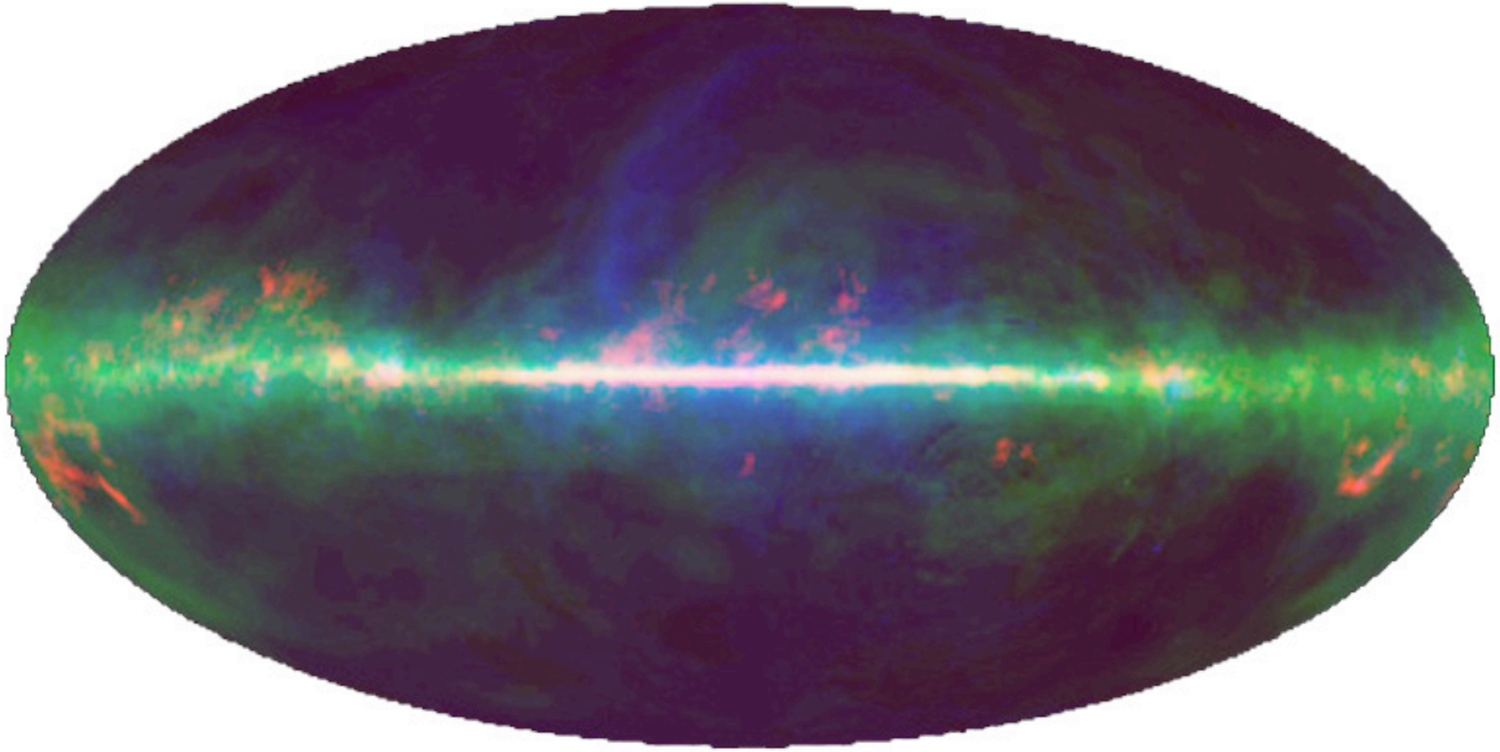
Emissions diffuses galactiques en rayons X et gamma



J. Knödlseder
Centre d'Etude Spatiale des Rayonnements
Toulouse (France)

Outline

I. What is diffuse emission ?

II. Diffuse emission processes

III. The X- and Gamma-Ray Sky

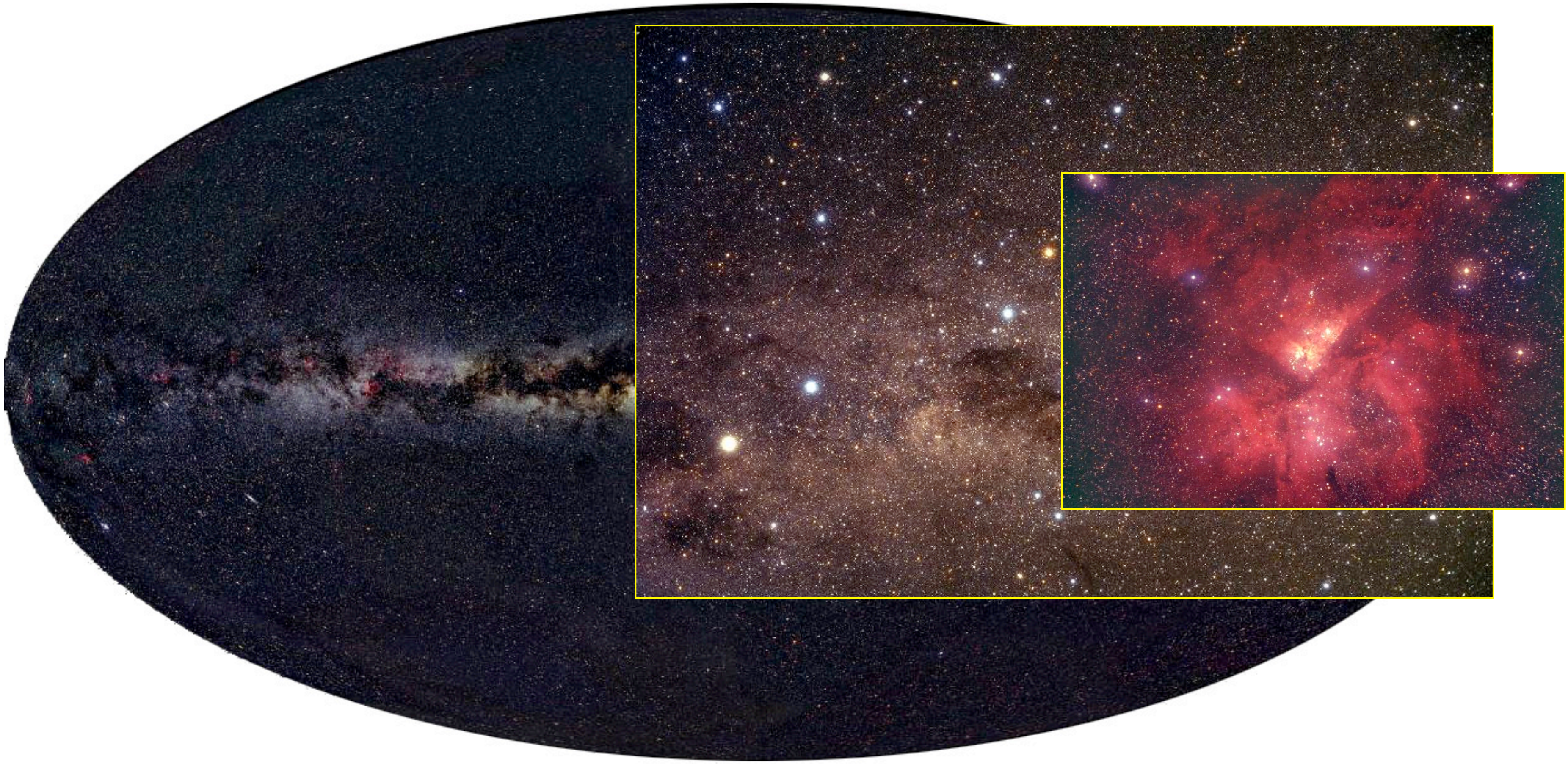
- Sky images
- The galactic emission spectrum

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

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"

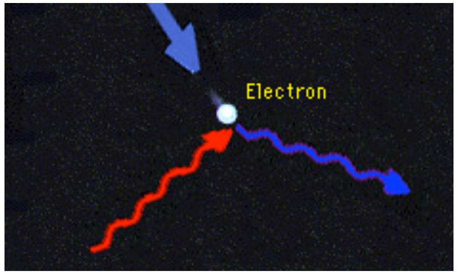
- emission of gaz and dust (thermal, non-thermal)
- emission related to magnetic fields (synchroton)
- emission related to diffuse stellar ejecta (particle diffusion)
- also applicable to extragalactic diffuse (e.g., intergalactic matter in clusters)
- also applicable for cosmic backgrounds (e.g., primordial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

Diffuse emission processes

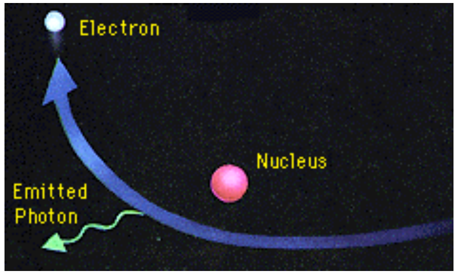
Continuum emission

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

Inverse Compton **electron** scattering



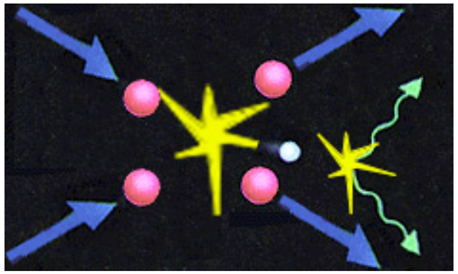
electron Bremsstrahlung



Pion (π^0) production and decay

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

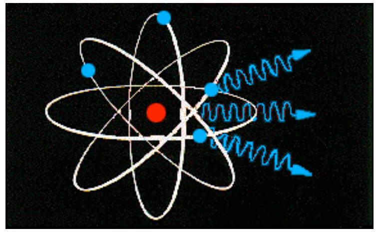
$E_p > 300$ MeV



Line emission

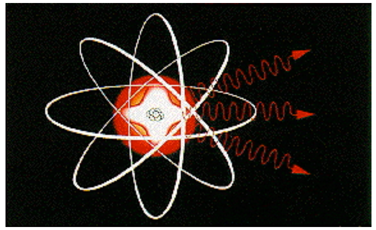
Excitation of **electrons** and **nucleons** in an atom; antimatter **annihilation**:

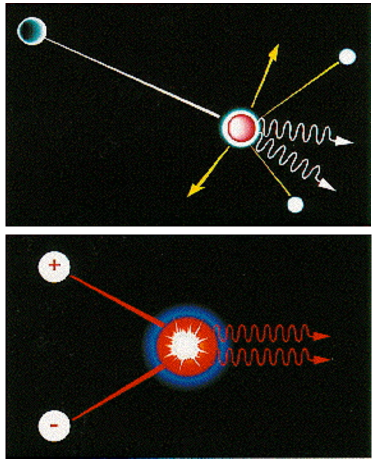
ionic lines (below 10 keV)



nuclear radioactive decay

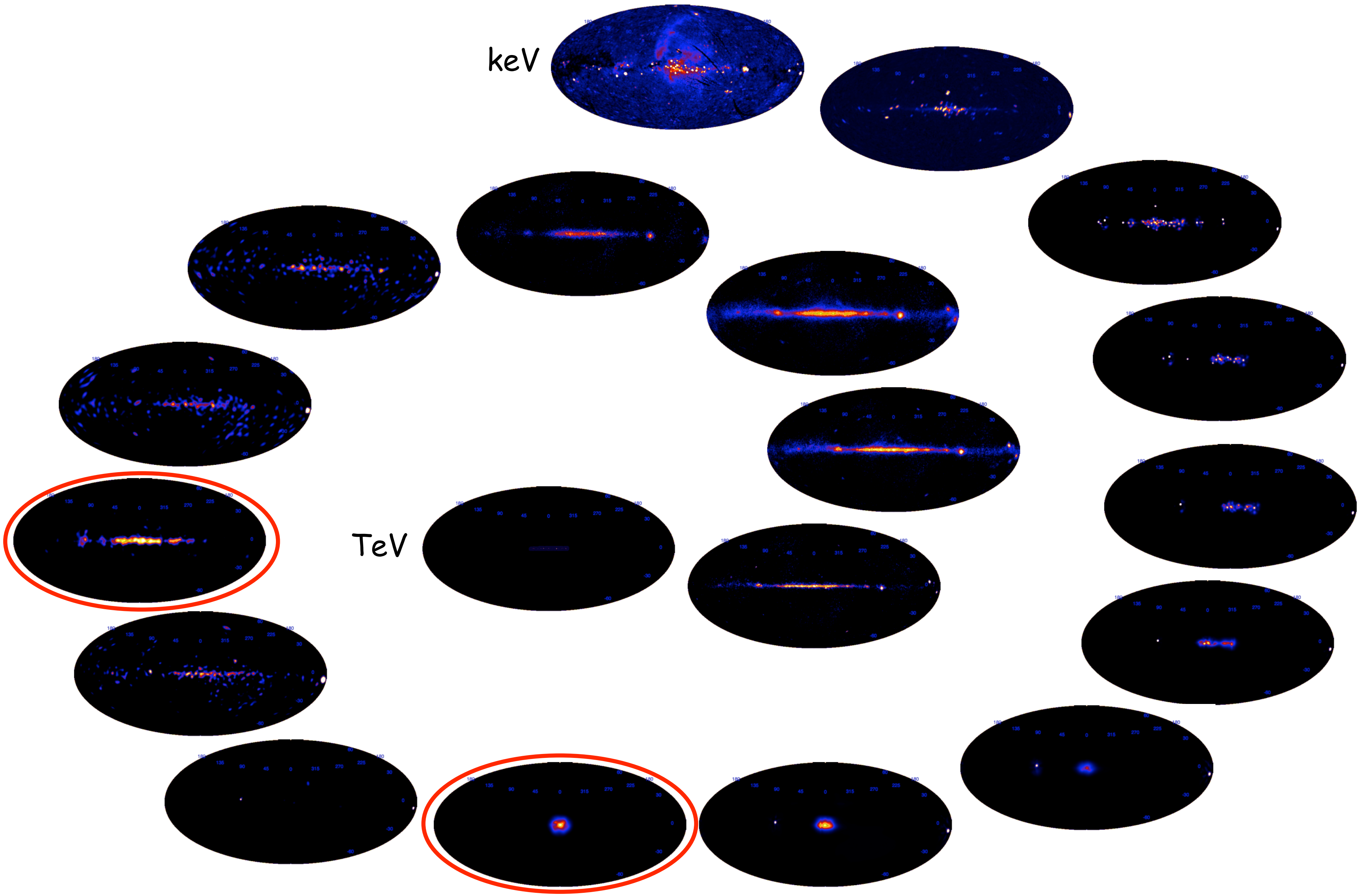
nuclear excitation





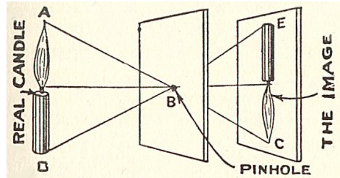
positron-electron **annihilation** (511 keV line)

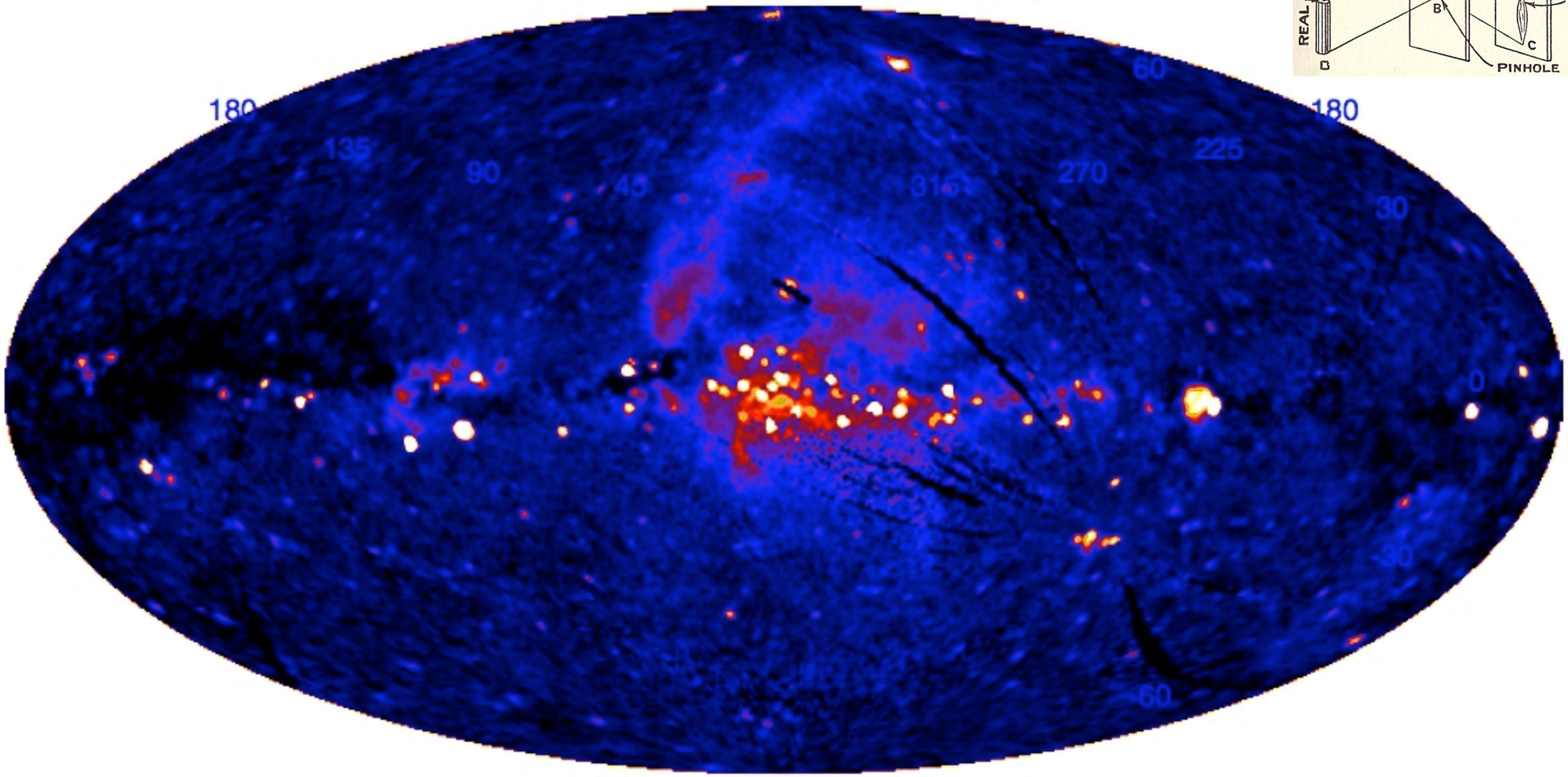
A high-energy gallery of the sky

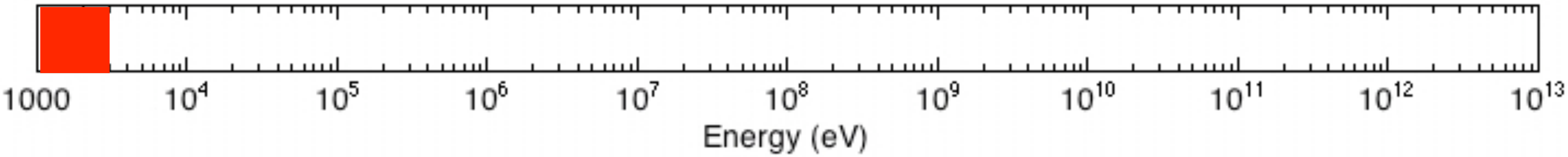


The Soft X-Ray Sky (1 - 3 keV)

ROSAT

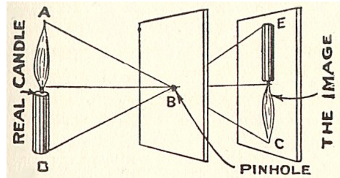


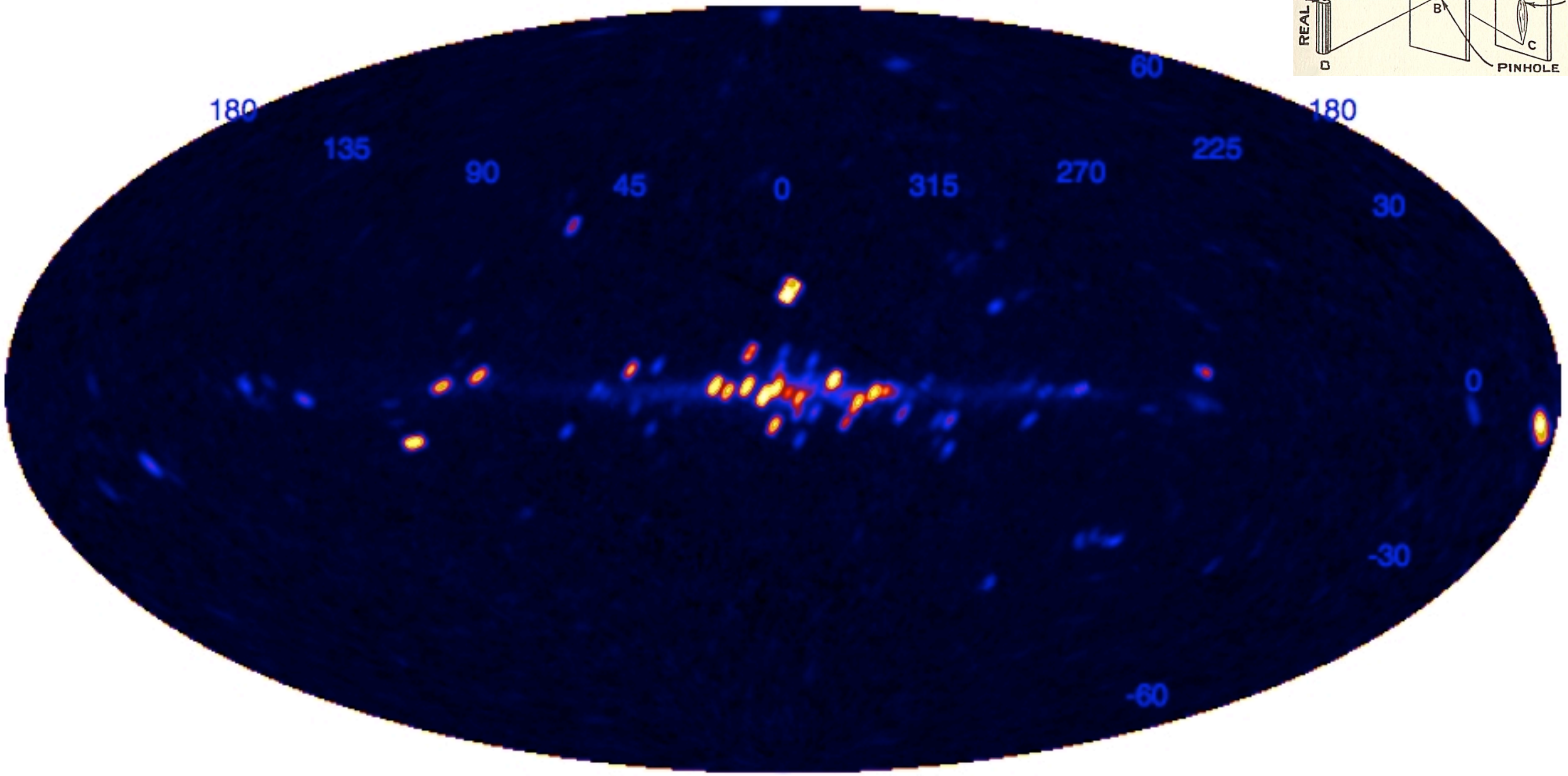


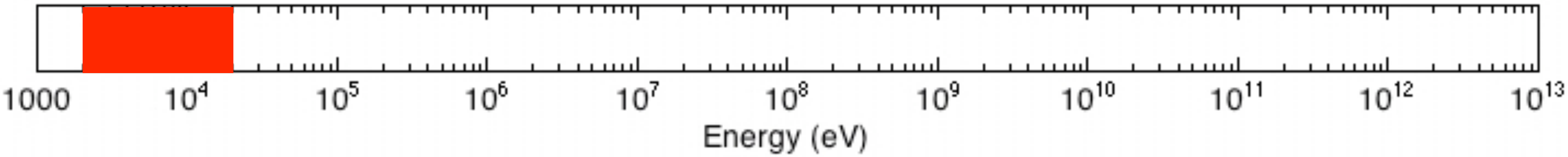


The X-Ray Sky (2 - 20 keV)

HEAO-1

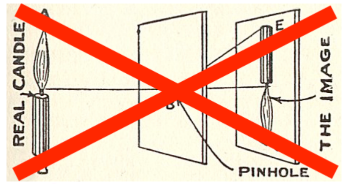


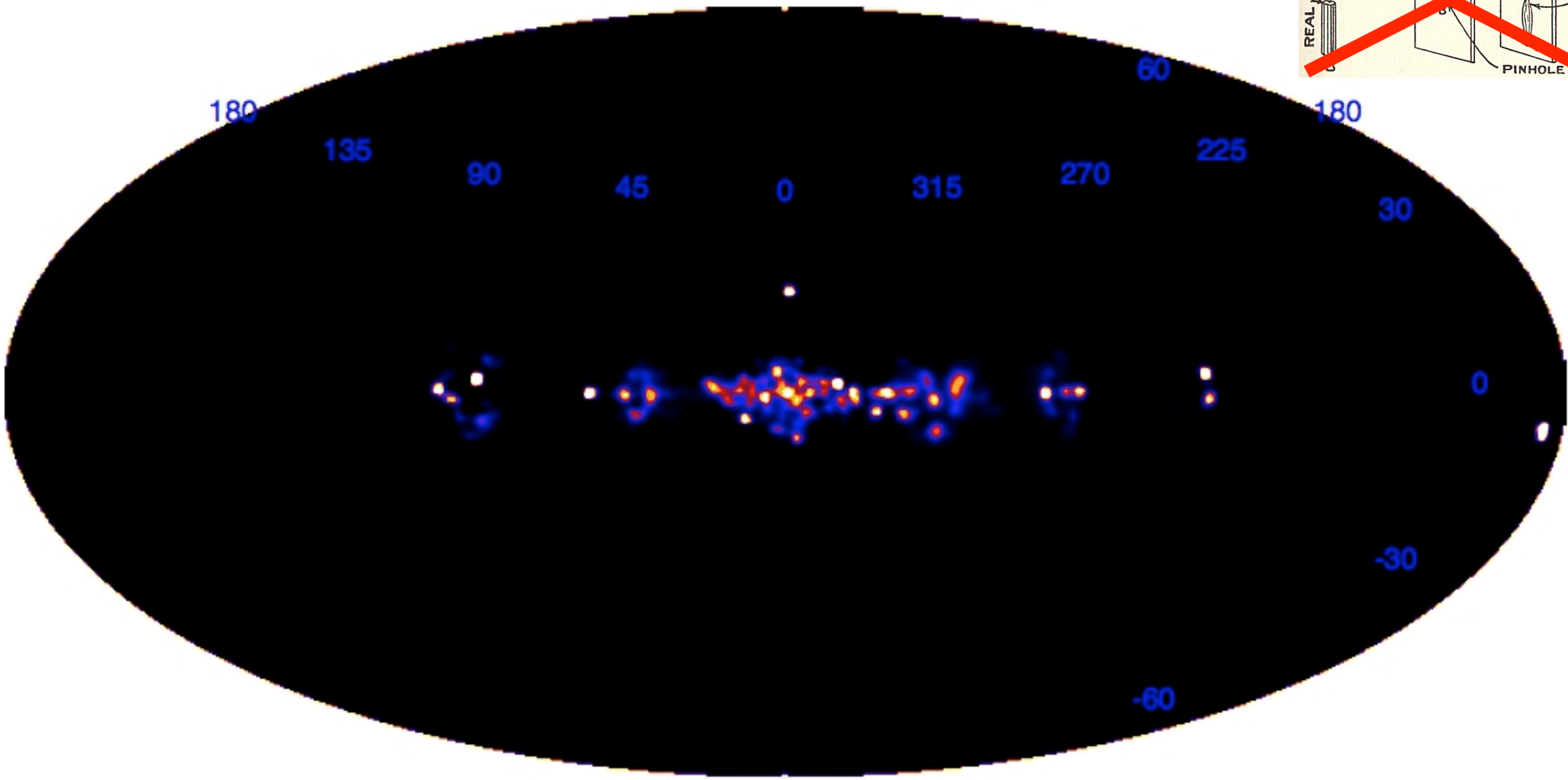


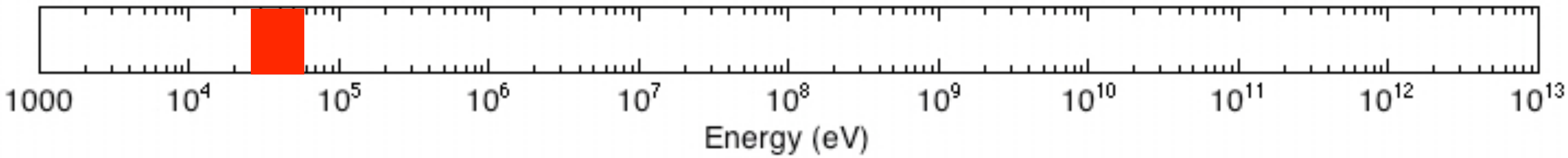


The Hard X-Ray Sky (25 - 50 keV)

SPI / INTEGRAL (2 yr)

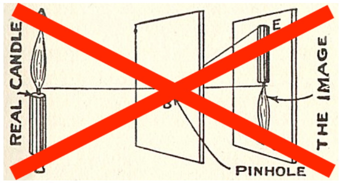


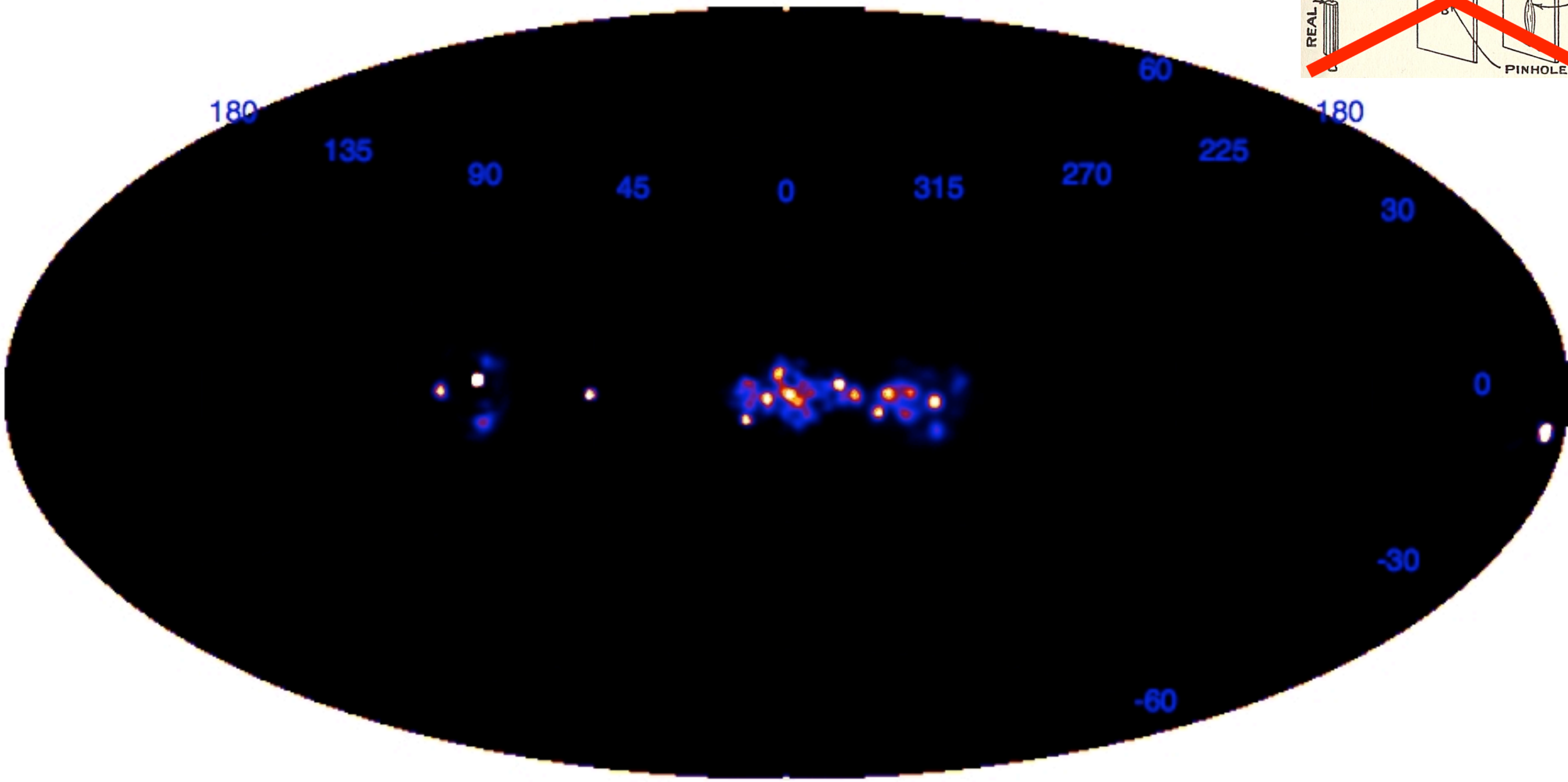


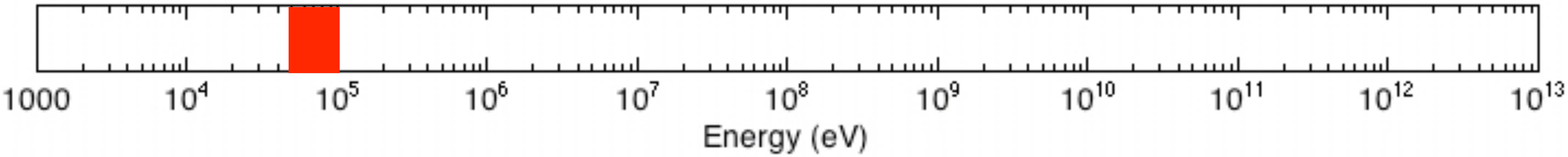


The Hard X-Ray Sky (50 - 100 keV)

SPI / INTEGRAL (2 yr)

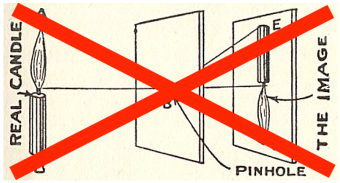


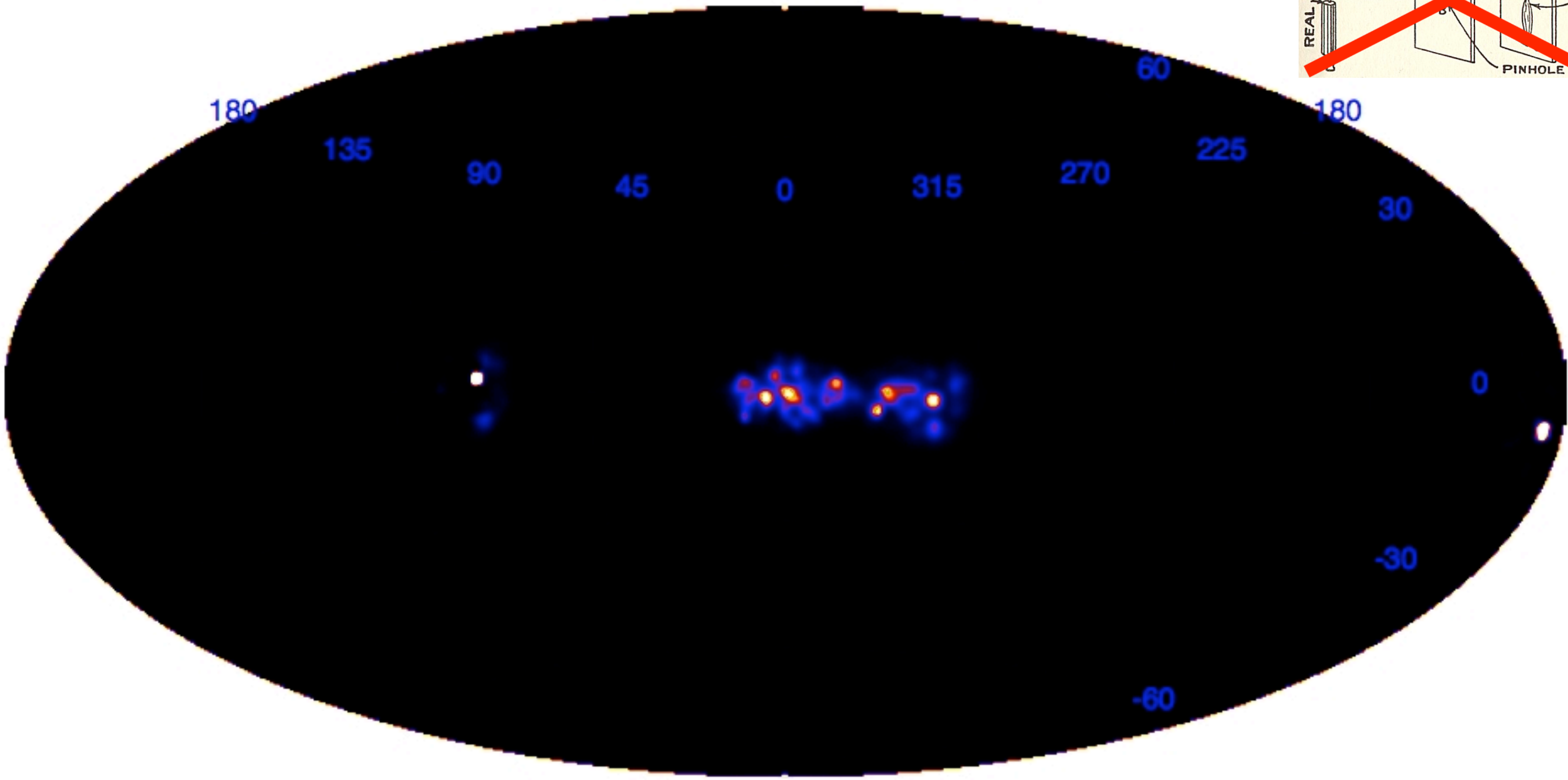


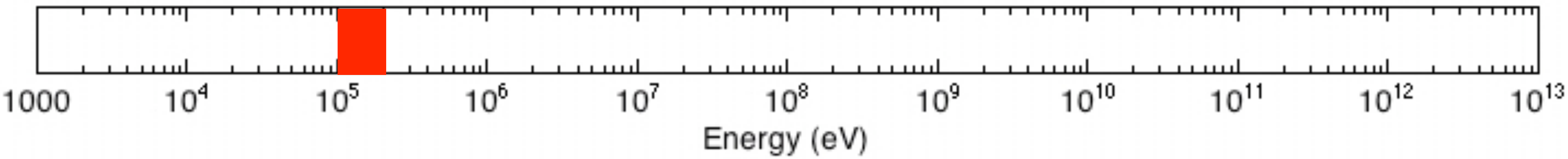


The Hard X-Ray Sky (100 - 200 keV)

SPI / INTEGRAL (2 yr)

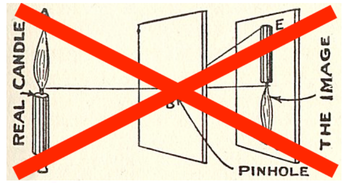


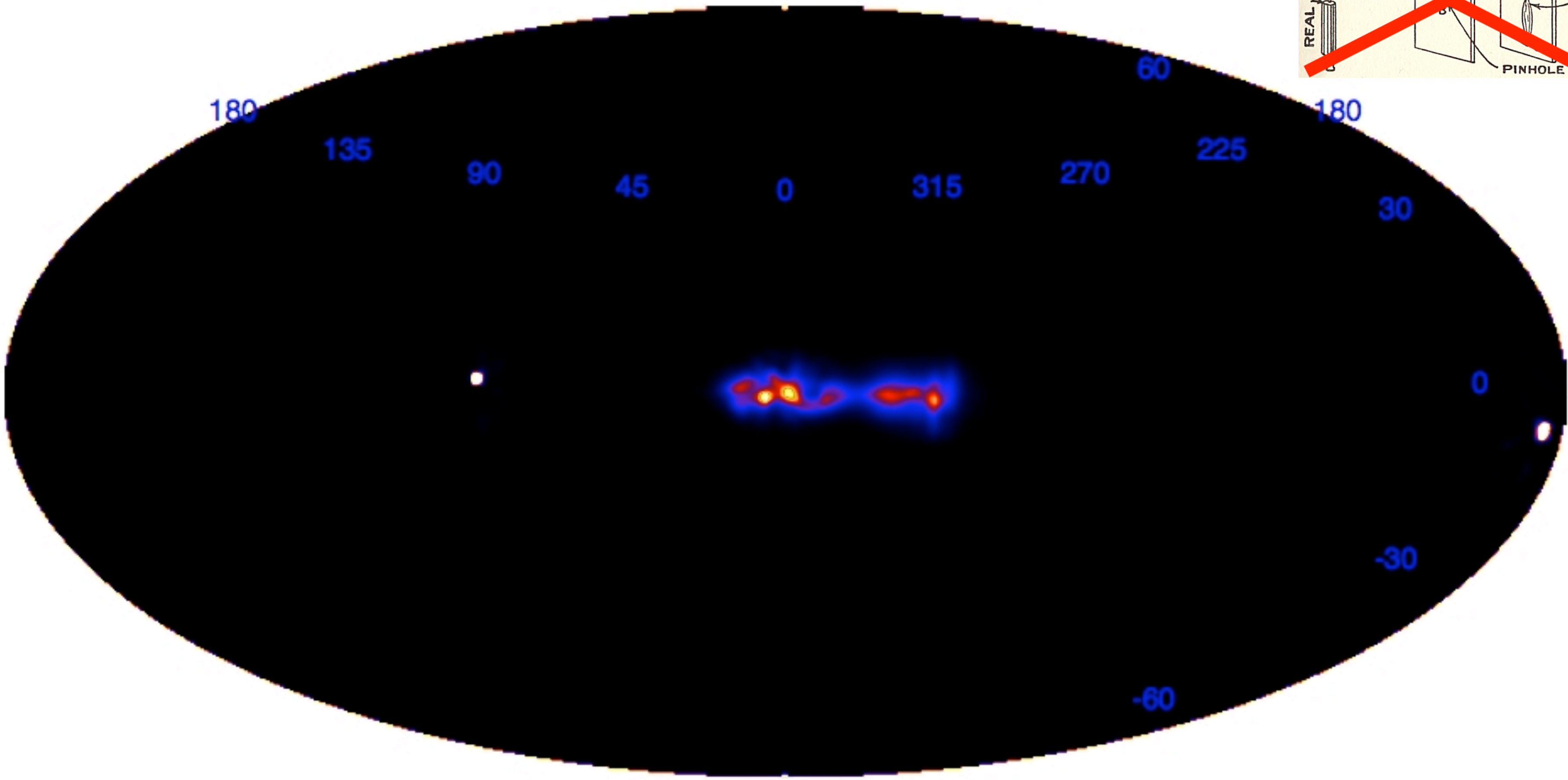


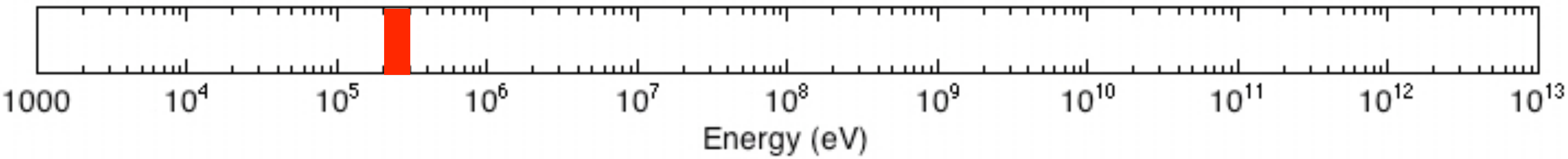


The Hard X-Ray Sky (200 - 300 keV)

SPI / INTEGRAL (2 yr)

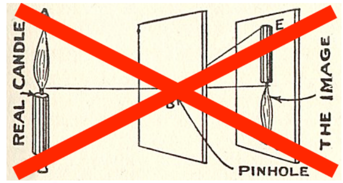


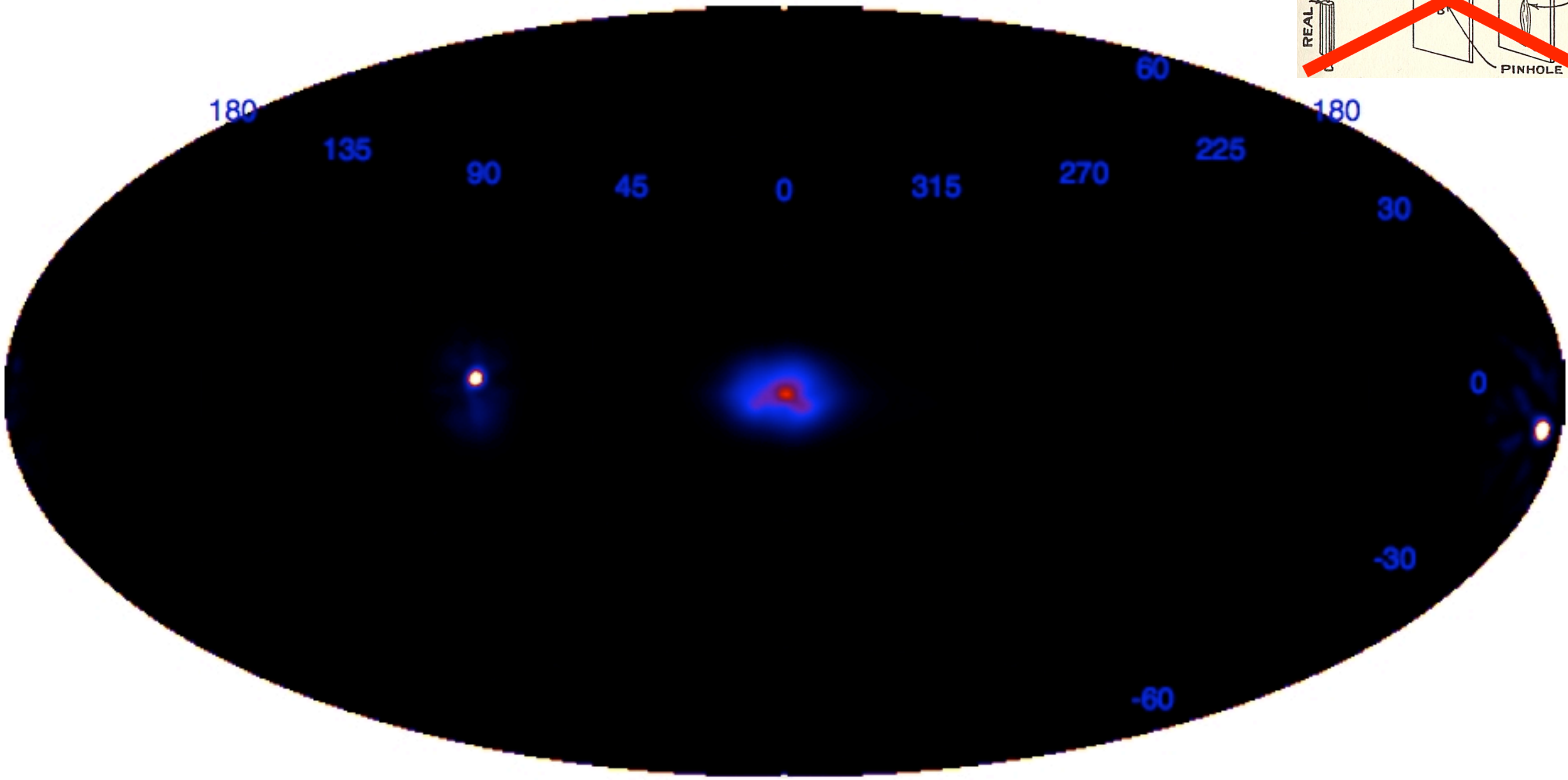


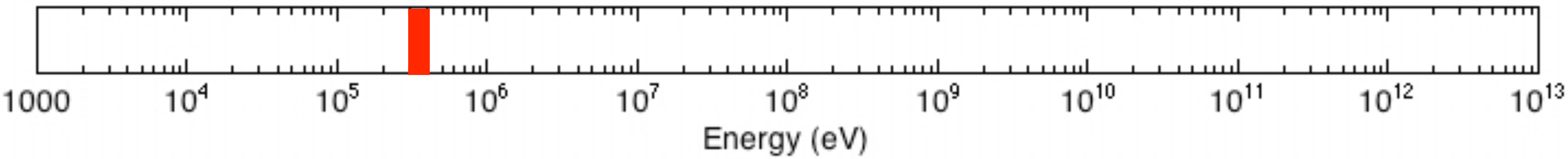


The Gamma-Ray Sky (300 - 400 keV)

SPI / INTEGRAL (2 yr)

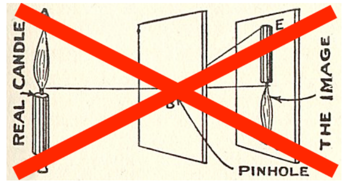


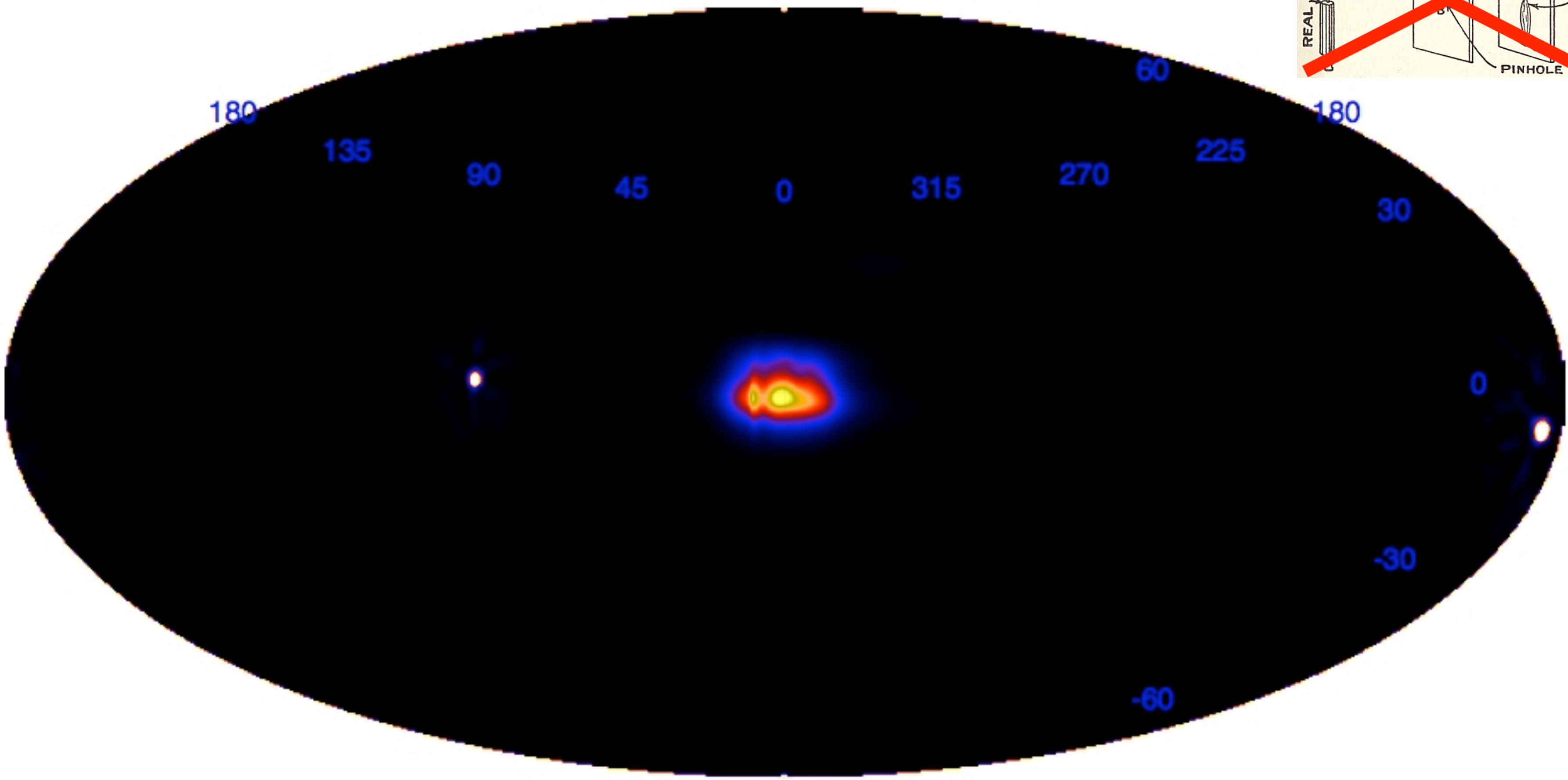


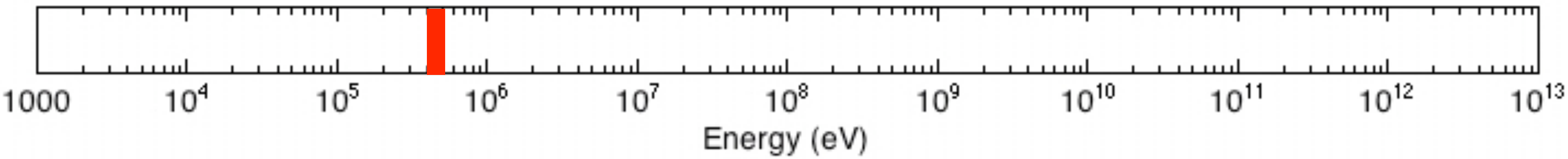


The Gamma-Ray Sky (400 - 500 keV)

SPI / INTEGRAL (2 yr)

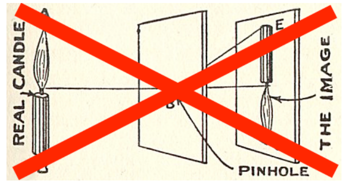


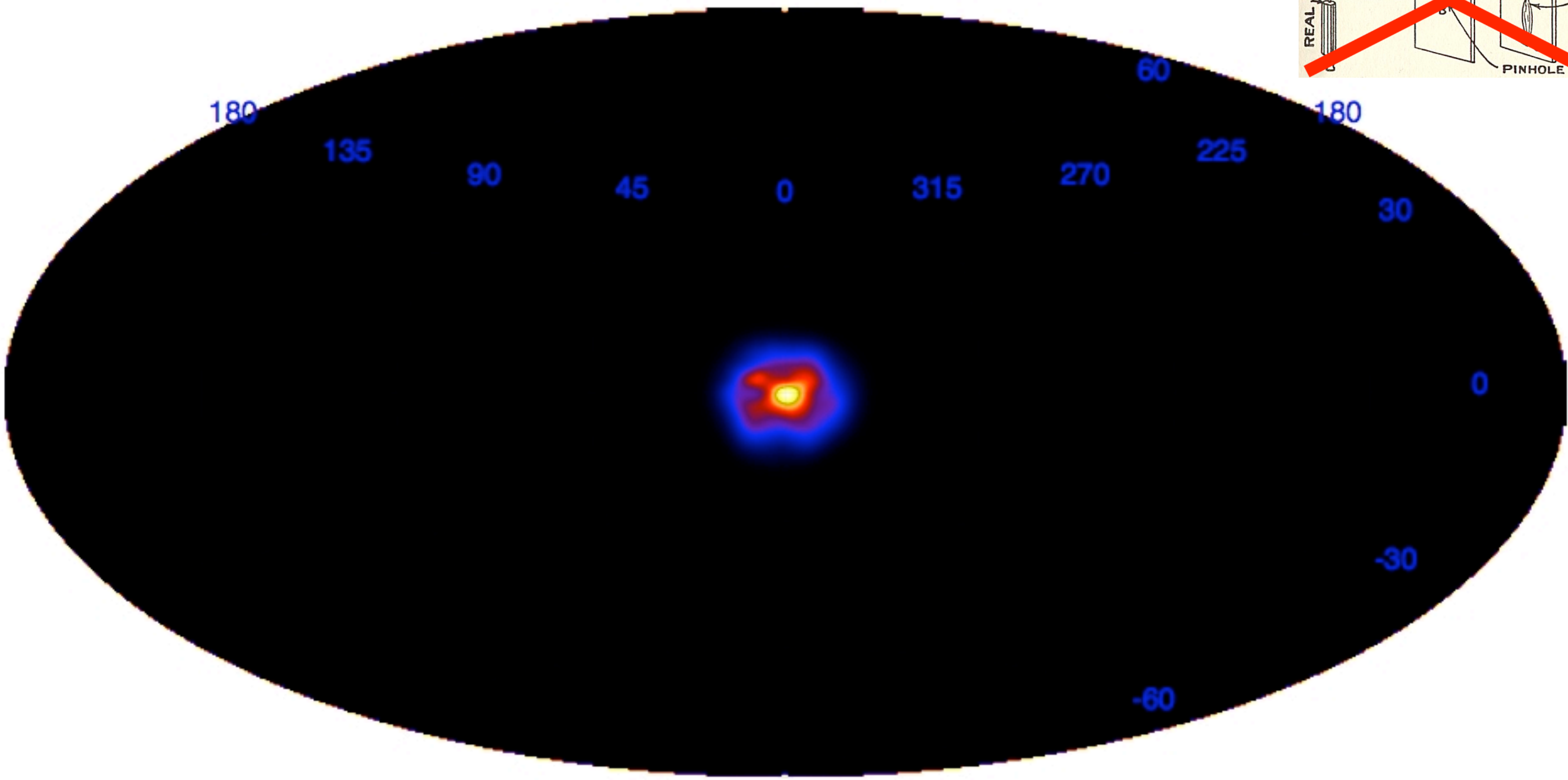


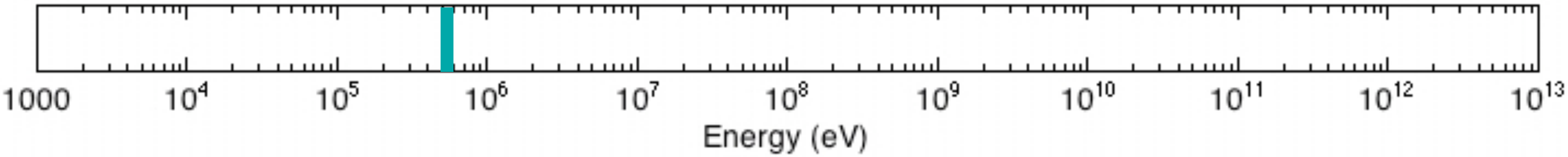


The Gamma-Ray Sky (511 keV line)

SPI / INTEGRAL (2 yr)

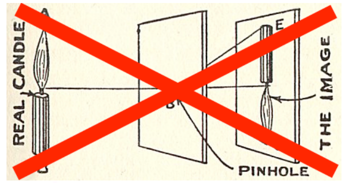


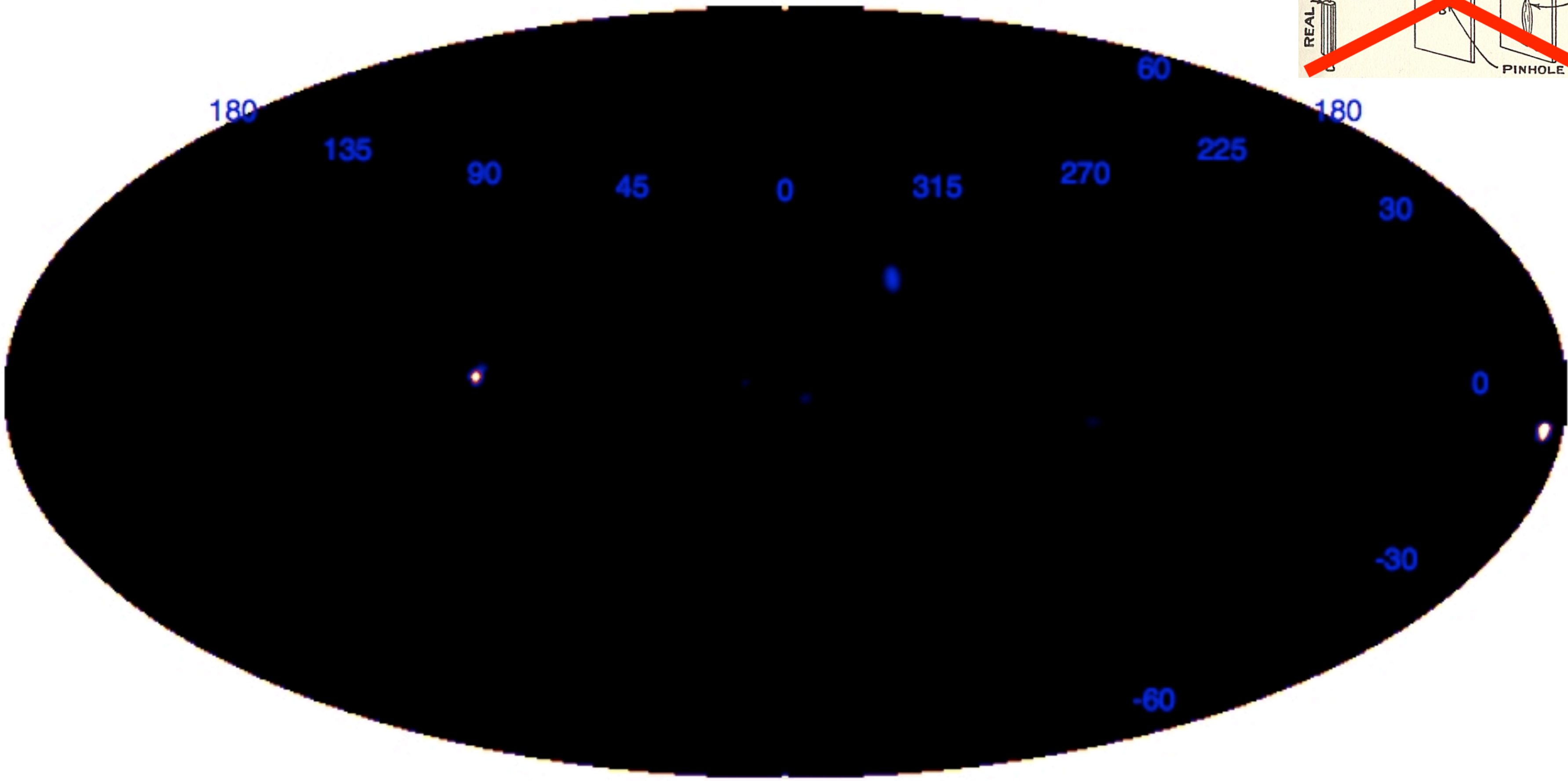


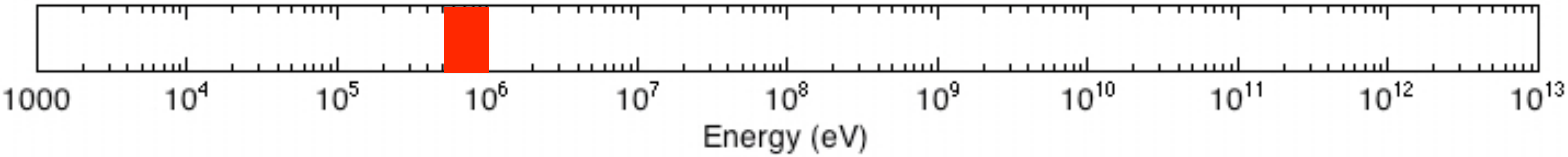


The Gamma-Ray Sky (514 - 1000 keV)

SPI / INTEGRAL (2 yr)

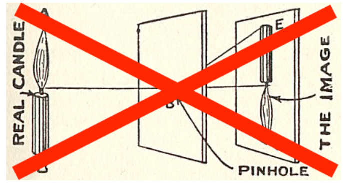


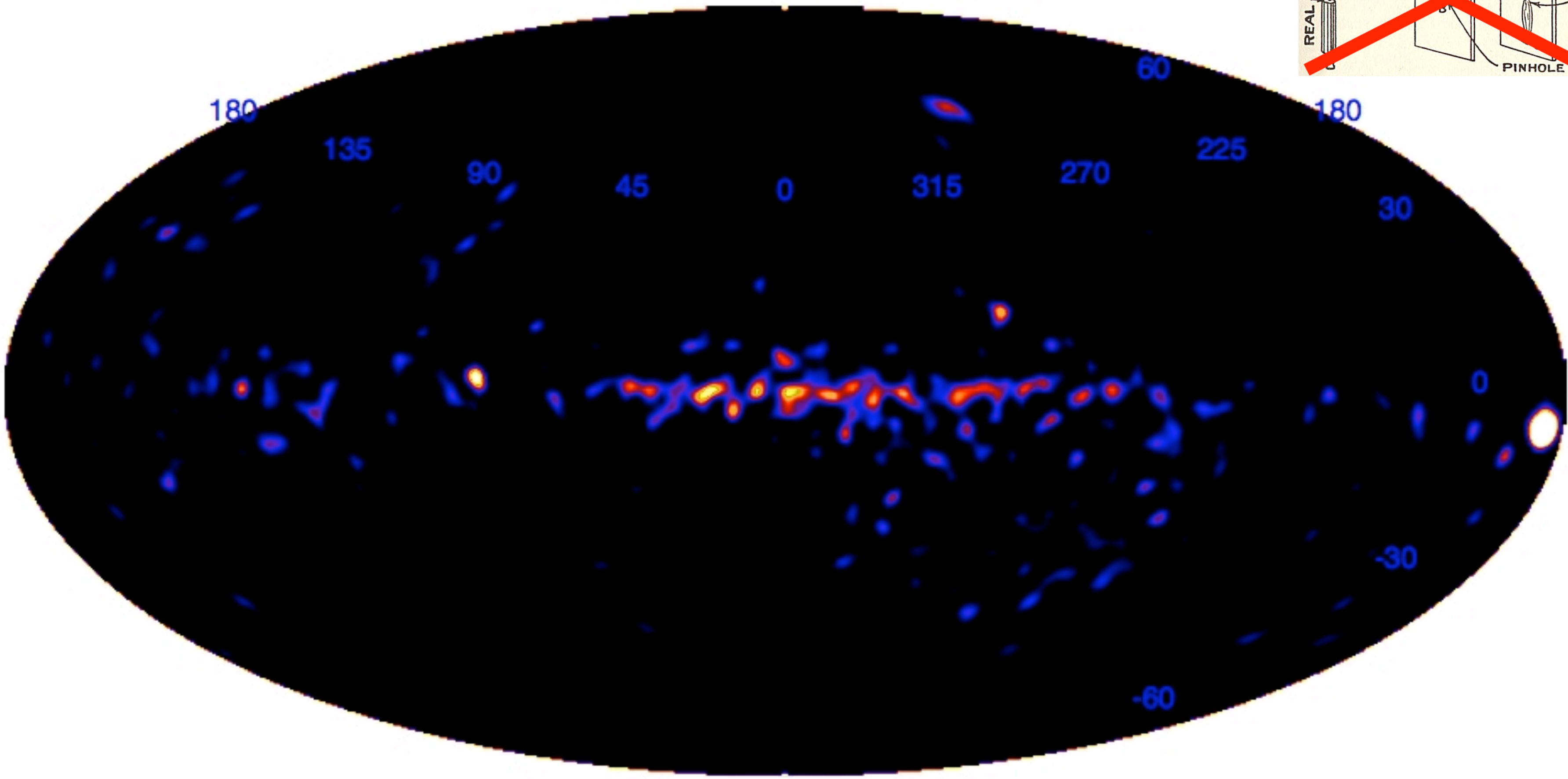


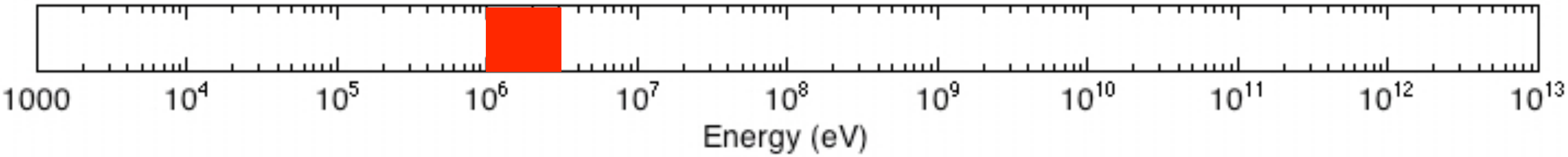


The Gamma-Ray Sky (1 - 3 MeV)

COMPTEL / CGRO (6 yr)

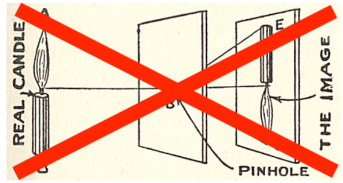


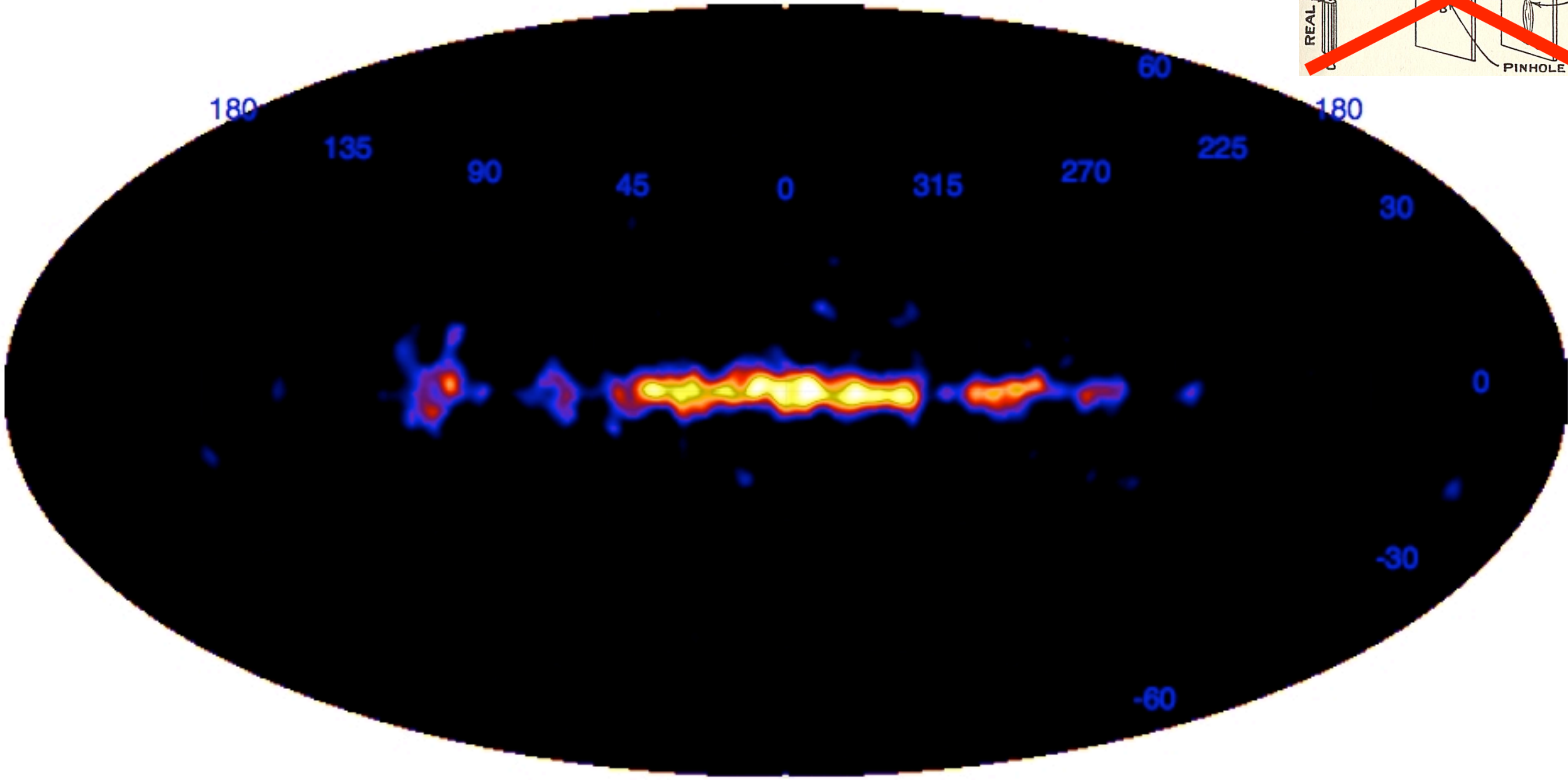


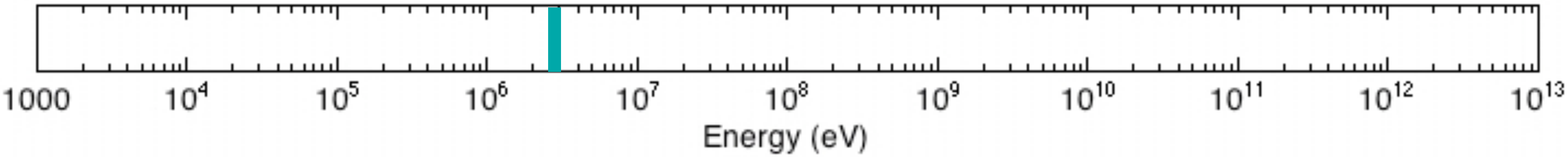


The Gamma-Ray Sky (1.809 MeV line)

COMPTEL / CGRO (9 yr)

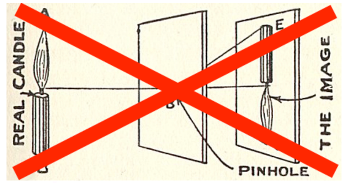


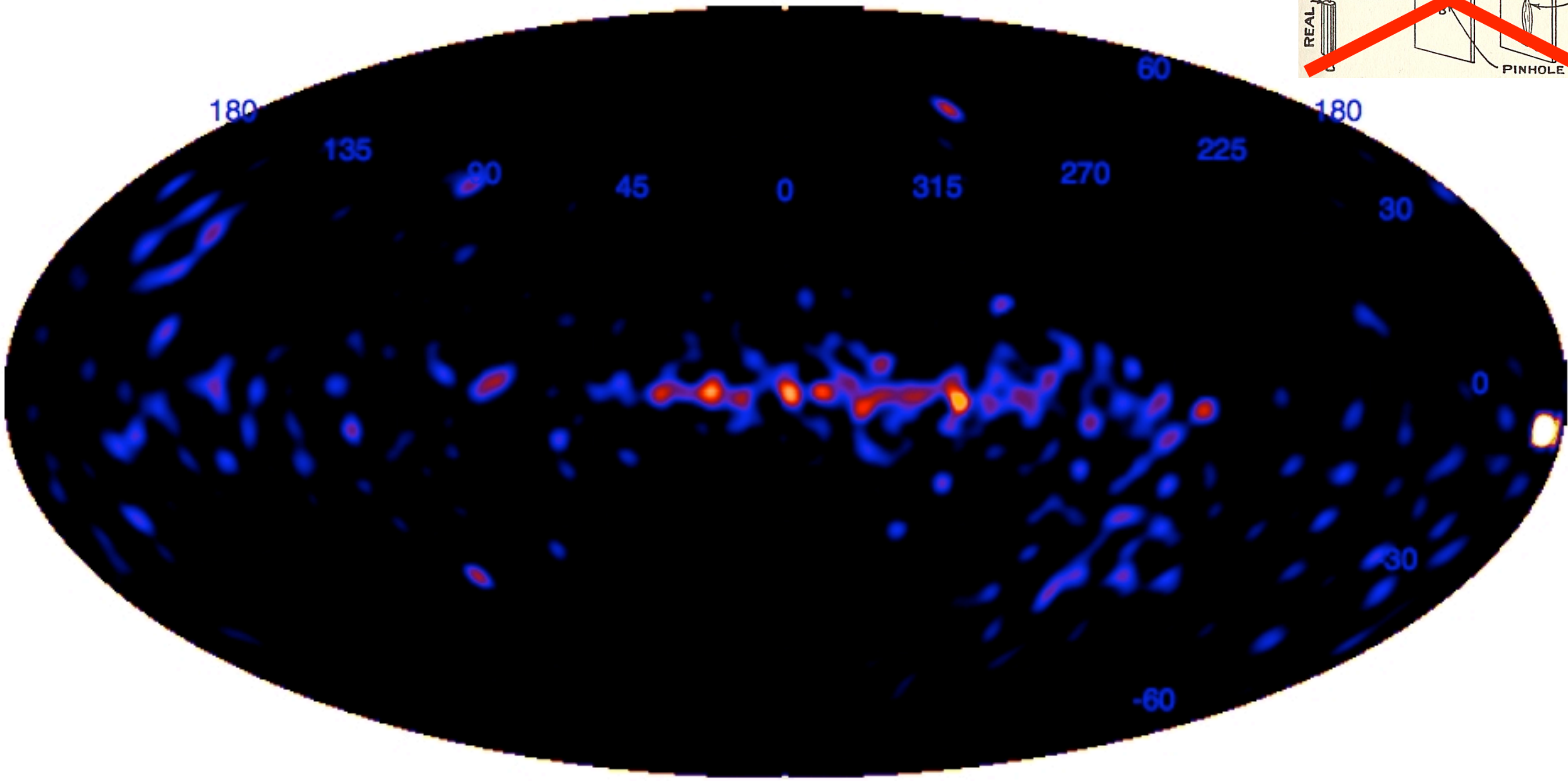


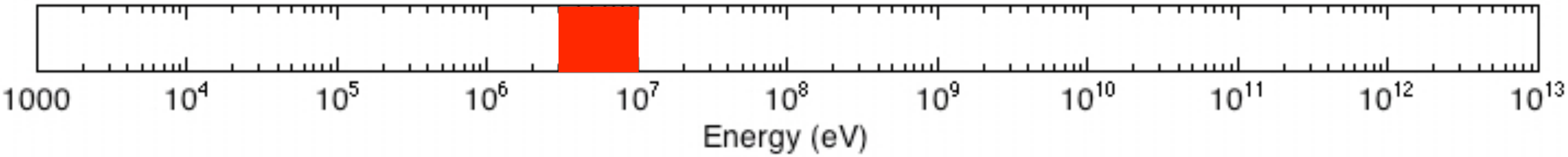


The Gamma-Ray Sky (3 - 10 MeV)

COMPTEL / CGRO (6 yr)

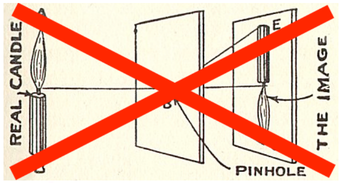


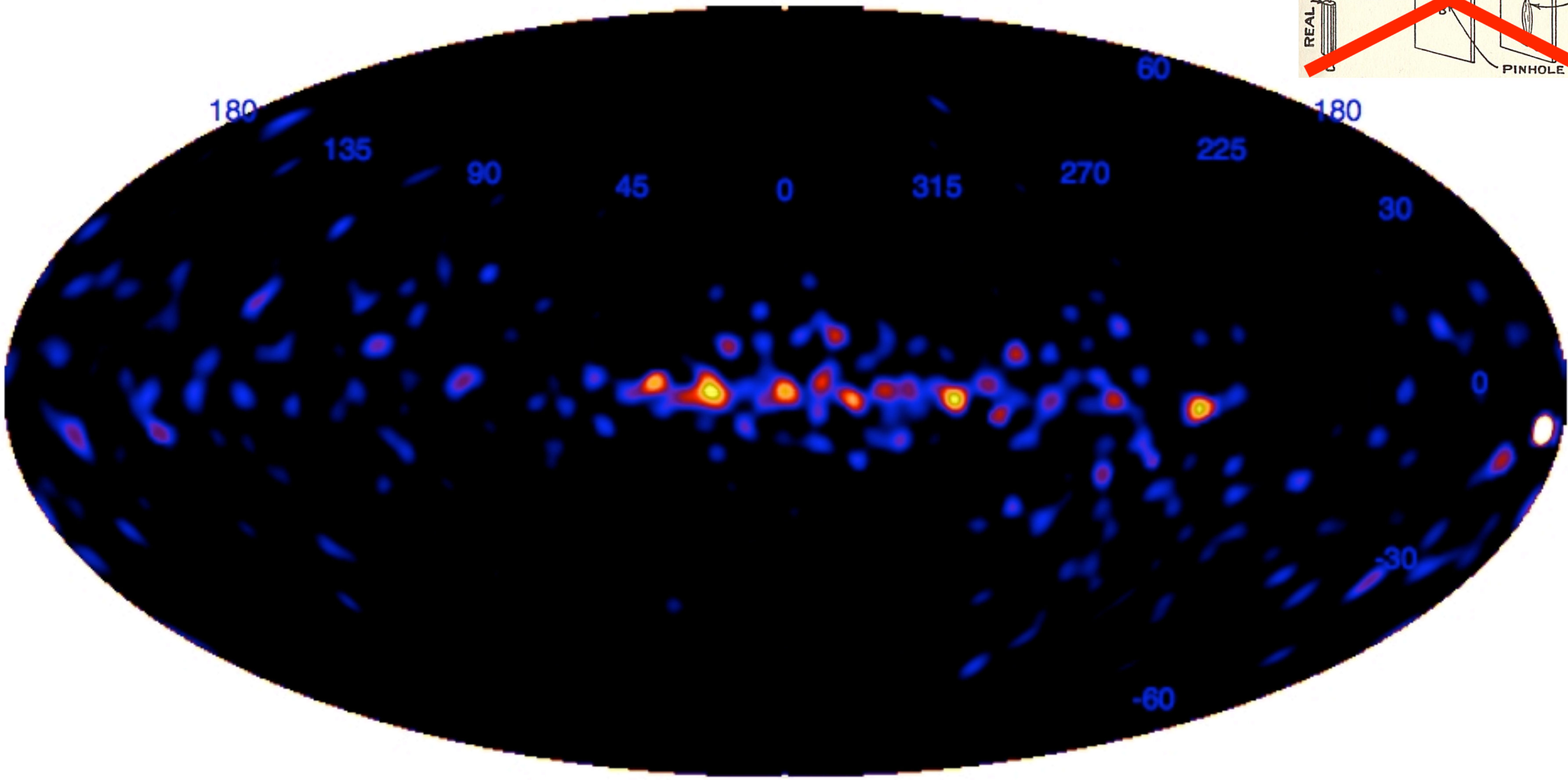


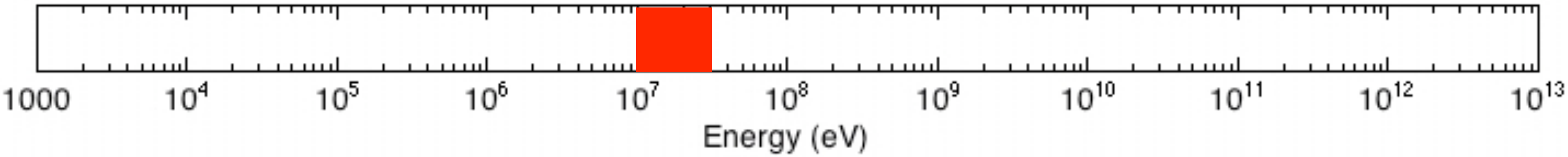


The Gamma-Ray Sky (10 - 30 MeV)

COMPTEL / CGRO (6 yr)

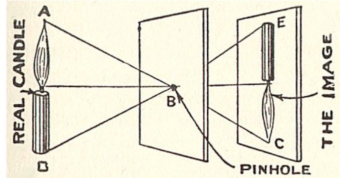


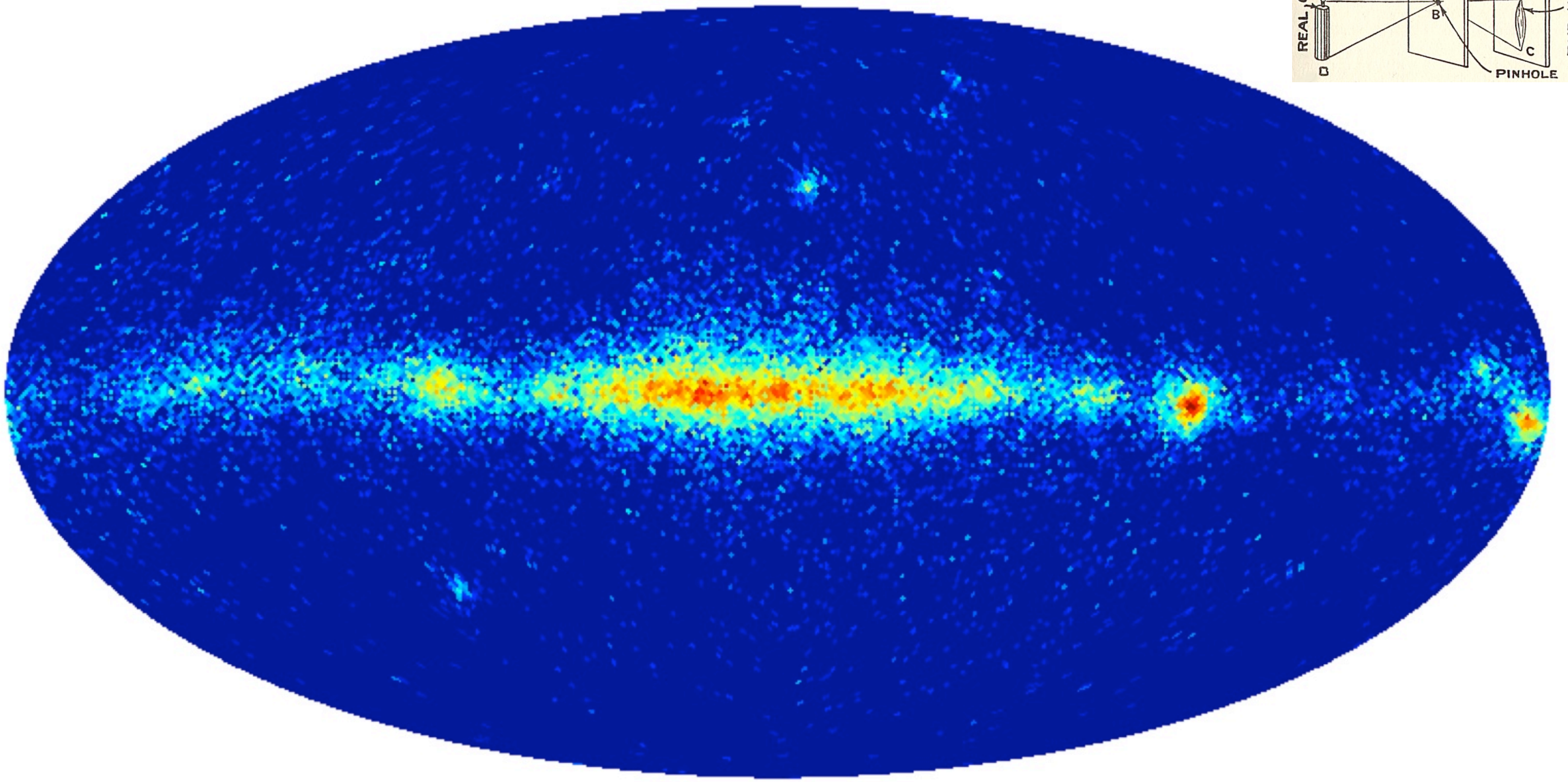


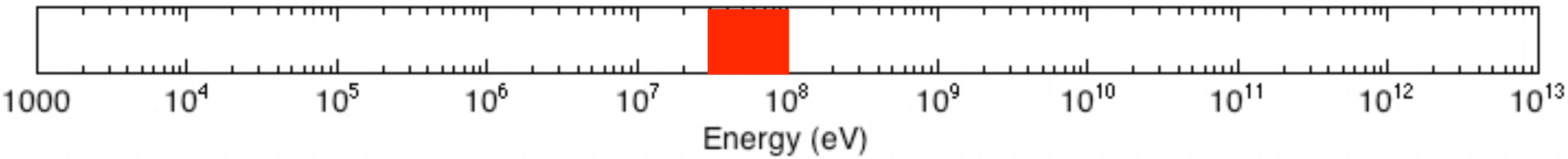


The HE Gamma-Ray Sky (30 - 100 MeV)

LAT / Fermi (1 yr)

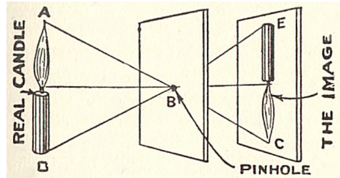


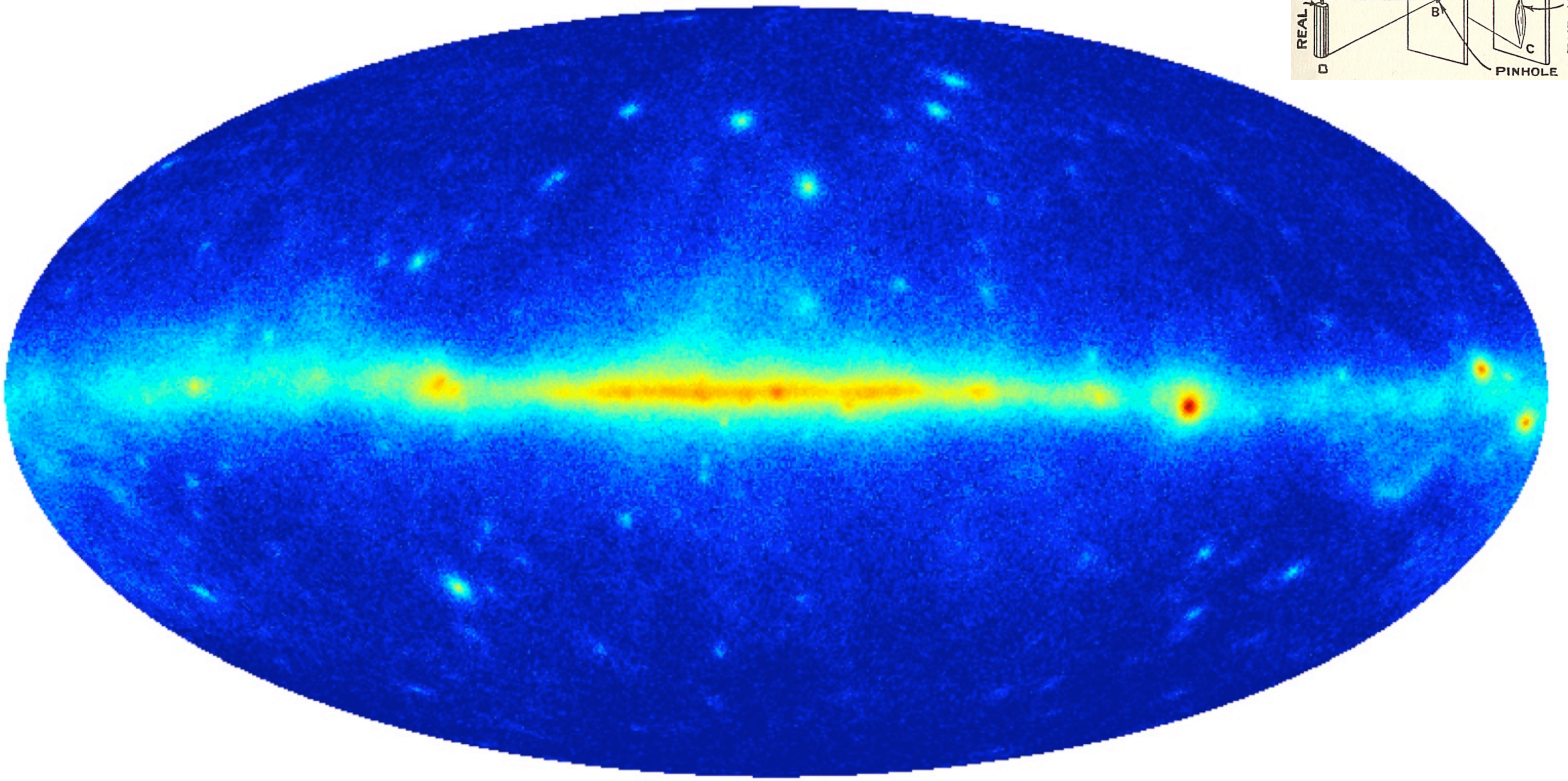


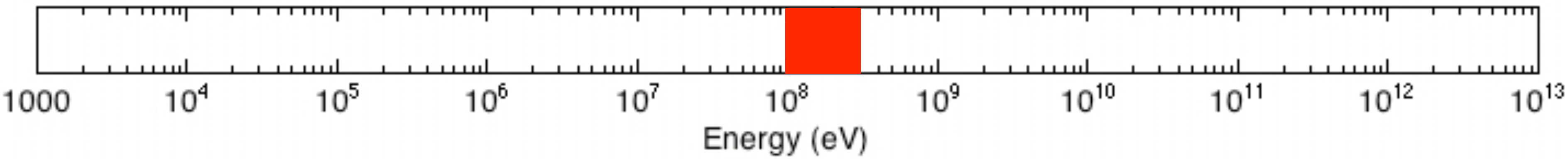


The HE Gamma-Ray Sky (100 - 300 MeV)

LAT / Fermi (1 yr)

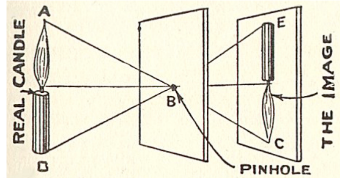


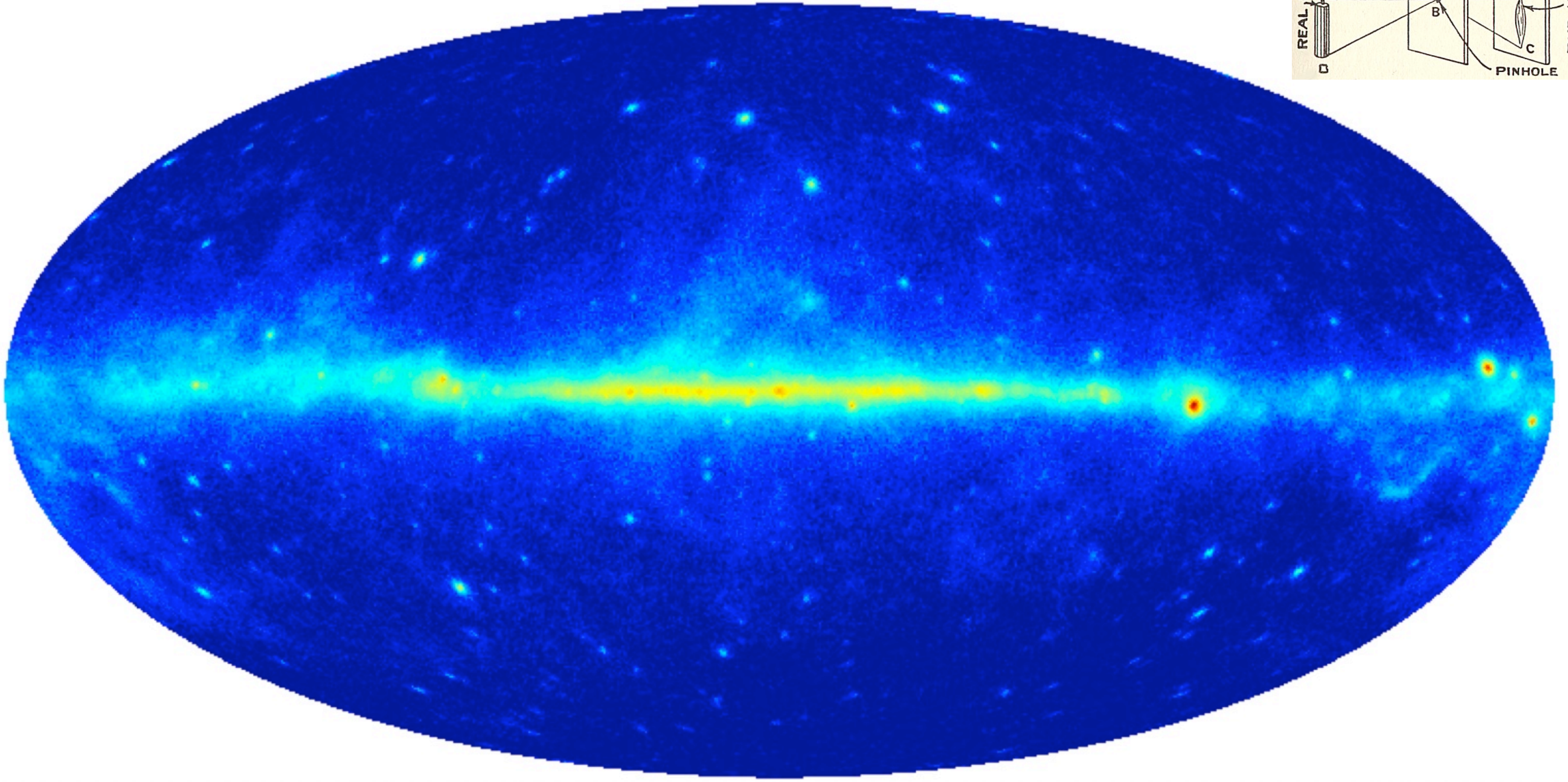


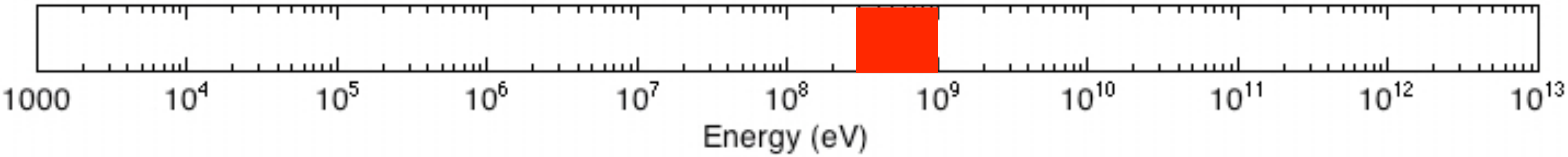


The HE Gamma-Ray Sky (300 - 1000 MeV)

LAT / Fermi (1 yr)

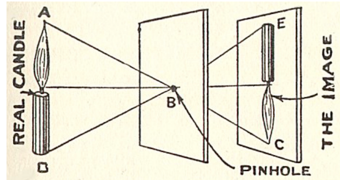


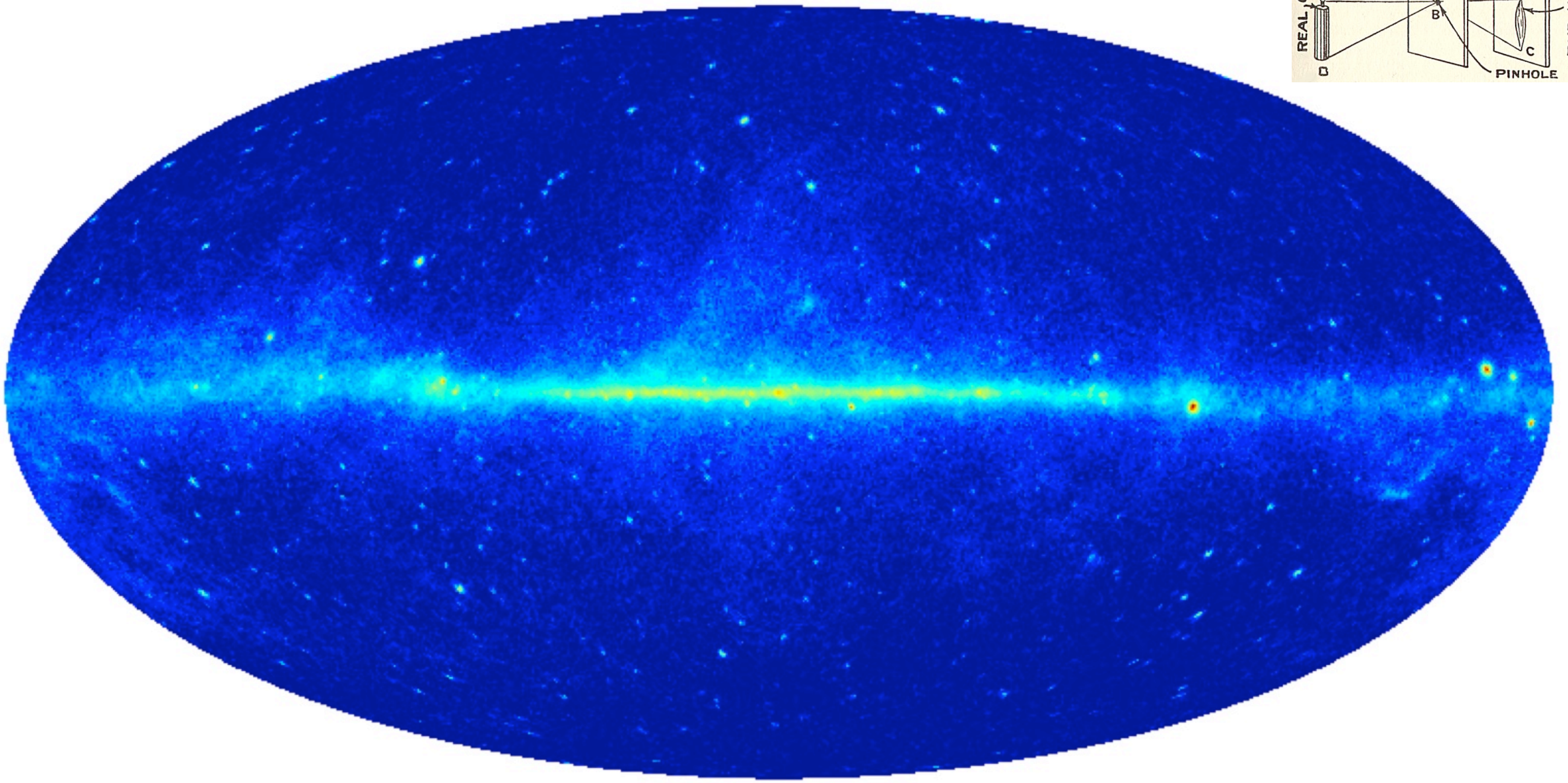


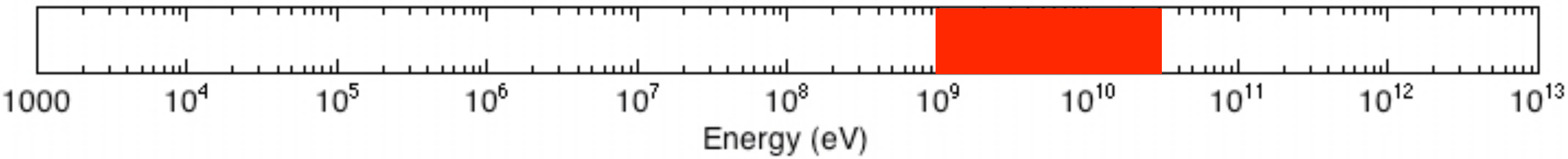


The HE Gamma-Ray Sky (1 - 30 GeV)

LAT / Fermi (1 yr)

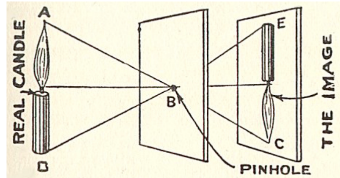


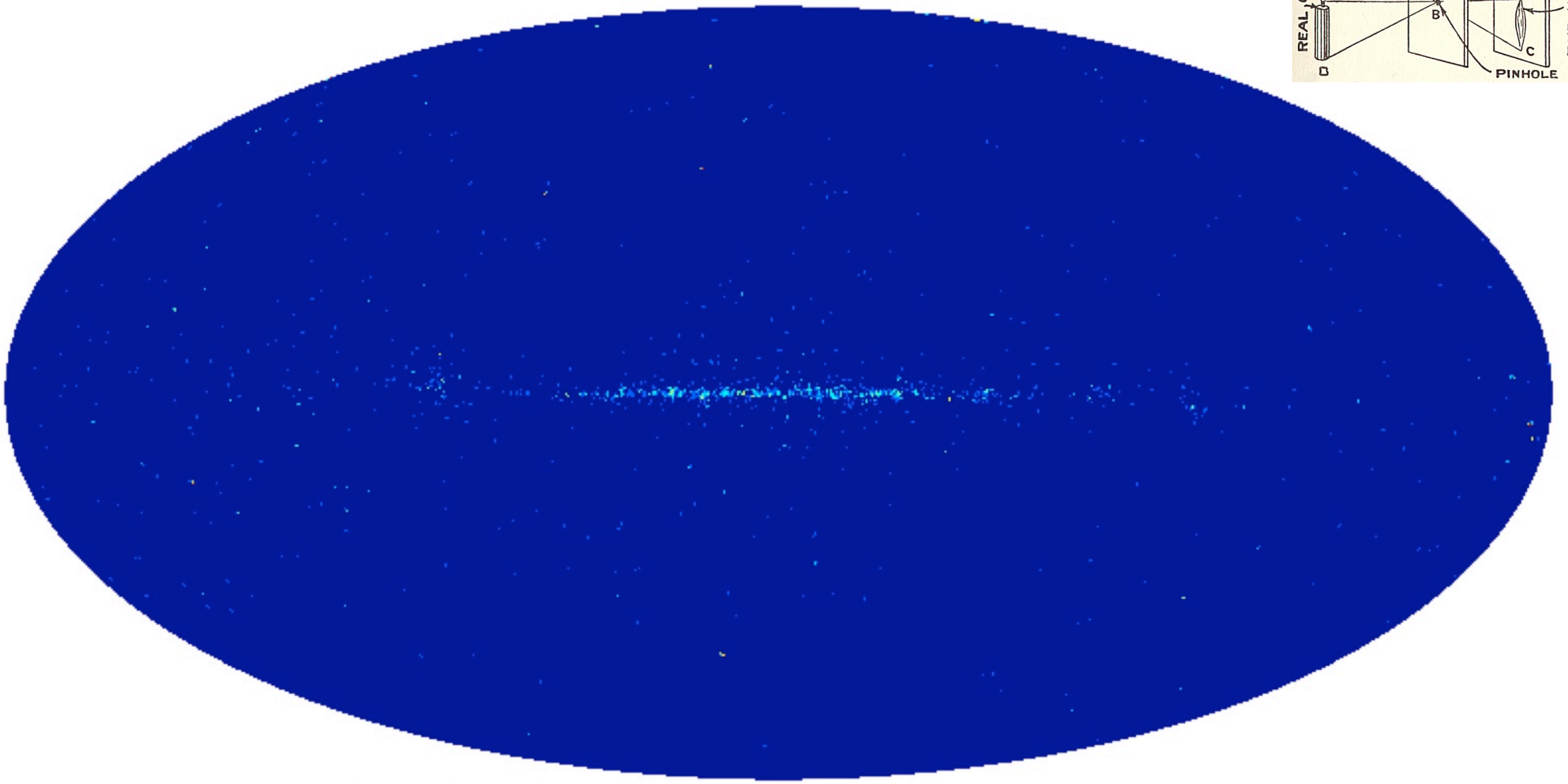


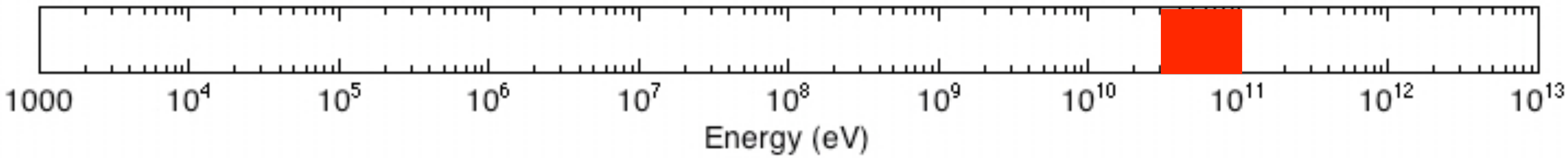


The HE Gamma-Ray Sky (30 - 100 GeV)

LAT / Fermi (1 yr)

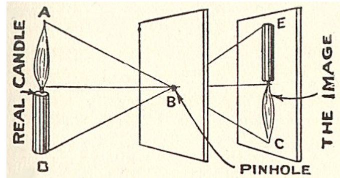


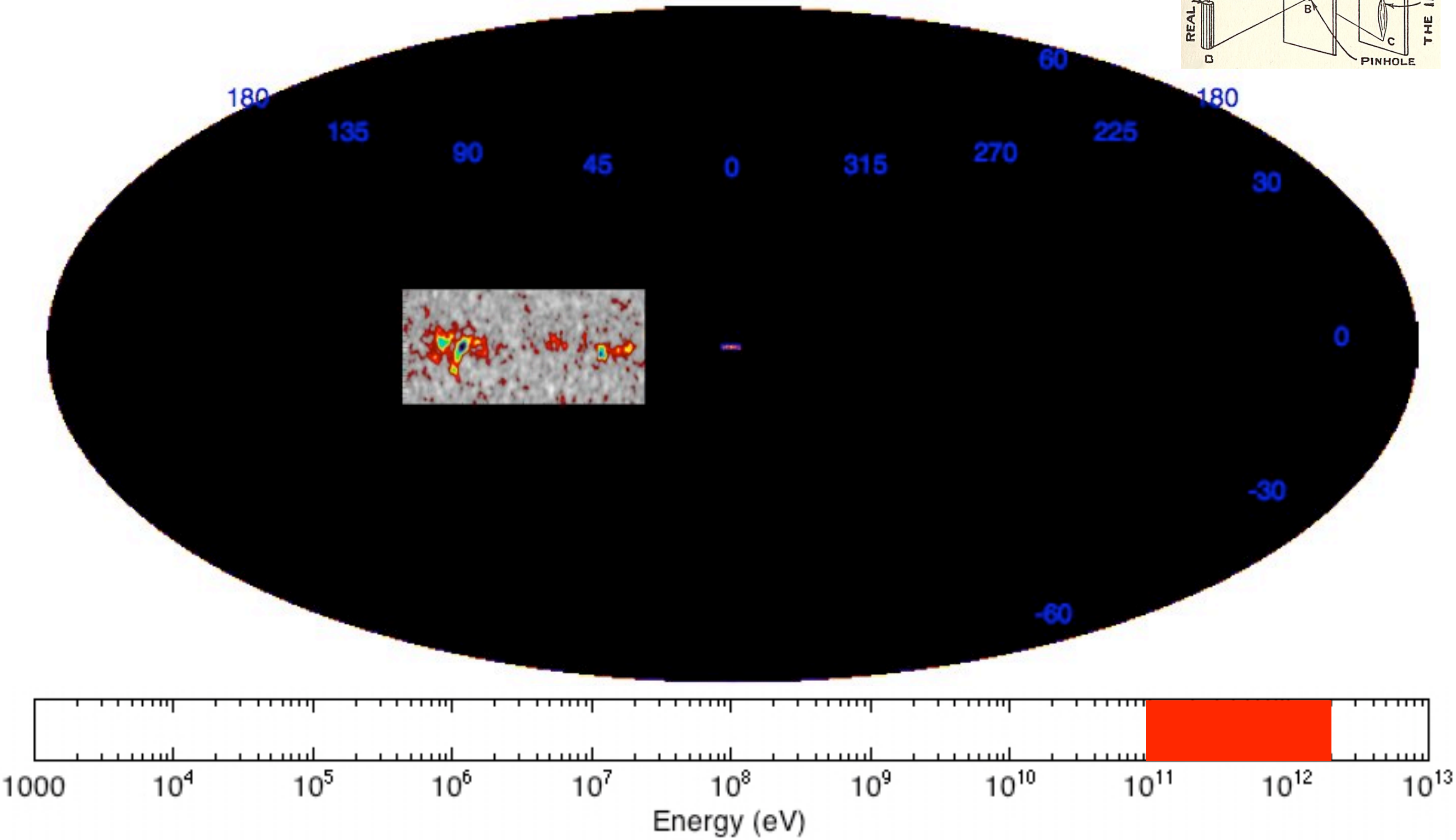




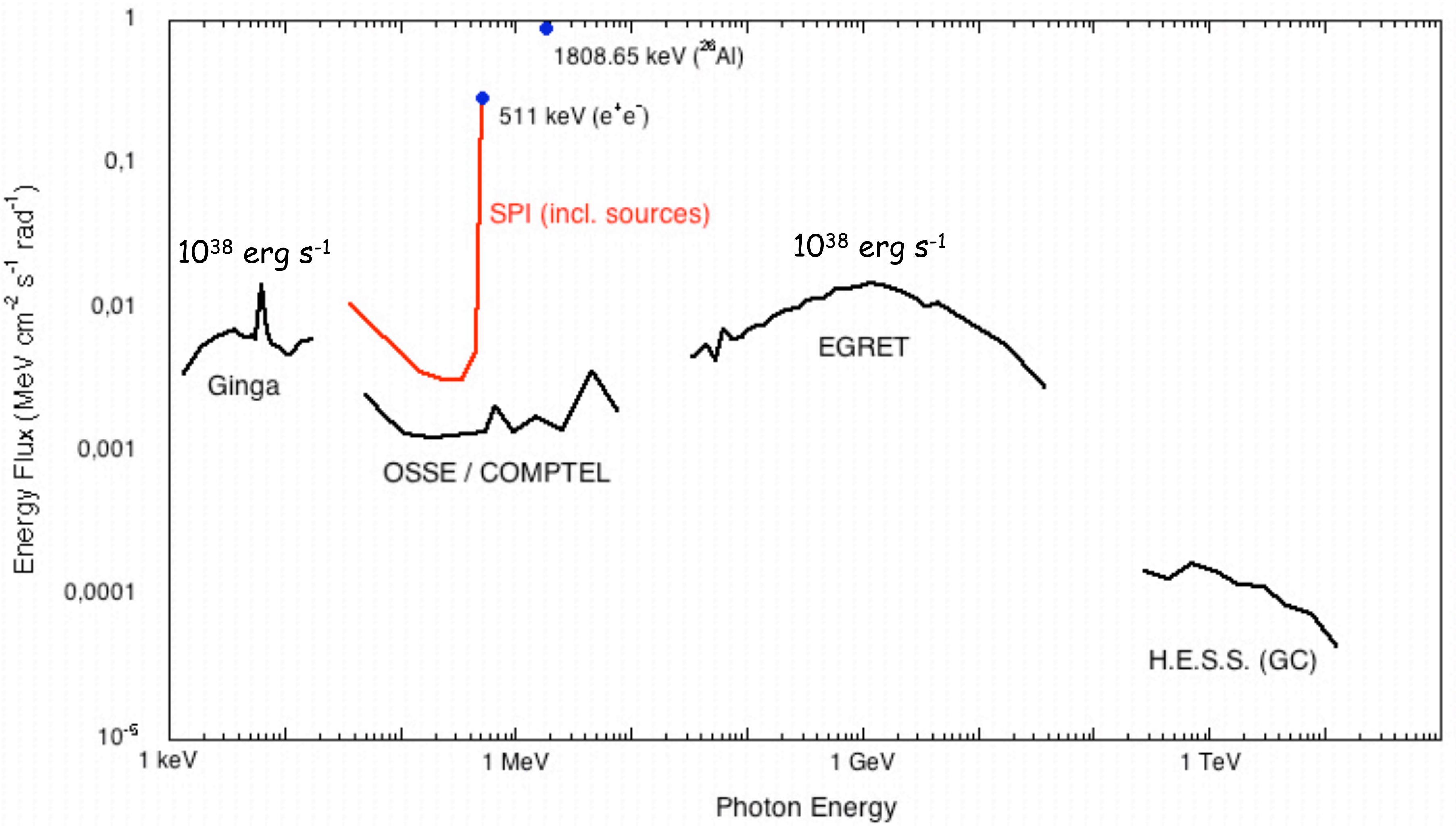
The VHE Gamma-Ray Sky (>100 GeV)

H.E.S.S. / MILAGRO



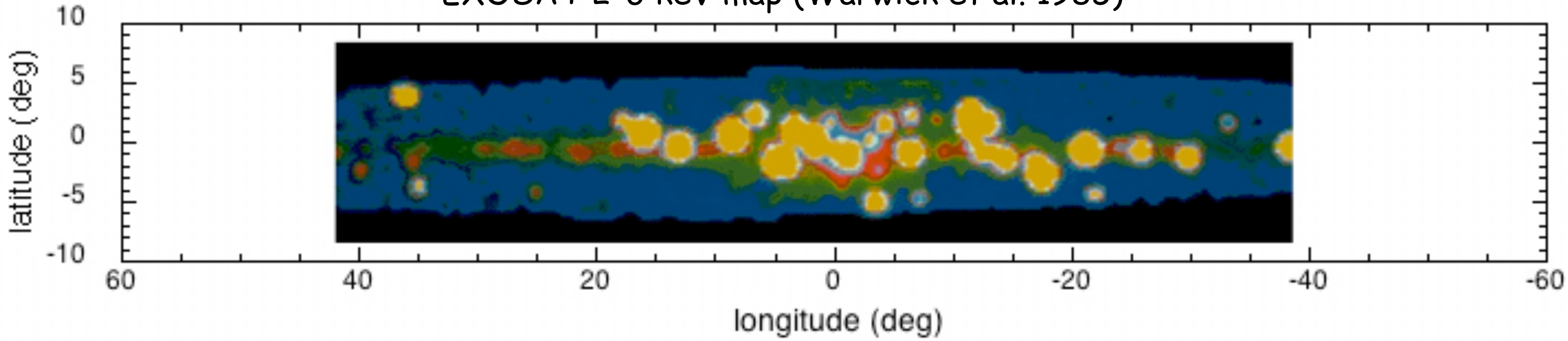


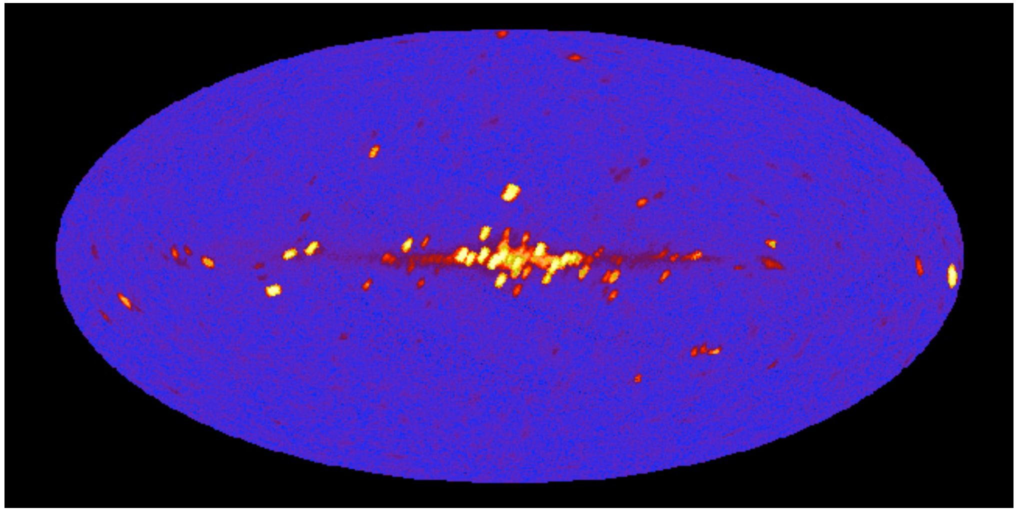
The galactic diffuse emission spectrum



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)

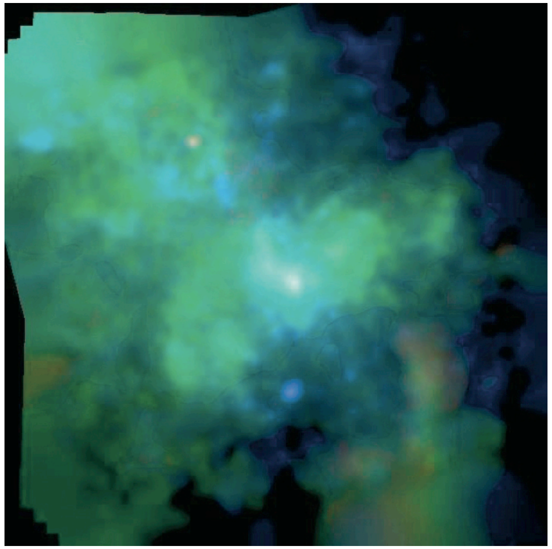
- exponential disk & bulge components
- confined to the inner disk (|l| < 60°)
- disk scale height z_0 ~ 100 - 300 pc
- luminosity ~ 10^{38} erg s^{-1} (2 - 10 keV) (few % of resolved sources luminosity)

Origin of GRXE

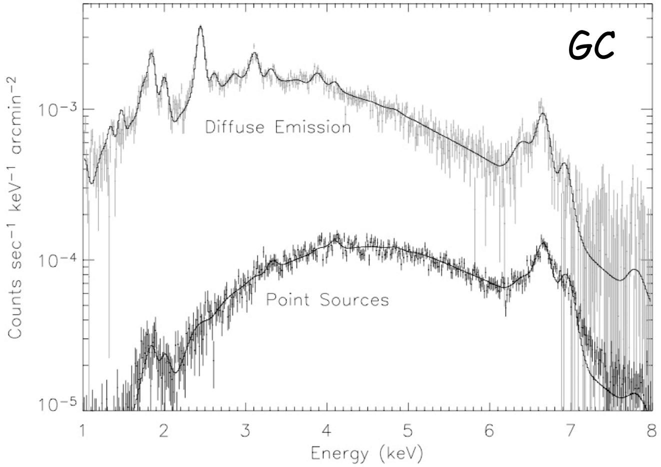
- unresolved point sources?
- truly diffuse emission?

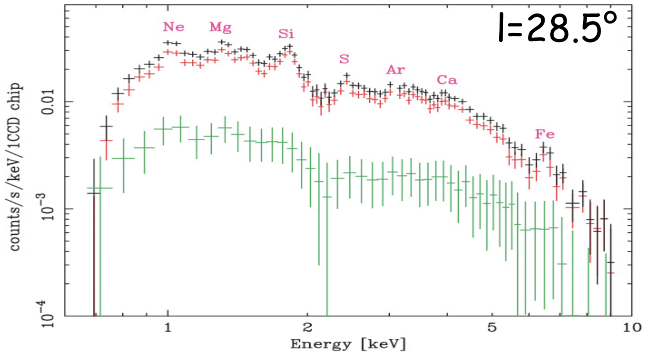
Deep* X-ray surveys (XMM & Chandra)

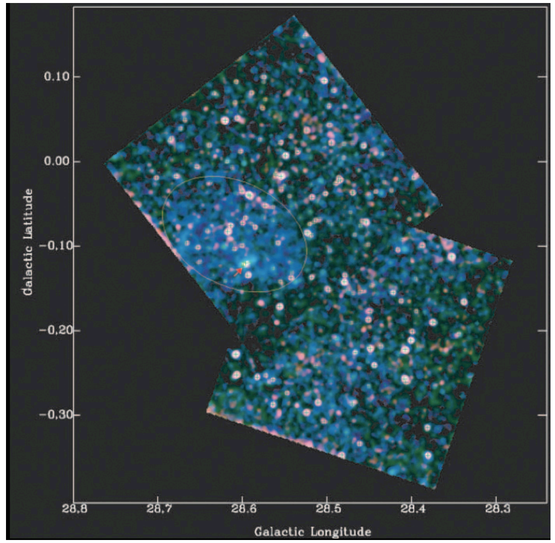
*100 ks (Ebisawa et al. 2005) -626 ks (Muno et al. 2004)



GC (Muno et al. 2004)





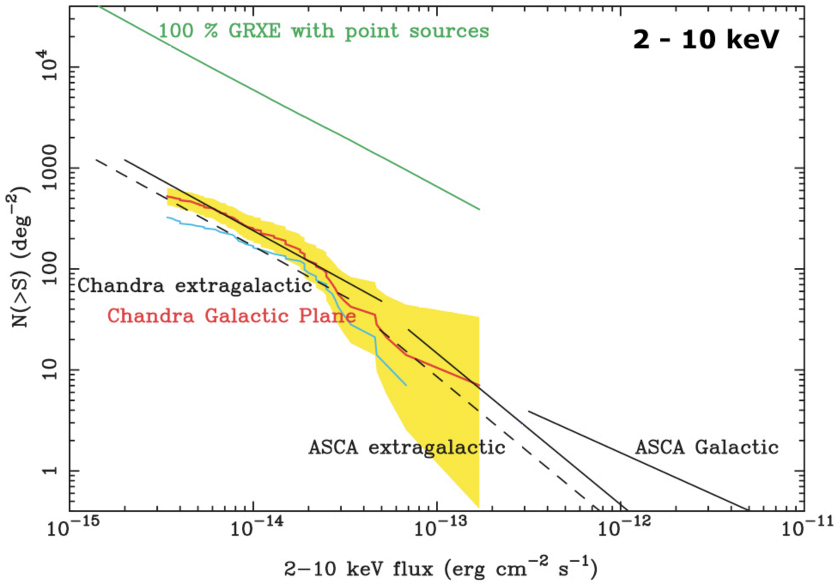


l=28.5° (Ebisawa et al. 2005)

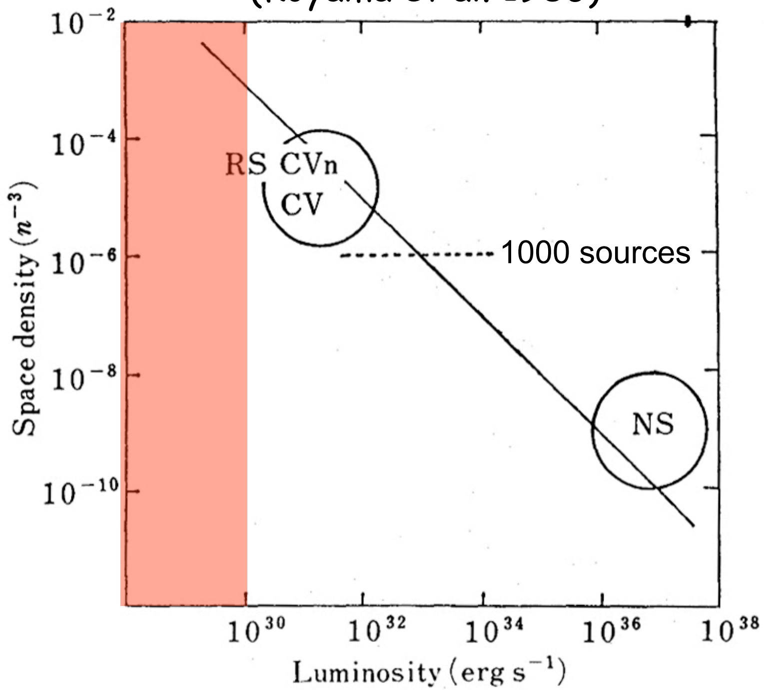
- XMM & Chandra detect new faint point sources and prominent diffuse emission
- Only 10-20% of flux originates from point sources, 80-90% of the emission is diffuse
- Soft (< 2 keV) point sources are of galactic origin
- Hard (2-10 keV) point sources are of extragalactic origin
- Prominent emission lines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

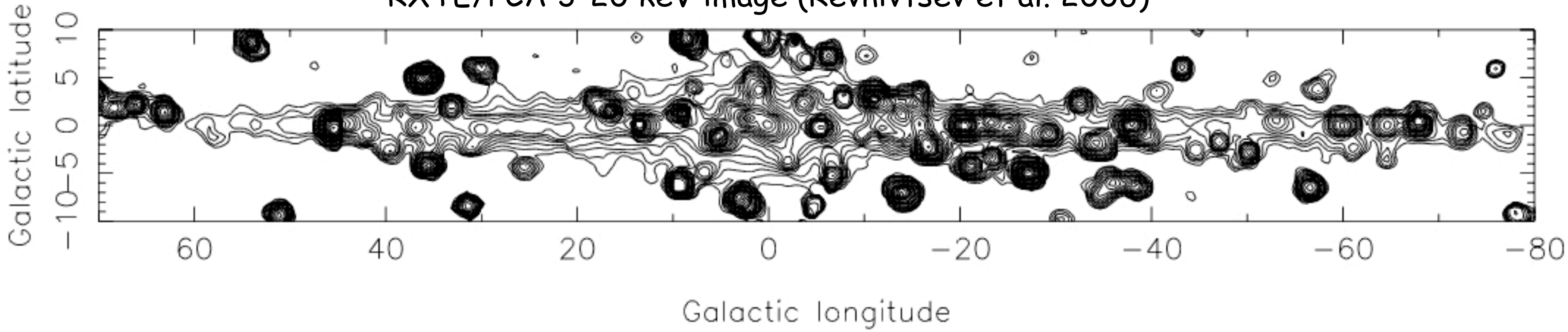
- requires T ~ 10^7 - 10^8 K ⇒ plasma exceeds escape velocity from galactic plane
- requires P/k ~ 10^5 cm^{-3} K ⇒ exceeds pressure of other ISM components
- required energy density ~ 10 eV cm^{-3} ⇒ 1-2 orders of magnitudes higher than CR, B, n

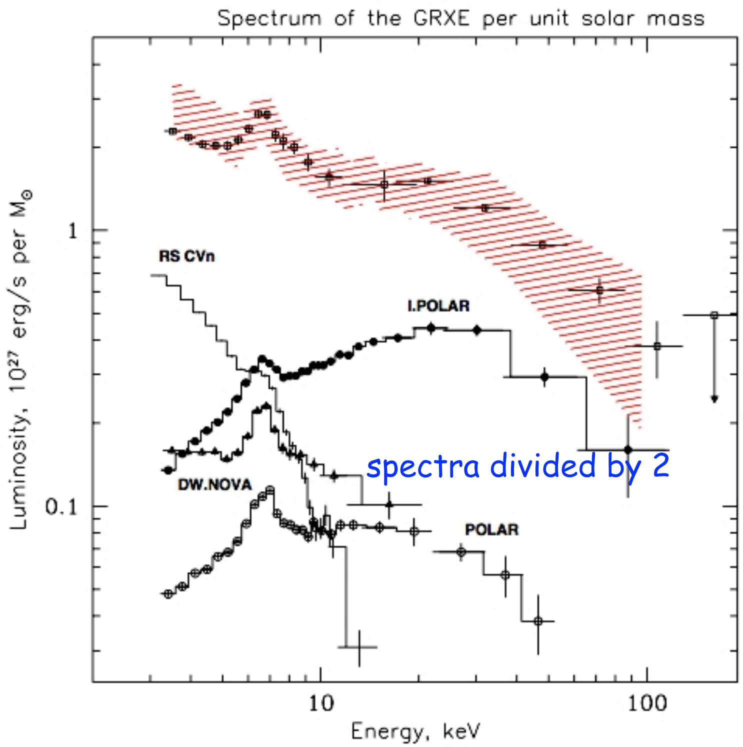
CR interactions with interstellar medium

- 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

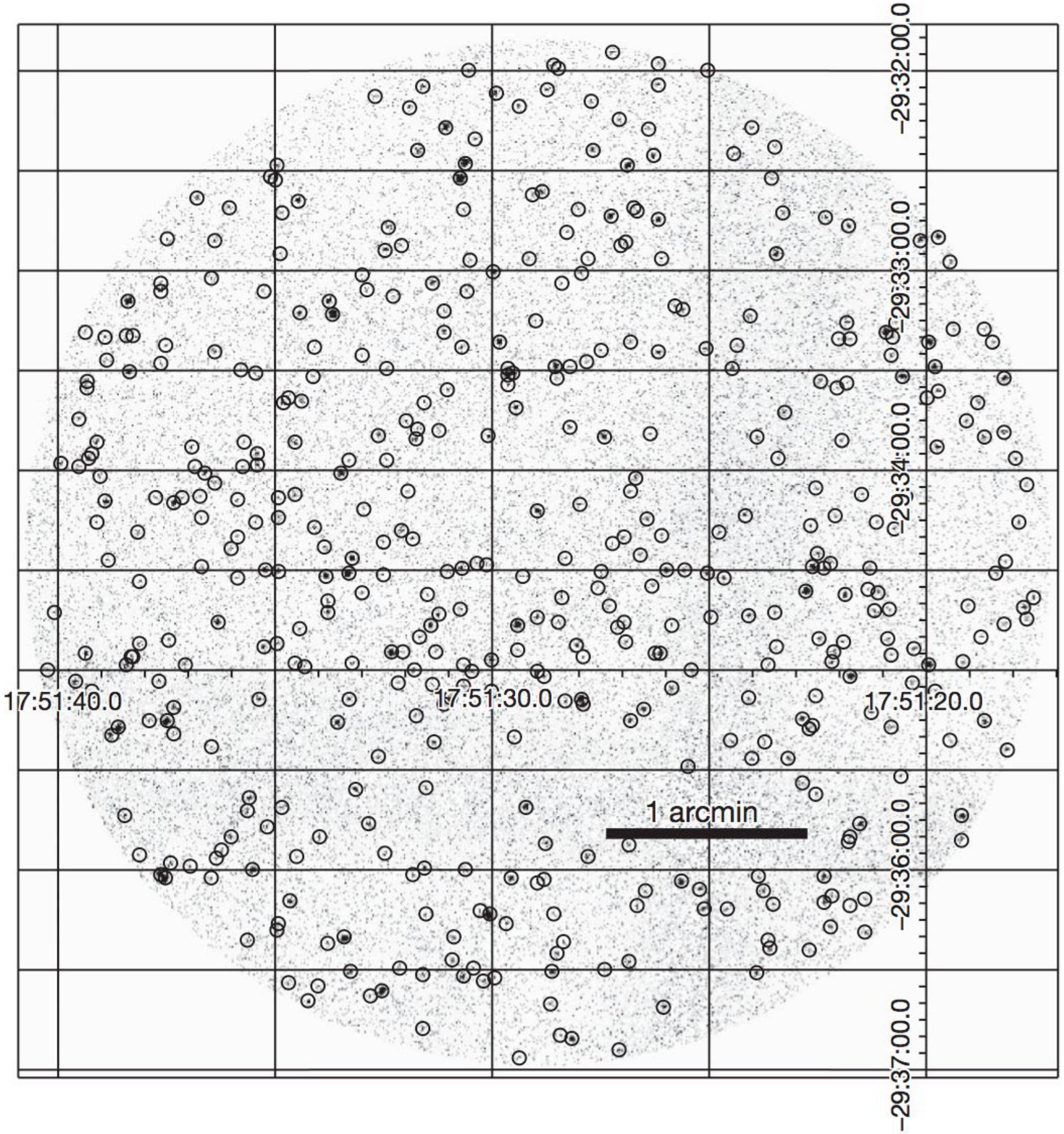
Luminosities

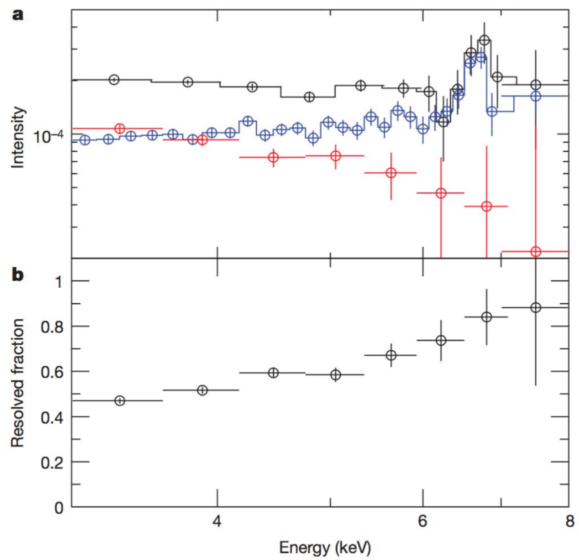
- $L_{X,bulge} = (3.9 \pm 0.5) \times 10^{37}$ erg s^{-1}
- $M_{bulge} = (1.0 - 1.3) \times 10^{10}\ M_\odot$
- $L_X/M_\odot = (3.5 \pm 0.5) \times 10^{27}$ erg s^{-1}
- **Comparable with cumulative emissivity per unit stellar mass of point X-ray sources in solar neighbourhood (coronally active late-type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

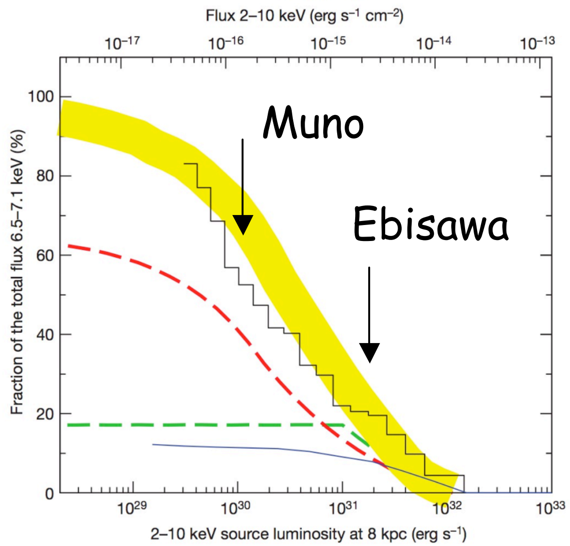
Finally point sources!

1 Ms Chandra exposure towards galactic bulge (Revnivtsev et al. 2009)

80% of emission resolved into individual point sources

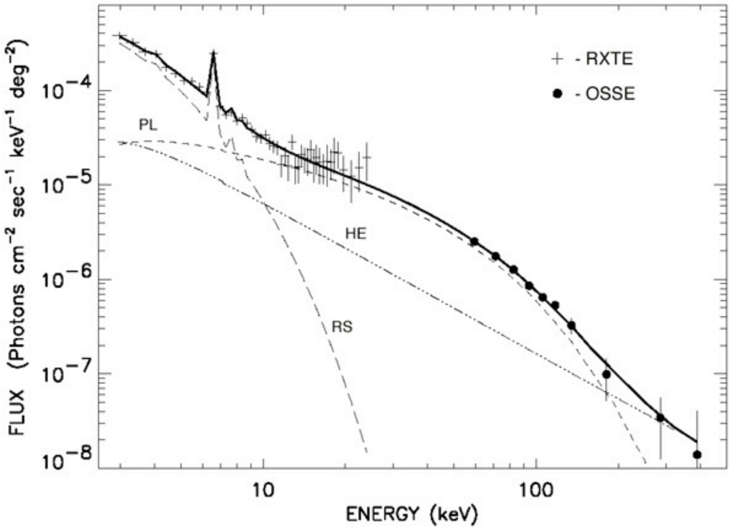






INTEGRAL resolves the hard X-ray ridge

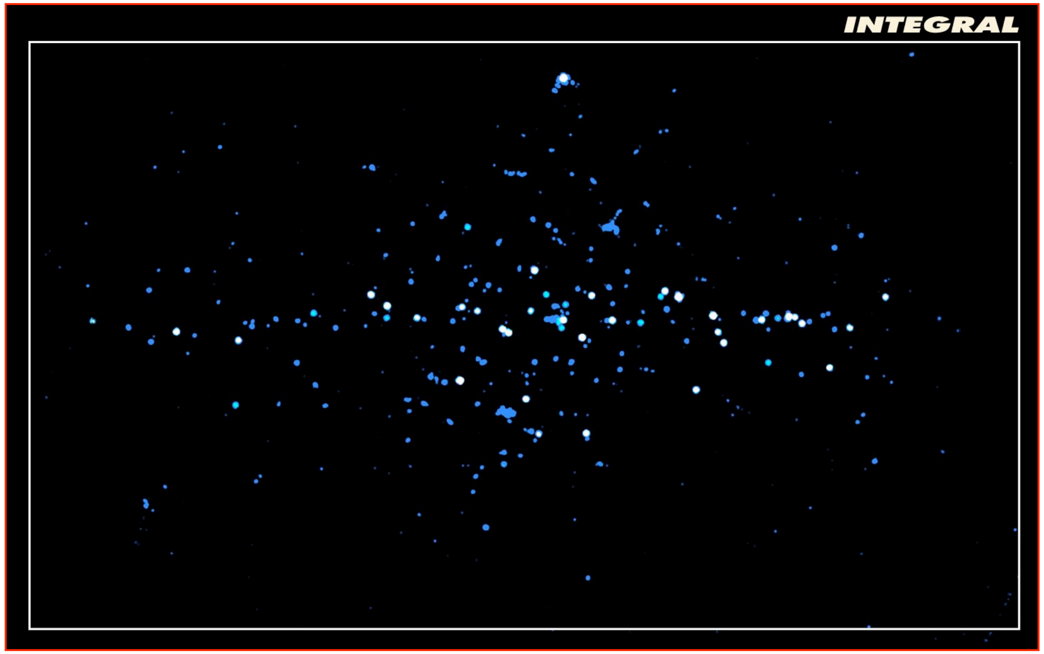
RXTE & OSSE (Valinia & Tatischeff 2001)



Hard X-ray emission components

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

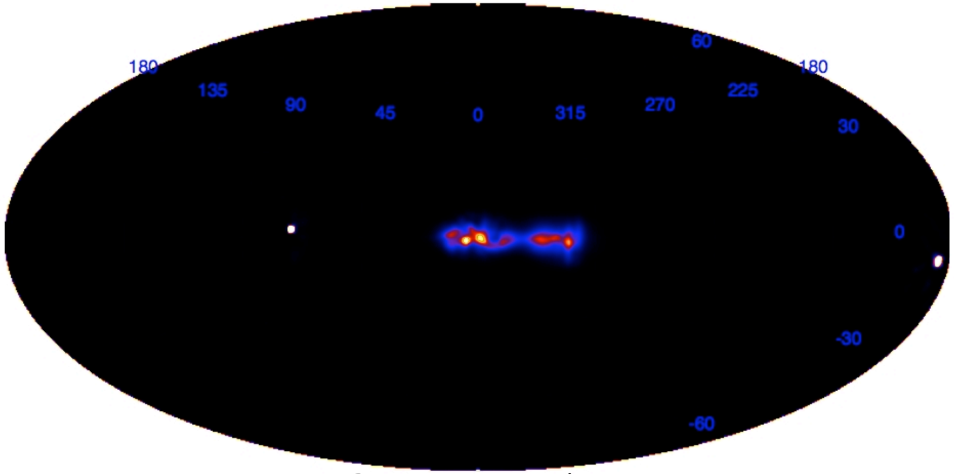
IBIS (Lebrun et al. 2004)



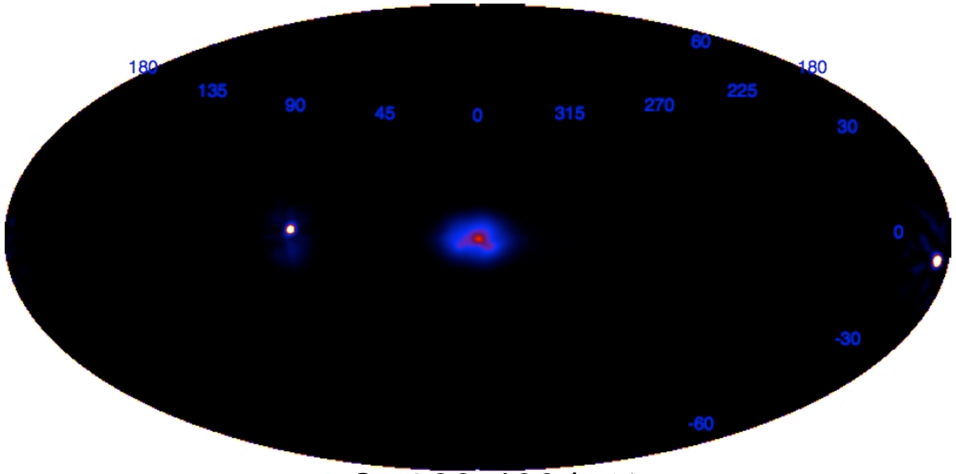
PL (exponentially cut-off powerlaw)

- 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

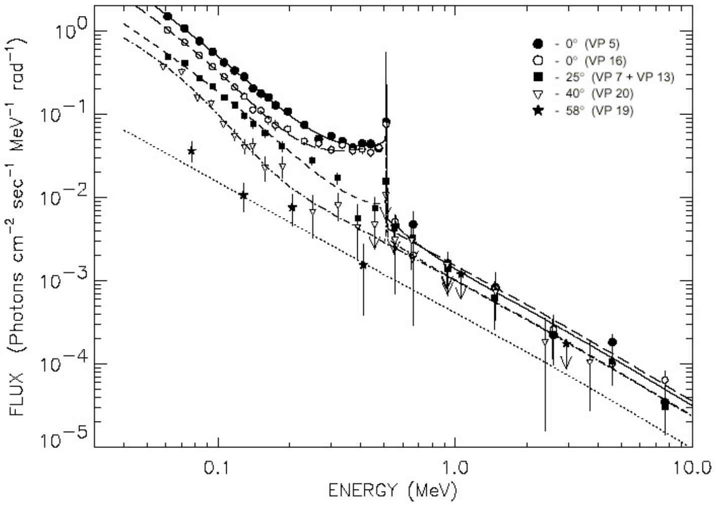
The hard X-ray to soft γ-ray transition



SPI 200-300 keV



SPI 300-400 keV



OSSE spectra (Kinzer et al. 1999)

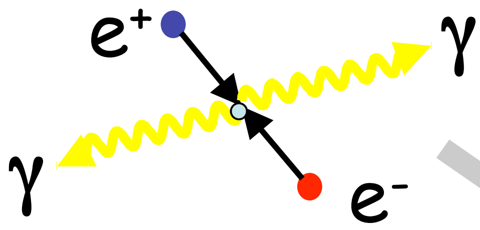
Emission components

- **< 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)

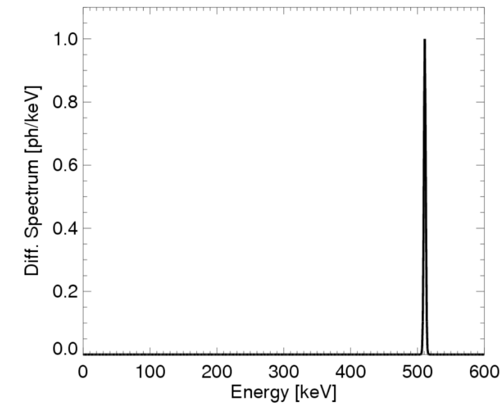
Is the transition hard X-ray ⇒ soft γ-ray
a point source ⇒ diffuse emission transition?

Antimatter annihilation in the Milky-Way

- Direct annihilation

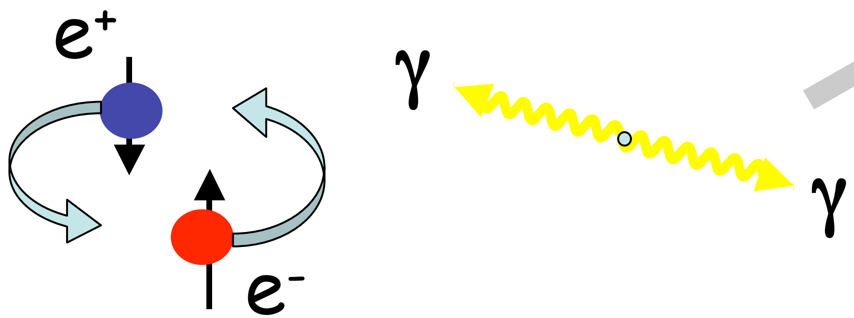


Annihilation line
E = 511 keV

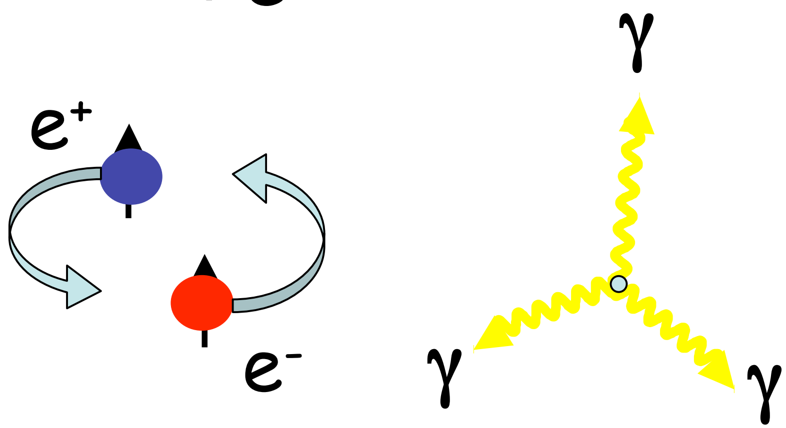


- Annihilation via positronium (Ps) formation

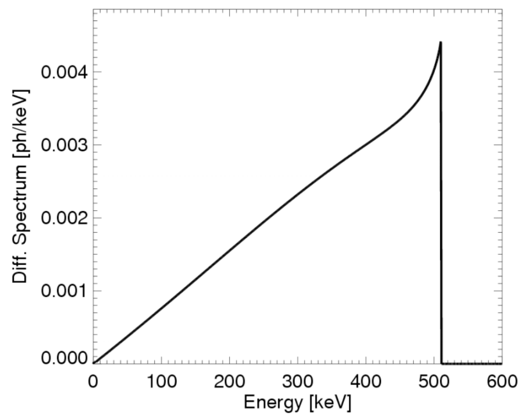
para-positronium
1/4



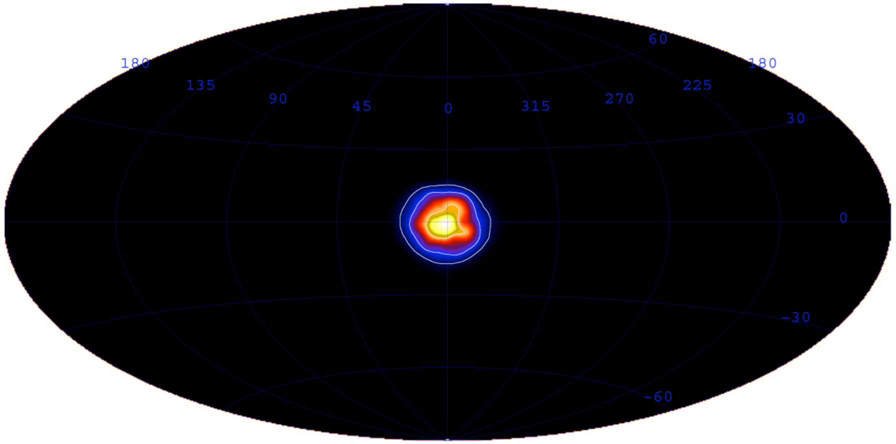
ortho-positronium
3/4



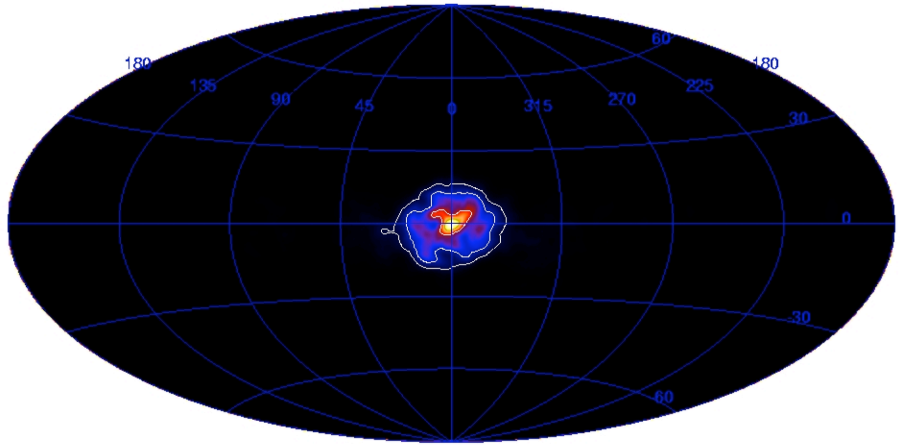
Positronium continuum
E < 511 keV



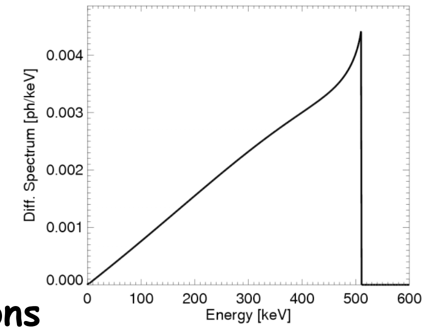
Positron annihilation: spatial distribution

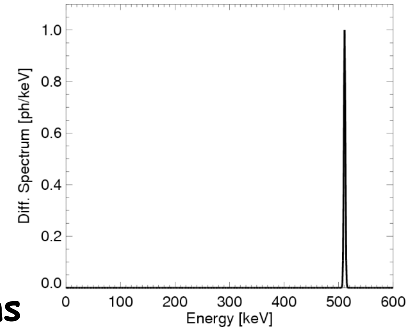


SPI Pscont image (Weidenspointner et al. 2006)



SPI 511 keV image (Knödlseder et al. 2005)





Observations

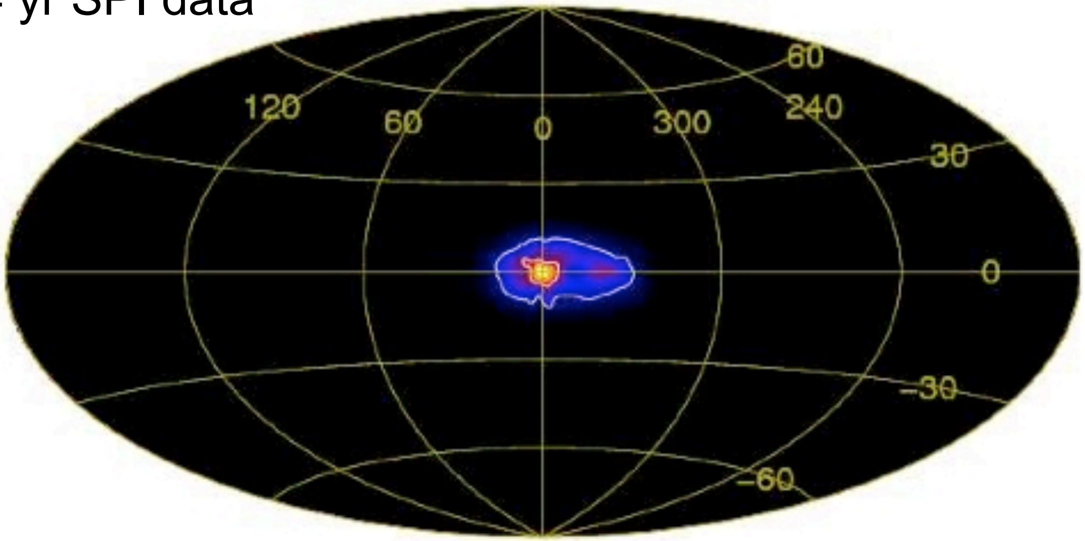
- No point sources seen (SPI & IBIS)
- Continuum and line are spatially consistent
- Galactic bulge dominates emission
- B/D luminosity ~ 3 - 9

Implications

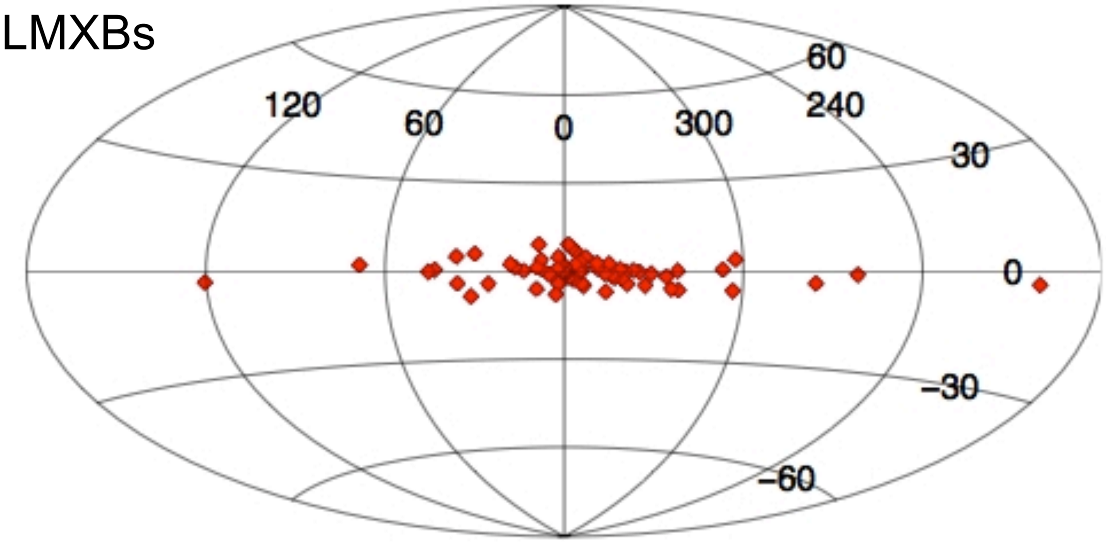
- Positron annihilation distribution is unique
  Once we identify the source we certainly learn something new! (new population, new mecanism, new physics, …)

Positron annihilation in the disk

4 yr SPI data



LMXBs



LMXB scenario:

- Positrons production in hot central regions of the accretion disk via gamma-gamma pair production
- Positron ejection into MIS through jets or winds
- Model prediction: $R_{e+} \sim 10^{41}\ \mathrm{e}^{+}\ \mathrm{s}^{-1}$

- IBIS catalogue: 71 LMXB (~100 µQSO predicted by Paredes 2005)
- Predicted production rates:

  $R_{e+} \approx 10^{43}\ \mathrm{e}^{+}\ \mathrm{s}^{-1}$

- Observed production rates:

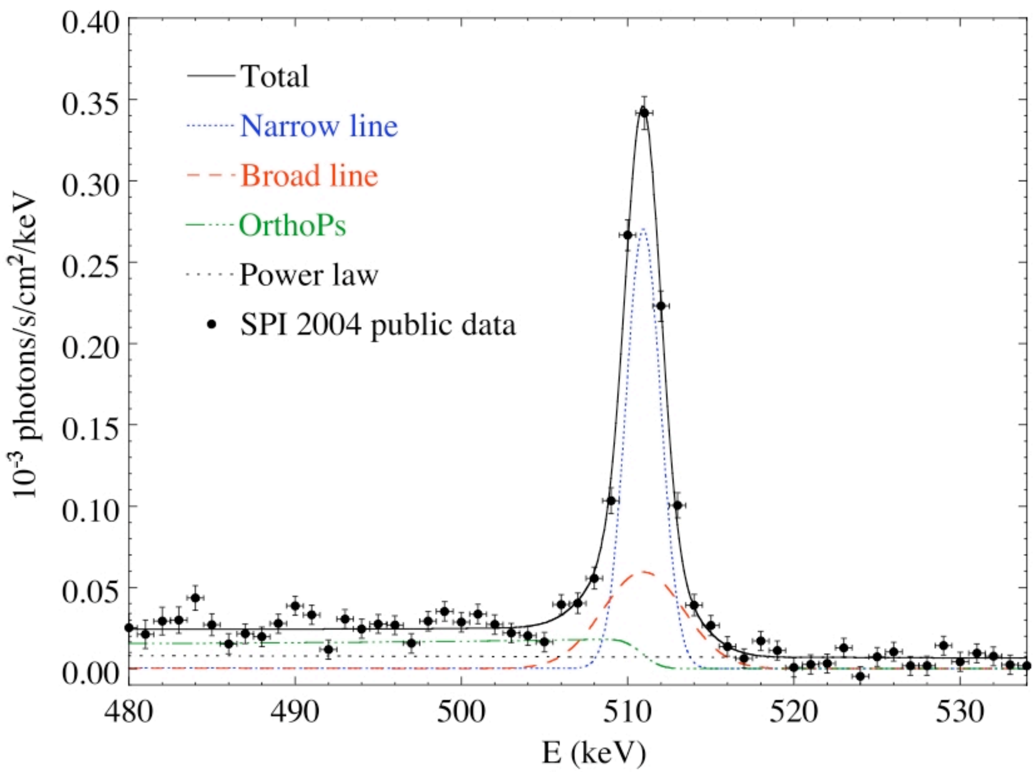
  $L_{\mathrm{spheroid}} = (13.9 - 19.8) \times 10^{42}\ \mathrm{e}^{+}\ \mathrm{s}^{-1}$

  $L_{\mathrm{disque}} = (1.5 - 5.1) \times 10^{42}\ \mathrm{e}^{+}\ \mathrm{s}^{-1}$

⇒ **LMXB may explain disk emission but still fail to explain bulge emission**

But what about ^{26}Al decay positrons?
What role plays de GC Black Hole?
What about diffusion?

Positron annihilation: spectral distribution



SPI spectrum (Jean et al. 2006)

SPI spectral fitting

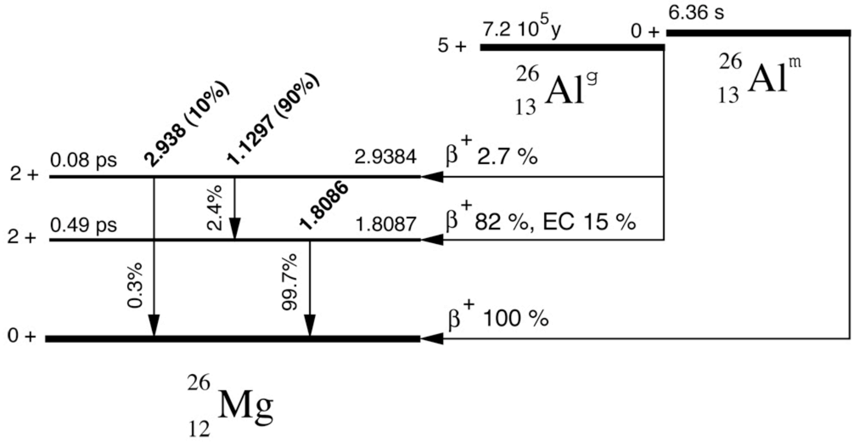
- Energy 510.98 ± 0.03 keV
- $FWHM_n$ 1.3 ± 0.4 keV
- $FWHM_b$ 5.4 ± 1.2 keV
- $Flux_n$ 7.2×10^{-4} ph cm^{-2} s^{-1}
- $Flux_b$ 3.5×10^{-4} ph cm^{-2} s^{-1}

Interpretation

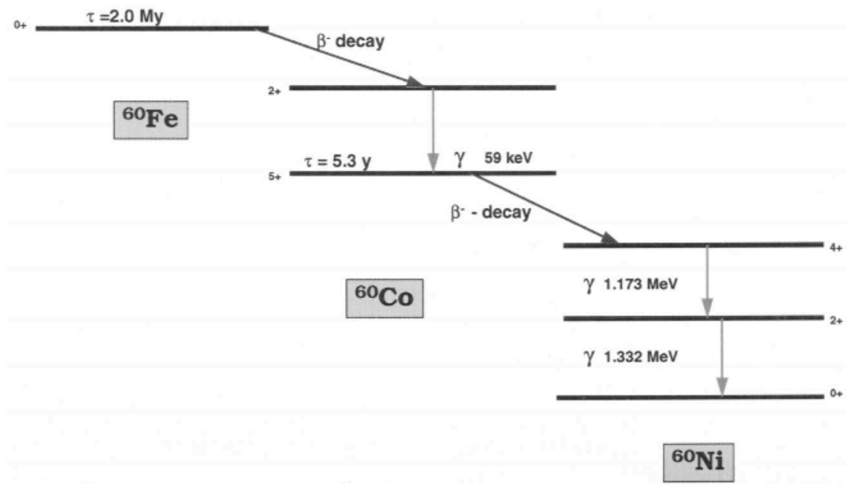
- Narrow line (1.1 keV)
  - thermalised positrons
  - consistent with 8000 K warm ISM (neutral & ionised)
- Broad line (5.1 keV)
  - inflight positronium formation
  - consistent with 8000 K warm ISM (only neutral, quenched if gaz is fully ionised)
- Narrow / broad line fraction ~ 2
  consistent with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

Radioactive decay in the Milky-Way

^{26}Al decay scheme



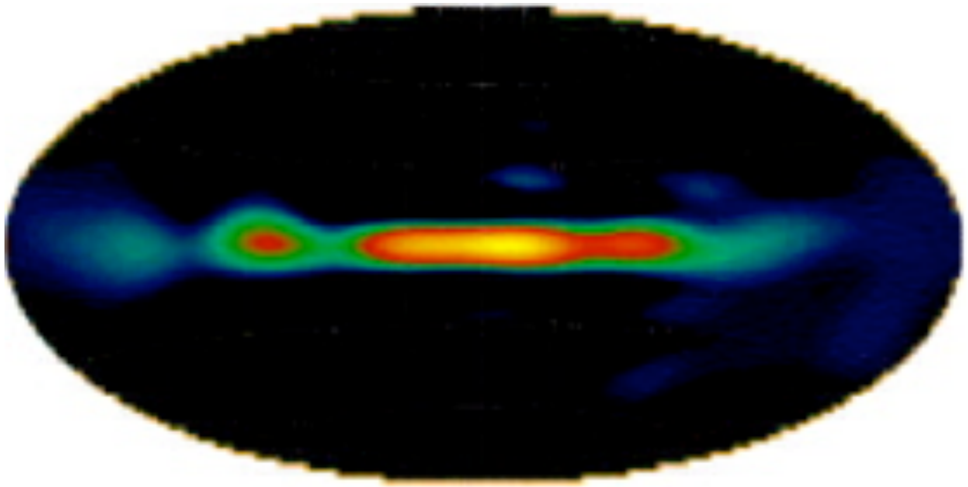
^{60}Fe decay scheme



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)

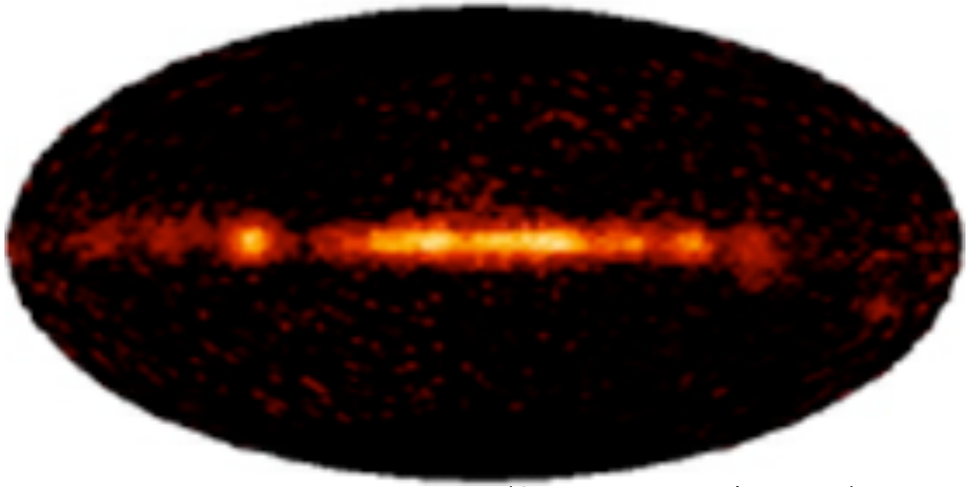
^{26}Al decay 1809 keV line emission



COMPTEL image (Knödlseder et al. 1999)

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

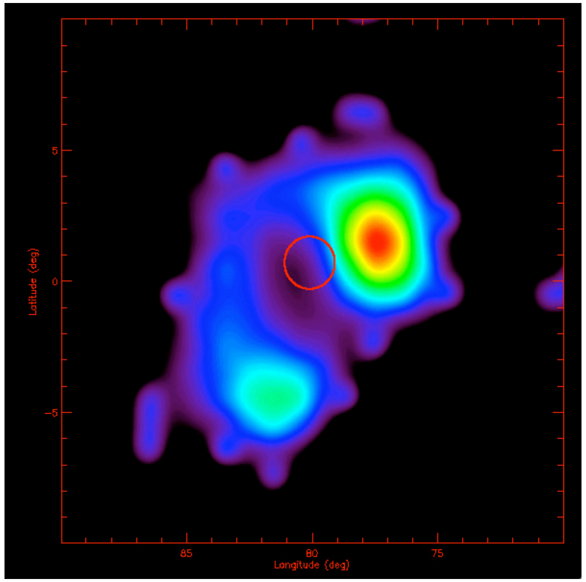


DMR microwave image (Bennett et al. 1992)

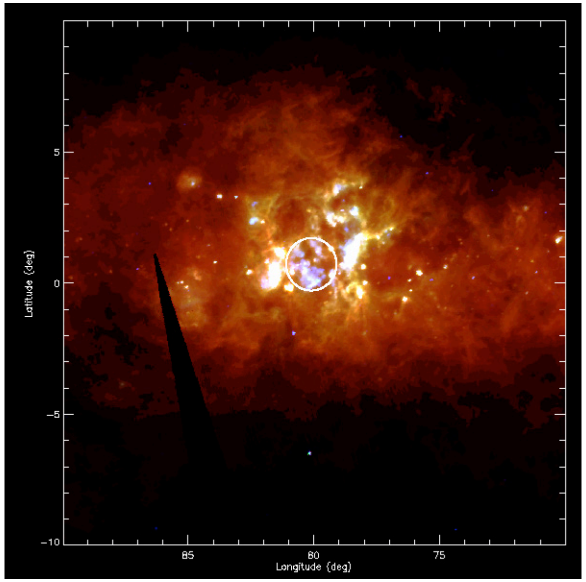
^{26}Al production and massive stars

- 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

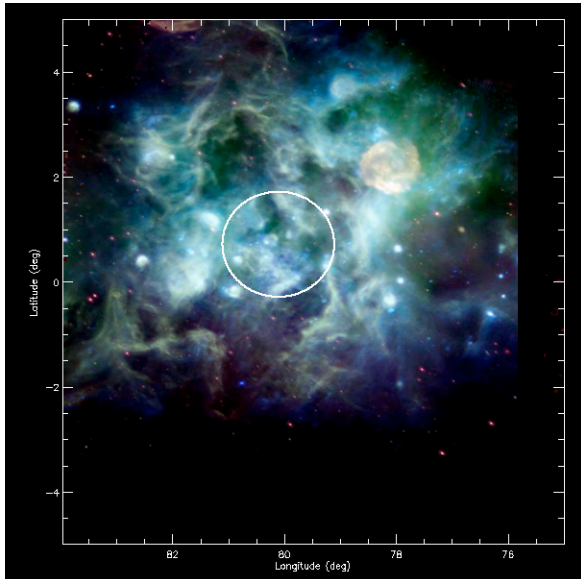
Calibrating stellar models



1809 keV γ-rays (COMPTEL)



Infrared (IRAS)

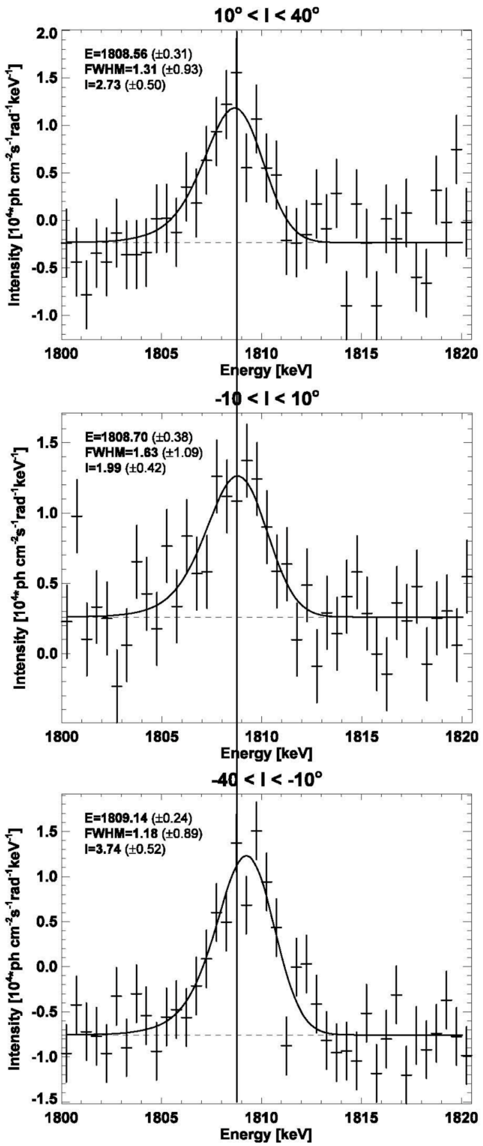


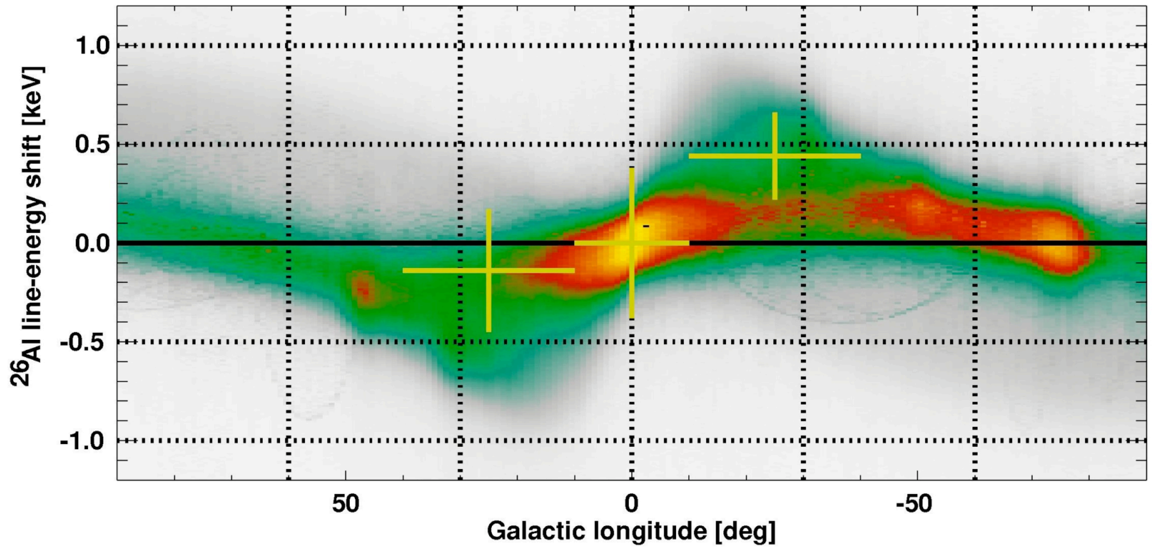
Radio (DRAO)

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





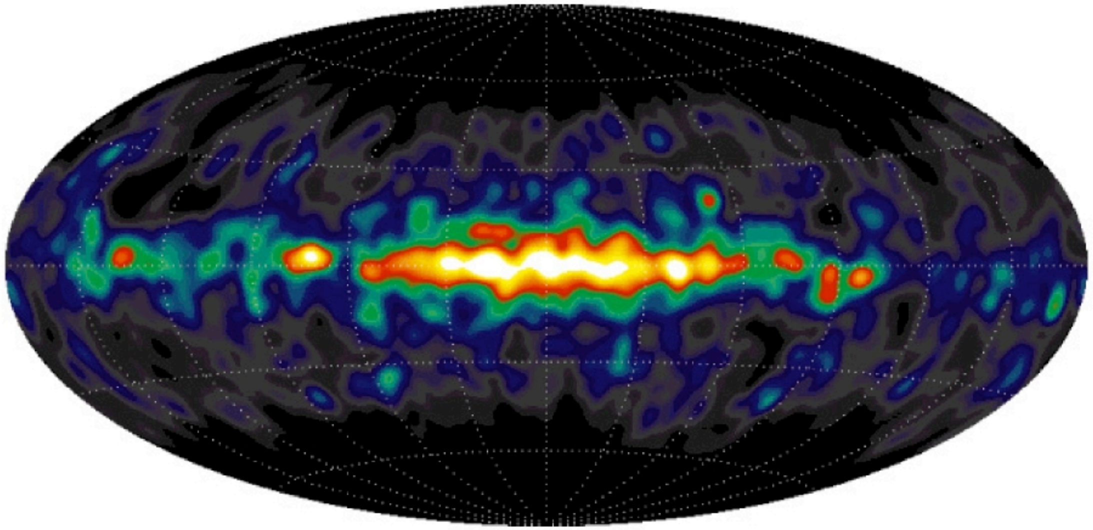
^{26}Al kinematics

- 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}**

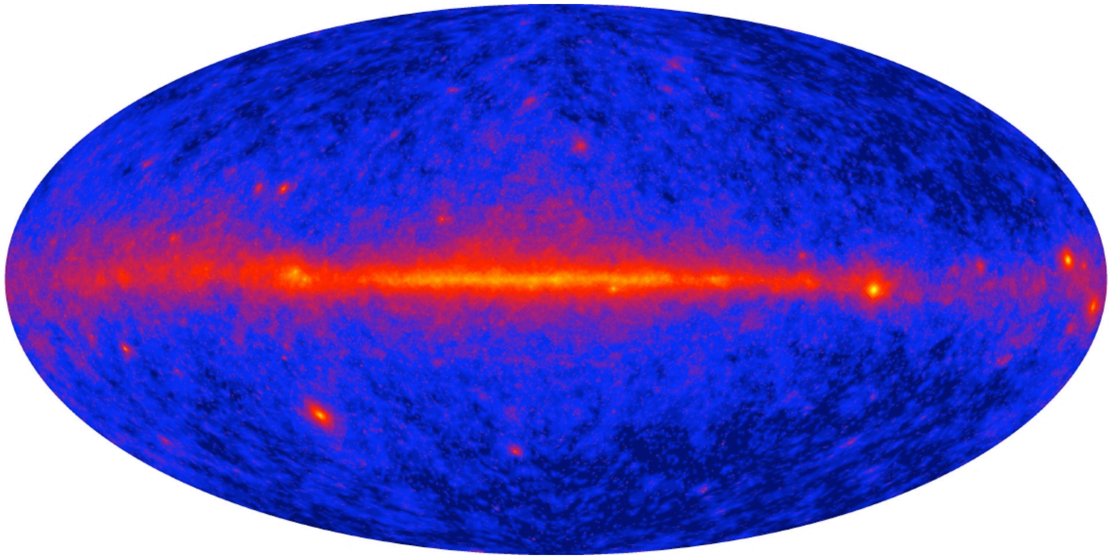
INTEGRAL spectra (Diehl et al. 2006)

Diffuse MeV and GeV Gamma-Ray emission

COMPTEL 1-30 MeV



LAT > 100 MeV

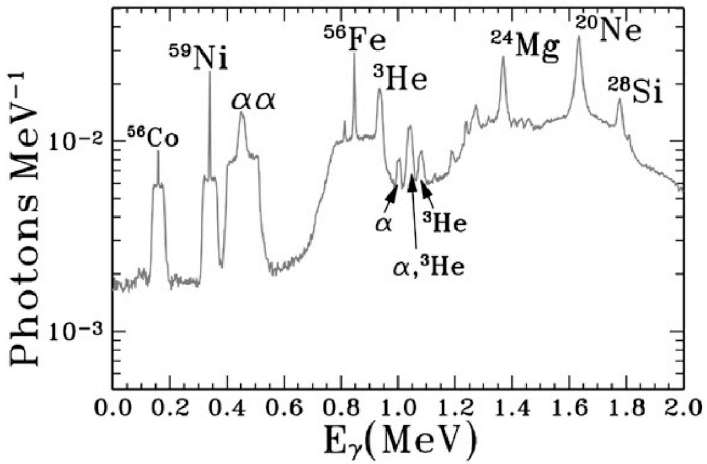


Point sources

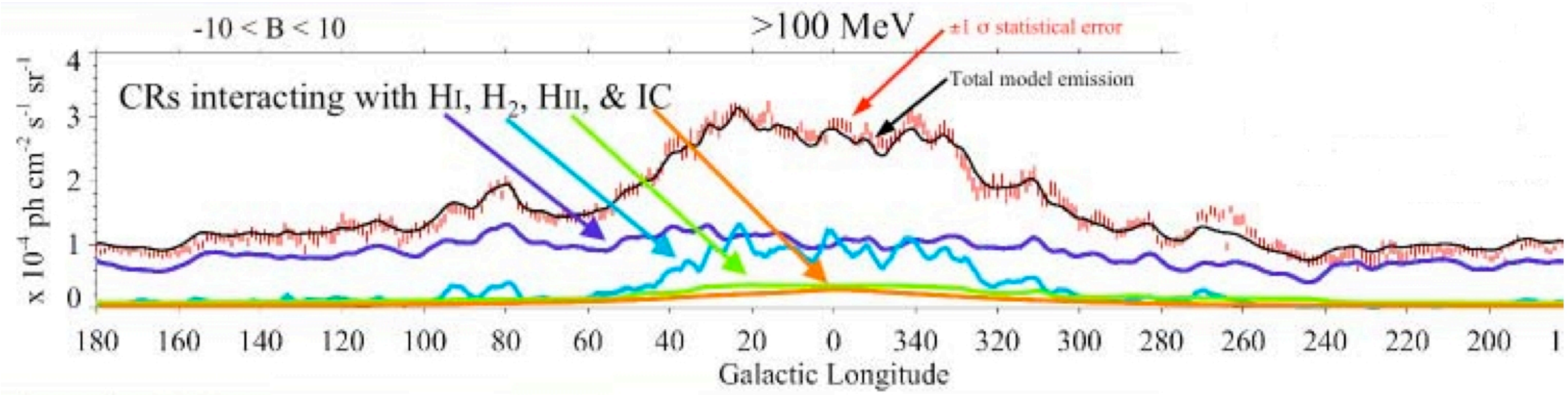
- Pulsars and PWN
- Supernova remnants
- Gamma-ray binaries
- Globular clusters
- AGN (extragalactic)
- unidentified sources

Diffuse emission processes

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



Spatial correlation between gaz and γ-rays



Observations (EGRET):

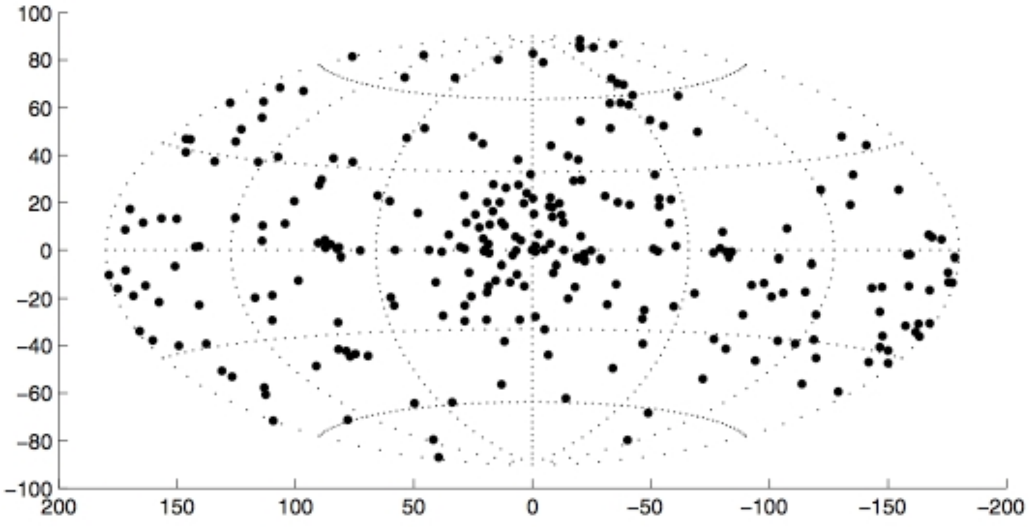
- large scale spatial distribution well modelled by combination of ISM phases (assuming $I \propto \rho^2$)
- fraction of unresolved point sources is small (unless distributed like the interstellar gas)
- spectrum does not vary (within relatively small uncertainties) in the Galaxy
- deviations from perfect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

Implications:

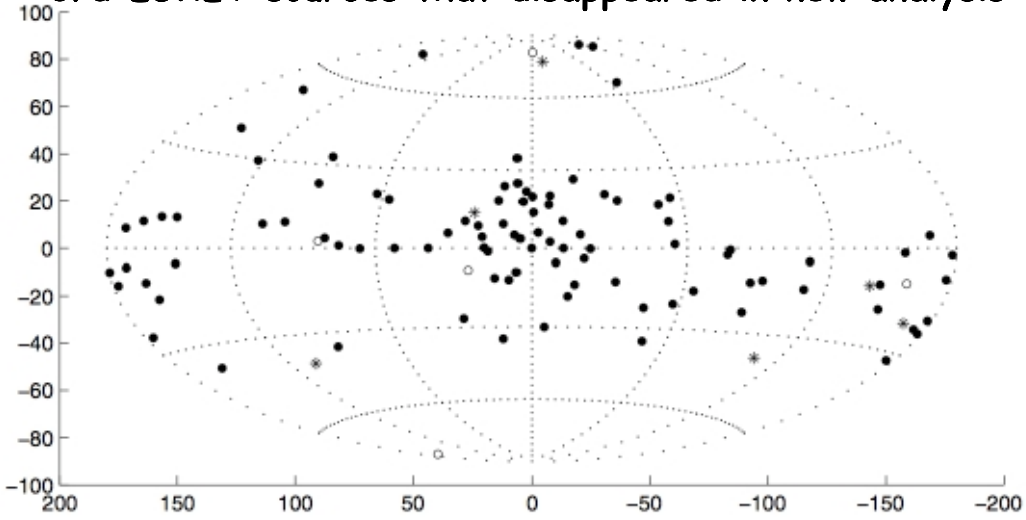
- Gamma-Rays probe galactic CR and ISM distributions
- CR electron-to-proton ratio roughly constant throughout Galaxy
- assumption of dynamic balance ($I \propto \rho^2$) between ISM and CR is reasonably correct (large matter density implies larger magnetic fields, allowing for larger CR energy density)

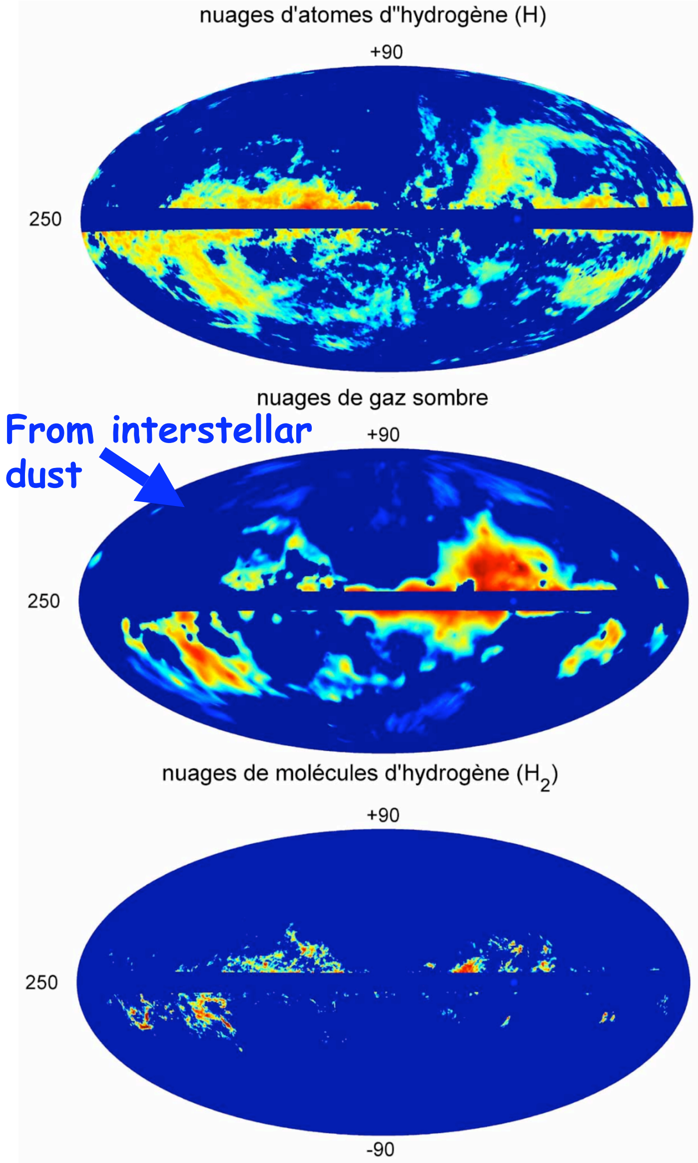
Hidden gas

3rd EGRET point source catalogue



3rd EGRET sources that disappeared in new analysis





(Grenier et al. 2005; Casandjian et al. 2008)

Spectral modelling: GALPROP

π^0

$$I(l,b,E)=\iint \rho_{CR_p}(E',s)\,q_{\pi^0}(E,E')\,\rho_{ISM}(s)\,dE'ds\;+$$

$$\iint \rho_{CR_e}(E',s)\left[q_B(E,E')\,\rho_{ISM}(s)+q_{IC}(E,E')\,\rho_{ISRF}(s,E')\right]dE'ds$$

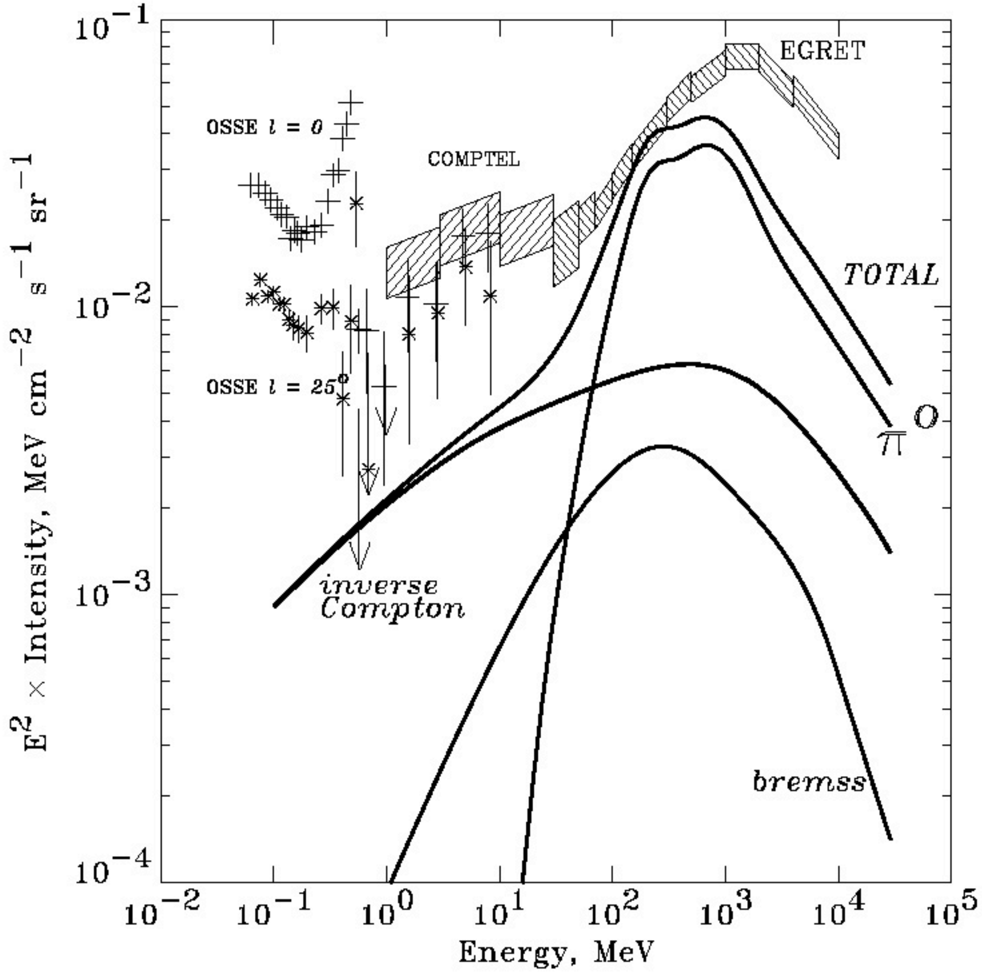
Bremsstrahlung **Inverse Compton**

Code features

- CR primary source distribution from models of SN distribution in Milky Way
- Assumed galactic magnetic field consistent with radio synchroton observations
- Computes CR secondaries and tertiaries (~90 species)
- Computes CR propagation
- Results satisfy radio synchrotron observations, B/C ratio, local CR protons and electron spectra
- uses 3D ISM model and ISRF for computation of gamma-ray emissions

(Strong et al. 2000)

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**

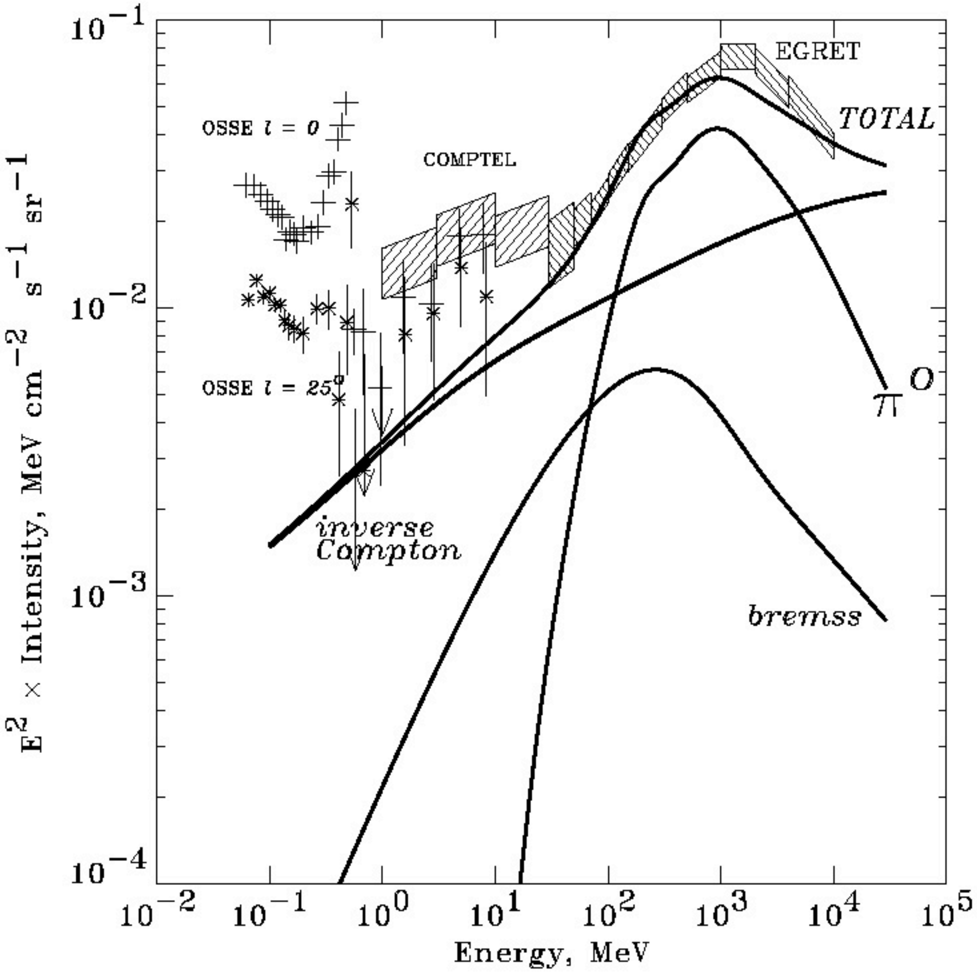
Electron spectrum

- $E^{-1.6}$: 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)**

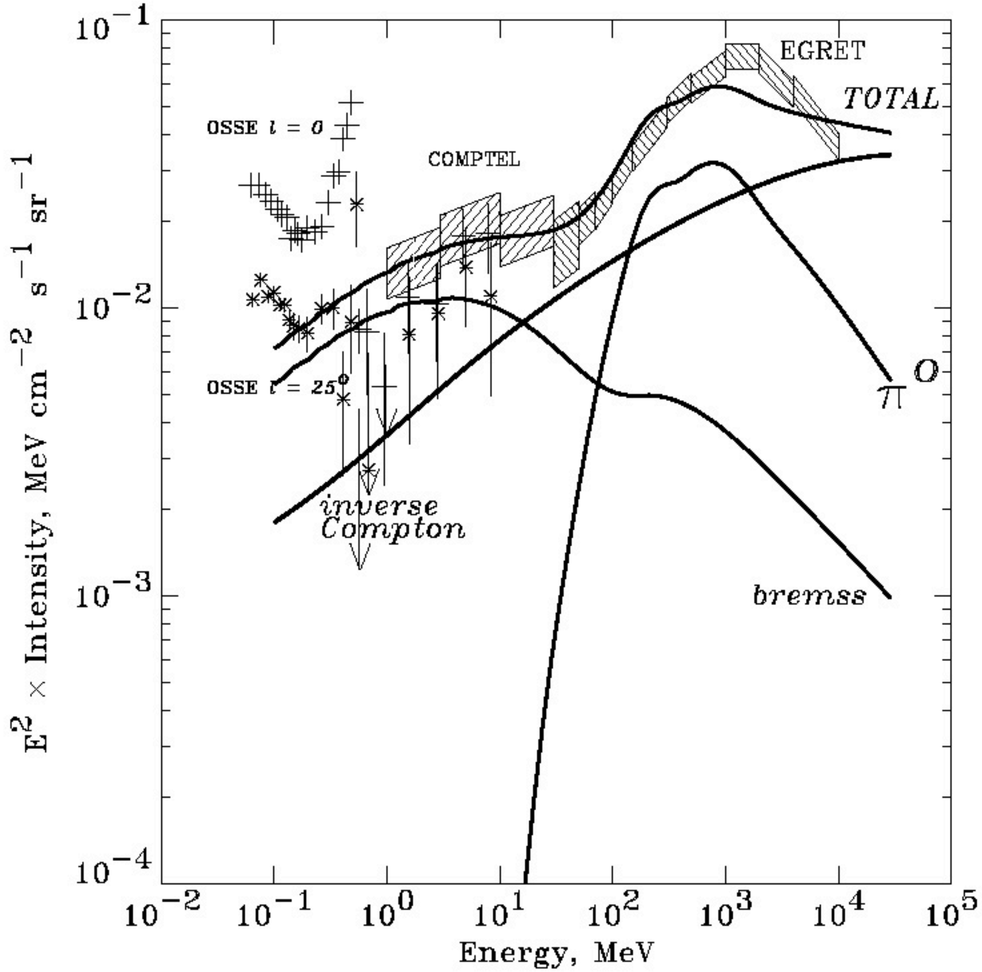
Electron spectrum

- $E^{-1.8}$ (harder than 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 than 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)**

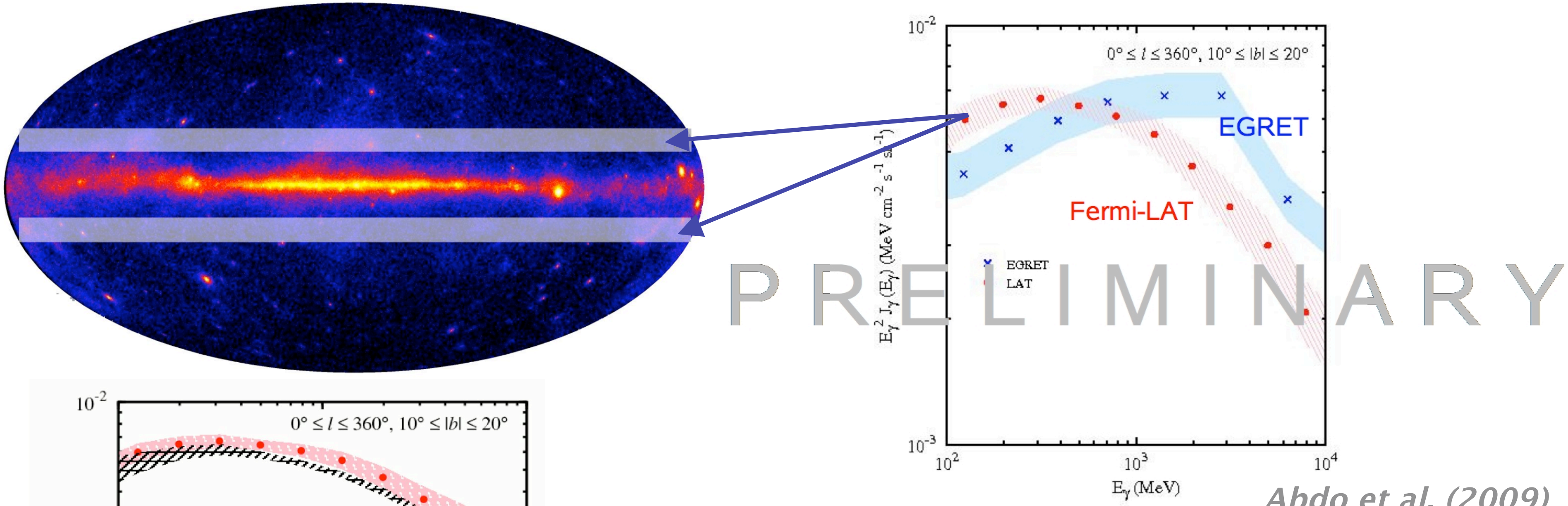
Electron spectrum

- $E^{-3.2}$: E < 200 MeV (steeper than 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)

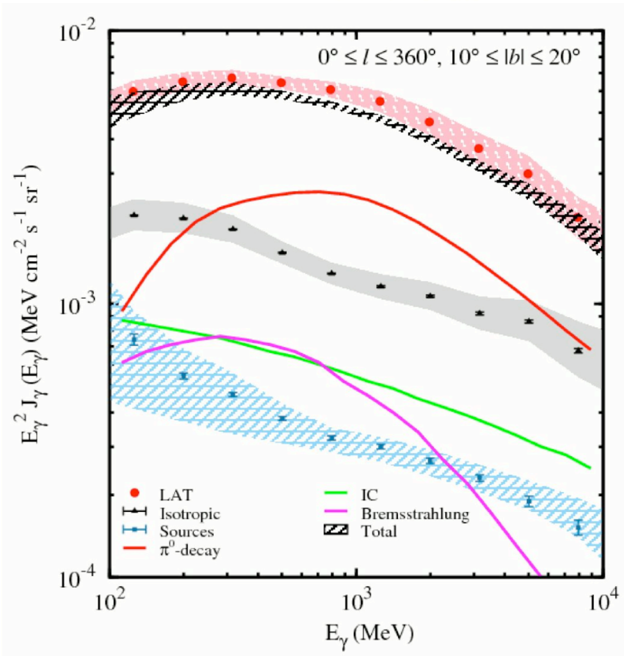
Proton spectrum

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

Fermi: no GeV excess anymore



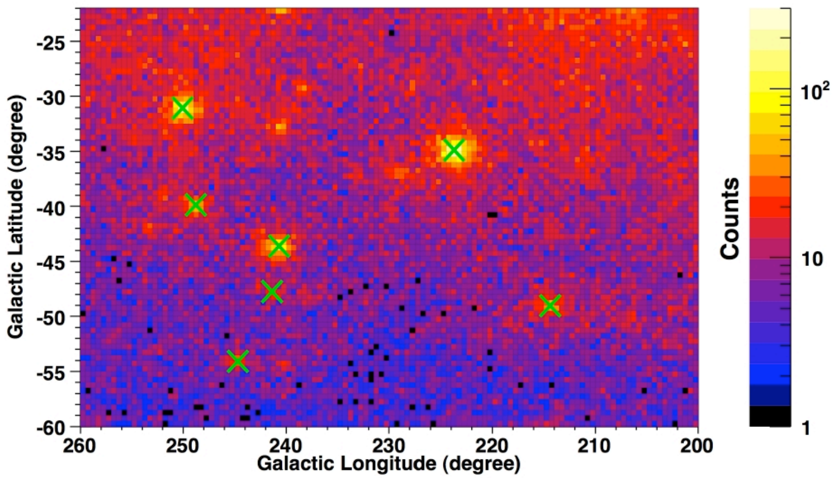
Abdo et al. (2009)
ApJ, submitted



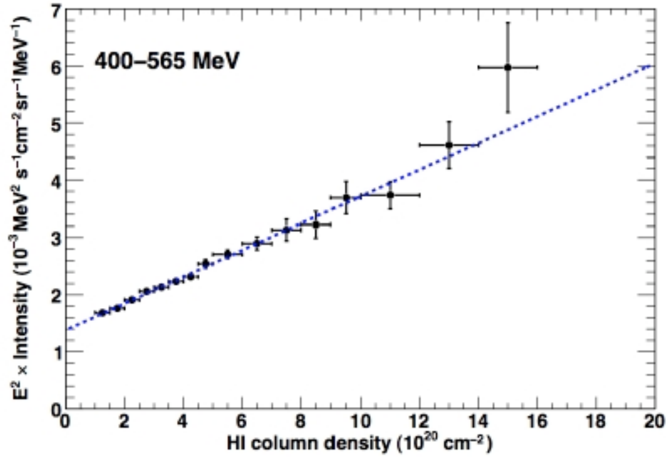
- Source contribution minor w/r diffuse
- LAT error are systematics dominated and estimated to ~10%
- Work to understand the diffuse emission over the entire sky and broader energy range is in progress

Fermi: measuring the local CR spectrum

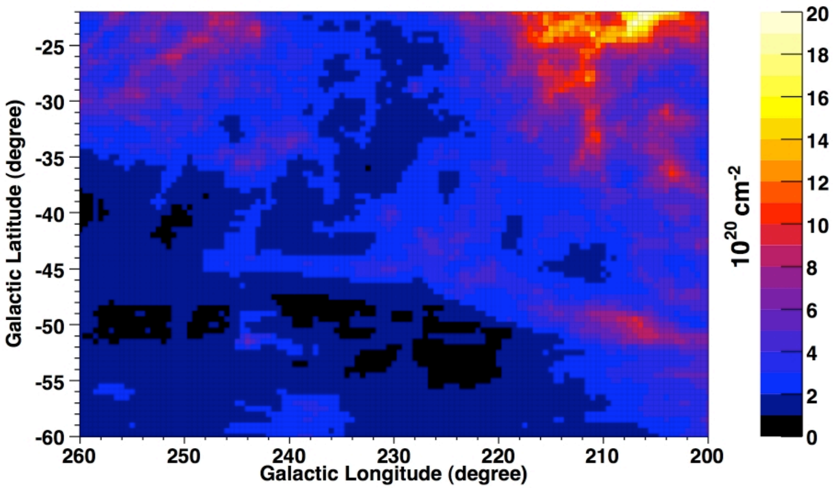
Fermi high-latitude counts map



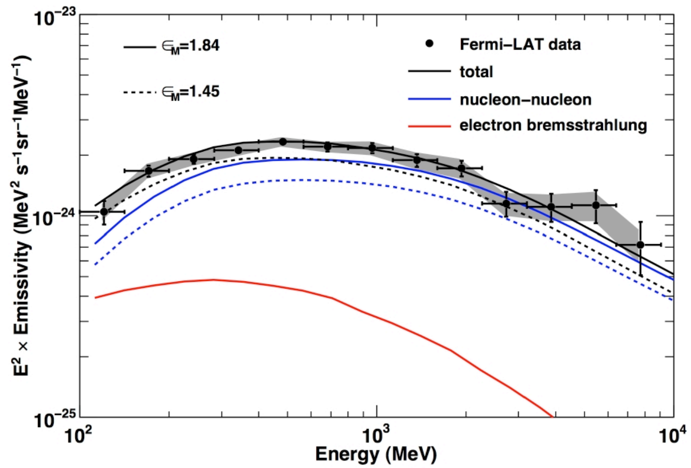
Diffuse gamma-ray flux versus HI column density



Atomic hydrogen column density map

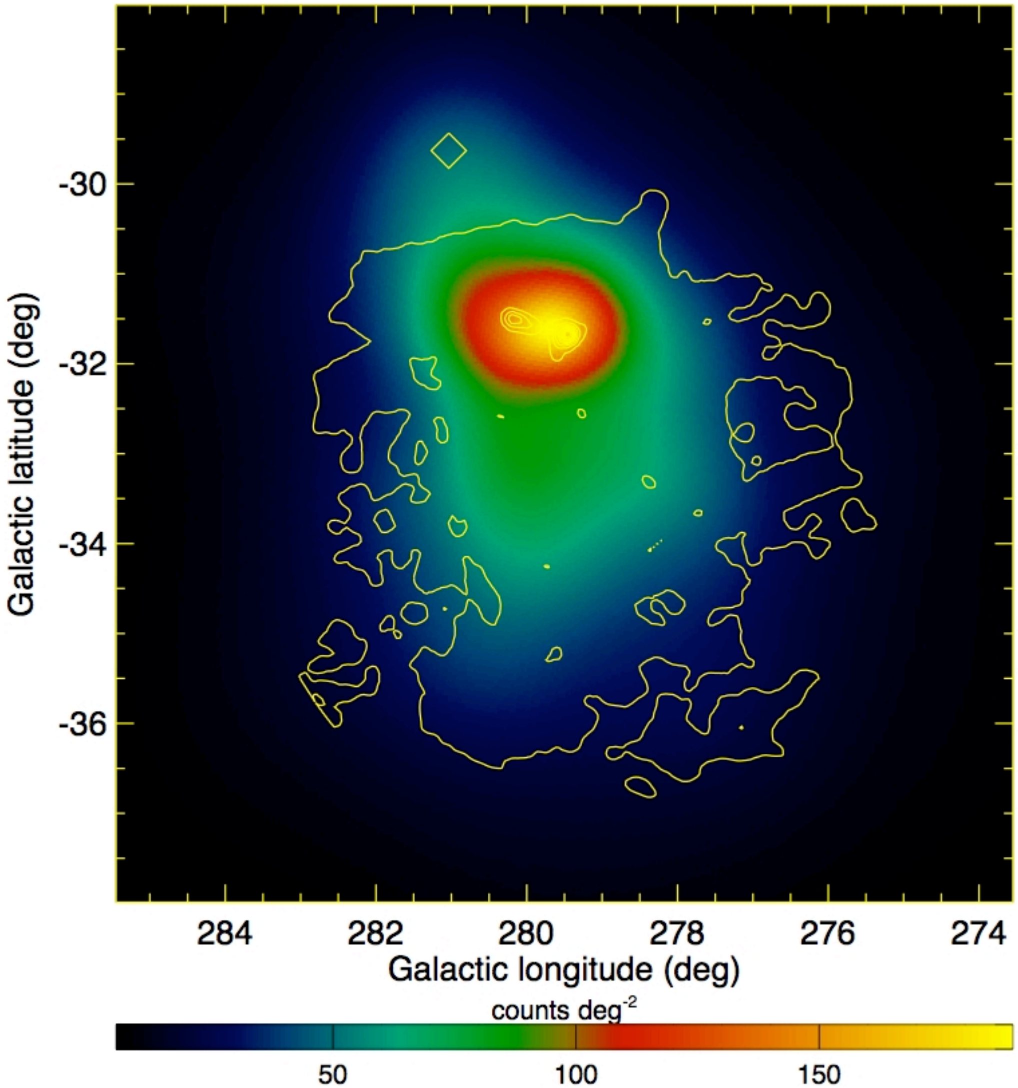


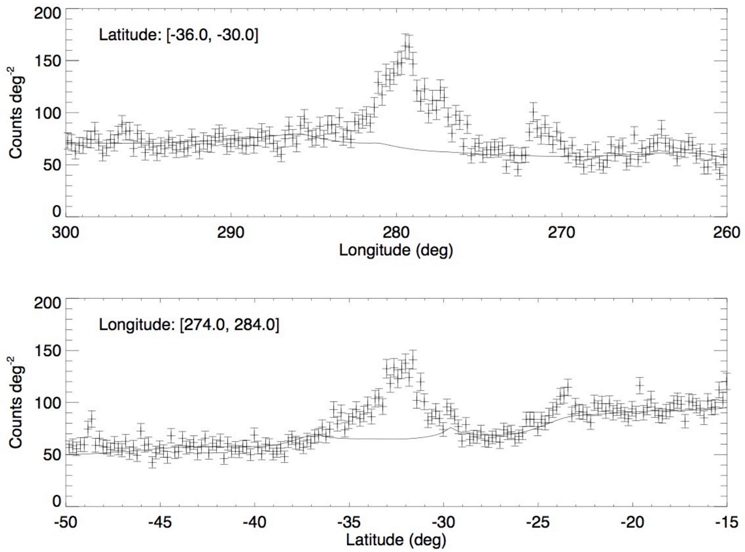
Gamma-ray emissivity per H-atom



Abdo et al. (2009)
ApJ, in press
(astro-ph/0908.1171)

Fermi: diffuse galactic emission in LMC

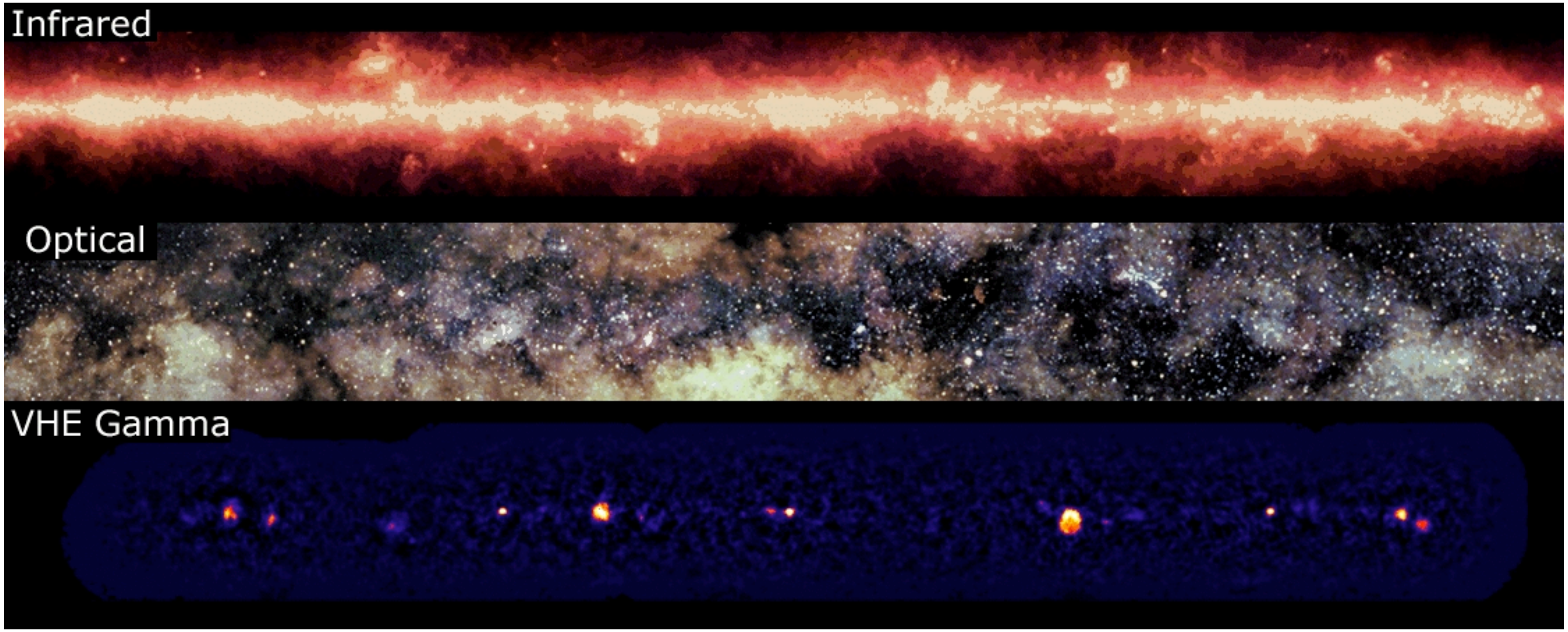




- Fermi clearly resolves the LMC
- Gamma-ray emission maximum near 30 Doradus
- Cosmic-ray interactions?
- Point source contributions?

Knödlseder (2009)
Jaén conference
astro-ph/0905.2498

The first VHE survey of the Galaxy

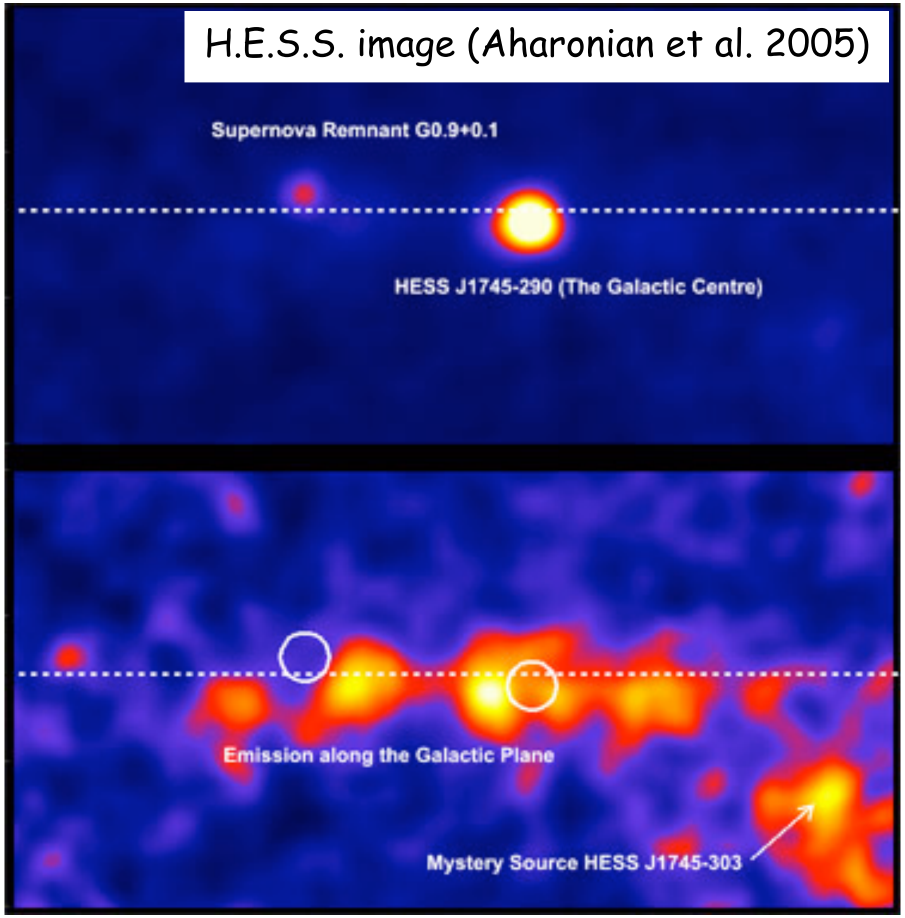


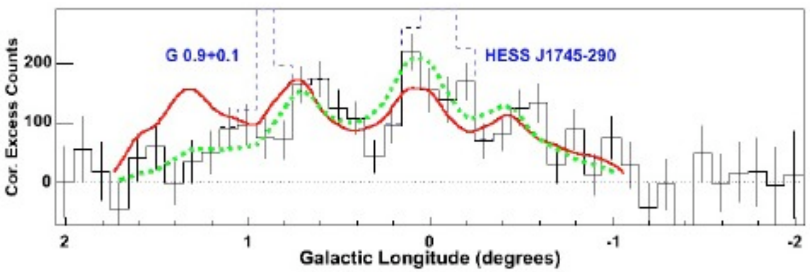
H.E.S.S. image (Aharonian et al. 2005)

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



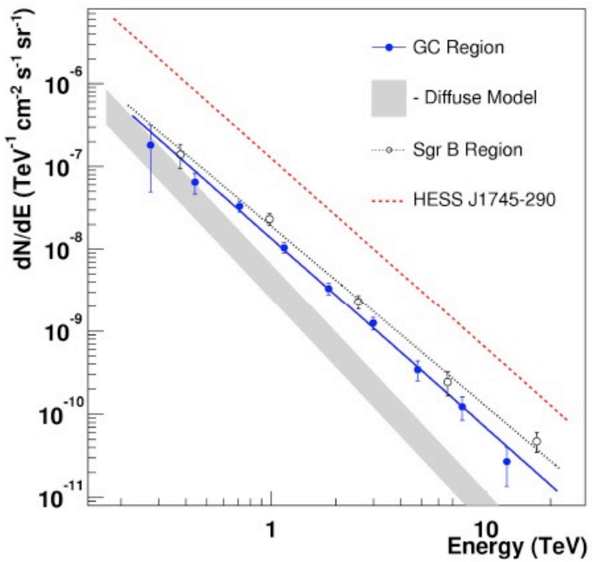


H.E.S.S. discovery of diffuse emission

- 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

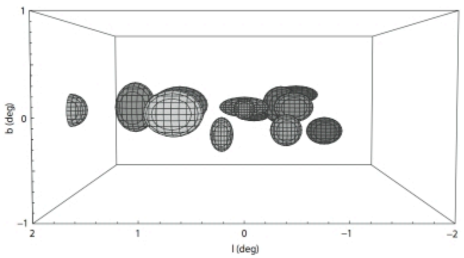
- π^0 decay following CR interaction with ISM
- Flux higher and harder than expected $\Rightarrow$ recent (~10,000 yr) CR acceleration at GC and diffusion

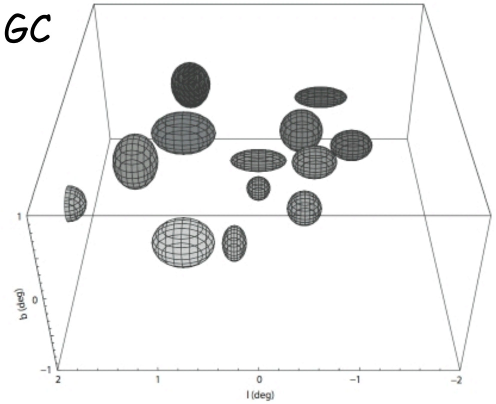


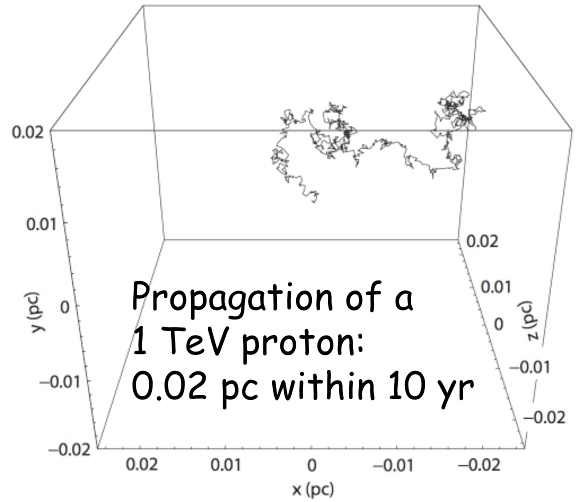
Source(s) of the VHE diffuse emission

Wommer et al. (2008)

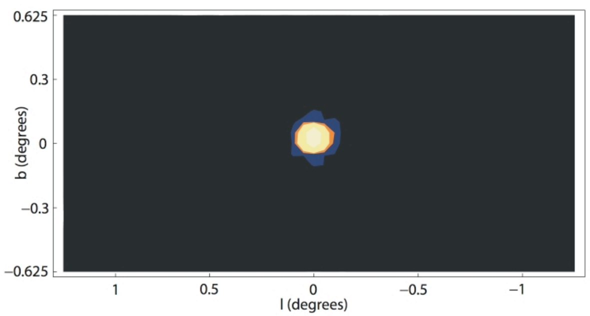
Gas distribution model near GC



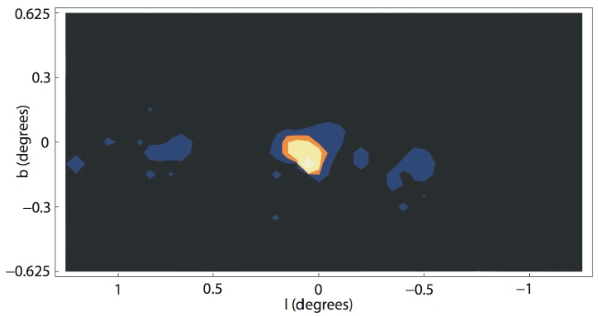




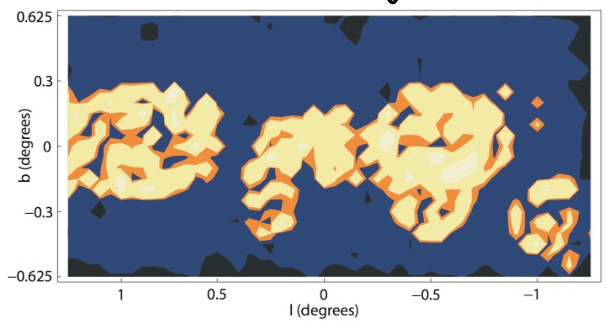
Sgr A* as only source



5 random sources

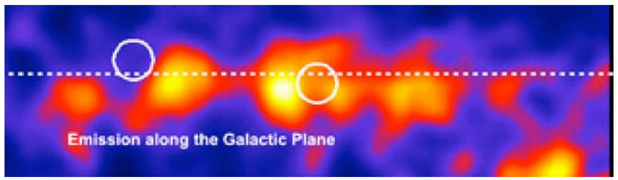


Diffuse CR injection

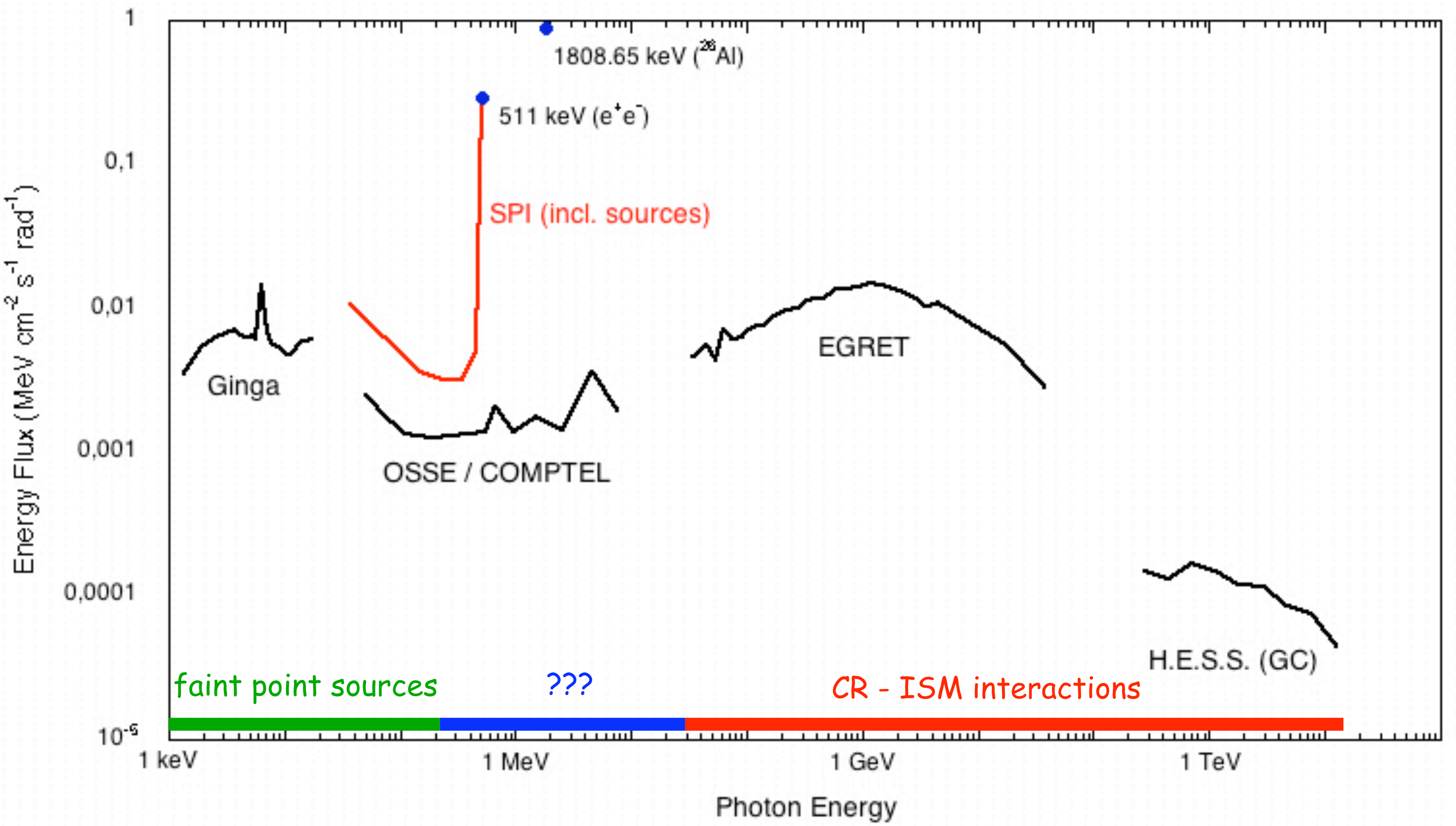


Conclusions

- TeV proton apparent diffusion length near GC ~ 0.1 deg (20 pc within 10000 yr)
- Extended diffuse emission only reproduced for diffuse CR injection in intercloud medium



The nature of galactic X-/γ-ray emission



Summary

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

- theoretically, diffuse emission is difficult to understand (pressure, gravitational binding)
- observationally, 80% of the emission has now been resolved into individual point source
- spatial distribution and spectrum consistent with **population of accreting white dwarfs and coronally active stars**

Soft γ-ray regime (200 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 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? Bremsstrahlung?)

GeV domain (30 MeV < E < 30 GeV)

- **diffuse emission** explained by CR interaction with ISM
- gamma-ray morphology well explained by interstellar gas distributions (evidence for dark gas)

TeV domain (E > 30 GeV)

- individual point sources identified (SNRs, pulsars)
- **diffuse emission** component correlates with molecular clouds, sources?
- large-scale picture still missing