Diffuse Galactic Continuum Interstellar and Source Components

A. Strong, MPE

INTEGRAL 5 Years, Sardinia, October 2007

With lots of help from

Igor Moskalenko (SLAC/Stanford)

Troy Porter (UCSC)

Laurent Bouchet (Toulouse)

Covered in next talks in this session :

Revnivtsev: IBIS diffuse analysis, source component < 100 keV

Bouchet: SPI source + diffuse analysis 20 keV – 1 MeV

I will concentrate on wide-band 'non-thermal' aspect 100 keV - GeV
mainly on interstellar emission
+ source contributions

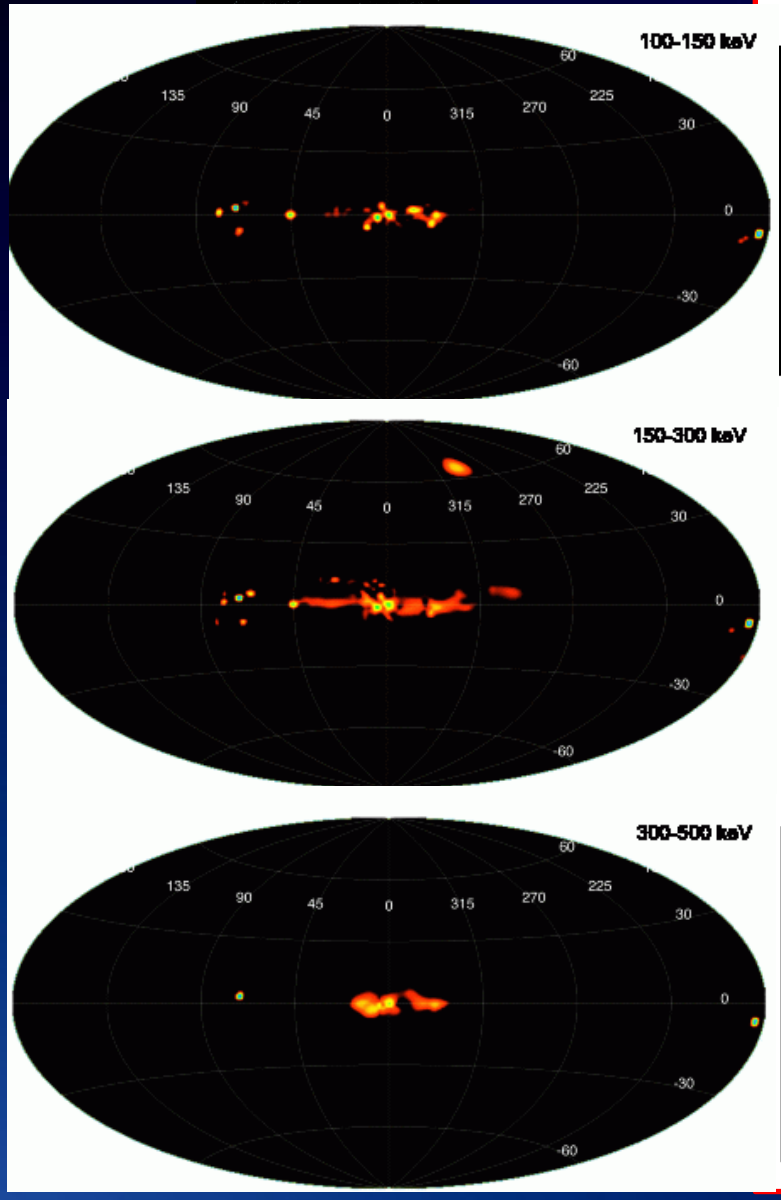
other topics in this session, not covered here :
Galactic Centre (Belanger, Trap)
Ridge Fe line: Suzaku (Ebisawa)

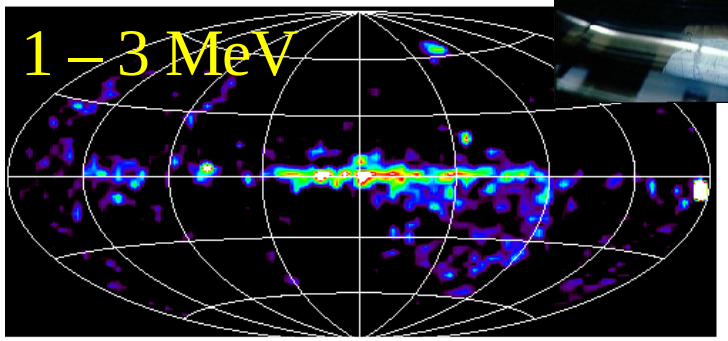
The story so far .....

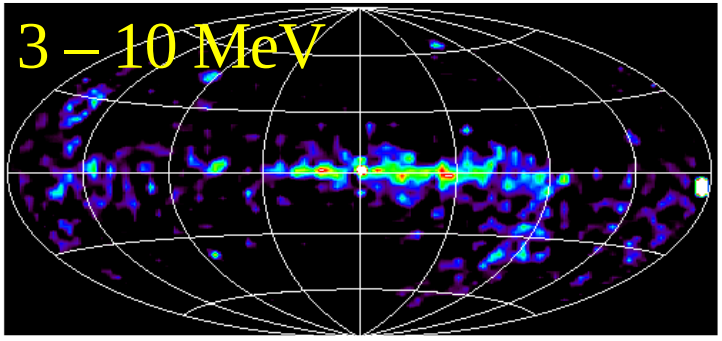
INTEGRAL / SPI

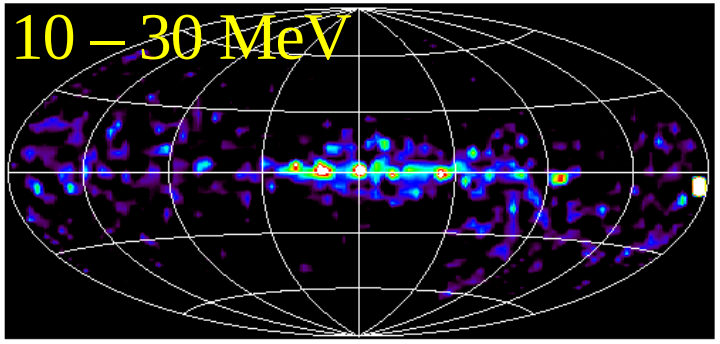
CGRO / COMPTEL

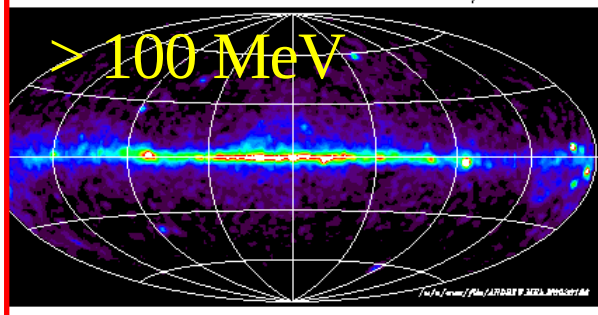
CGRO / EGRET









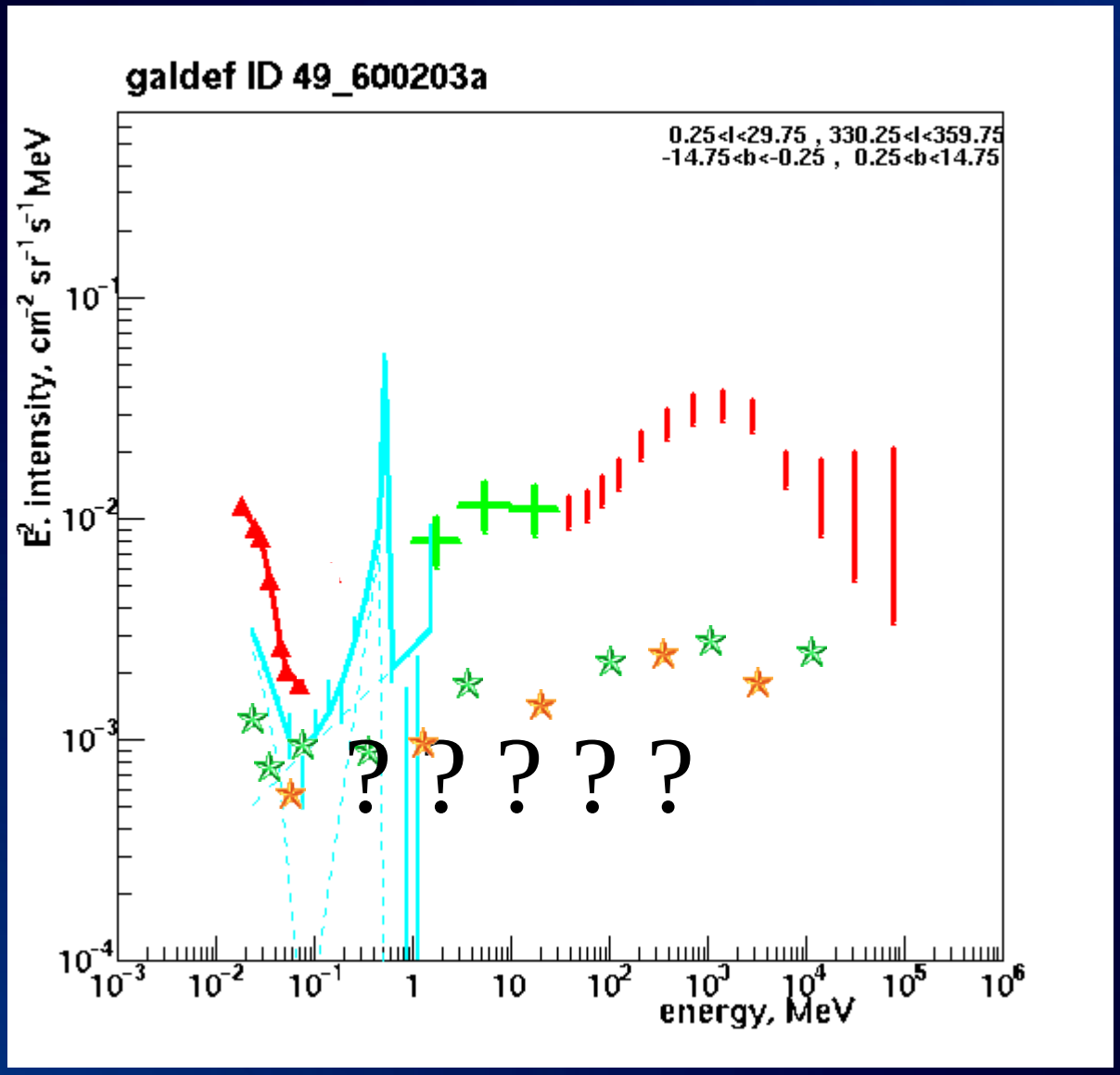


Knödlseder et al. 2007

Strong et al. 1999

Spectrum of Galactic ridge

plenty of interesting structure : lots of information



mix of interstellar + source populations: *but how much of each* ?

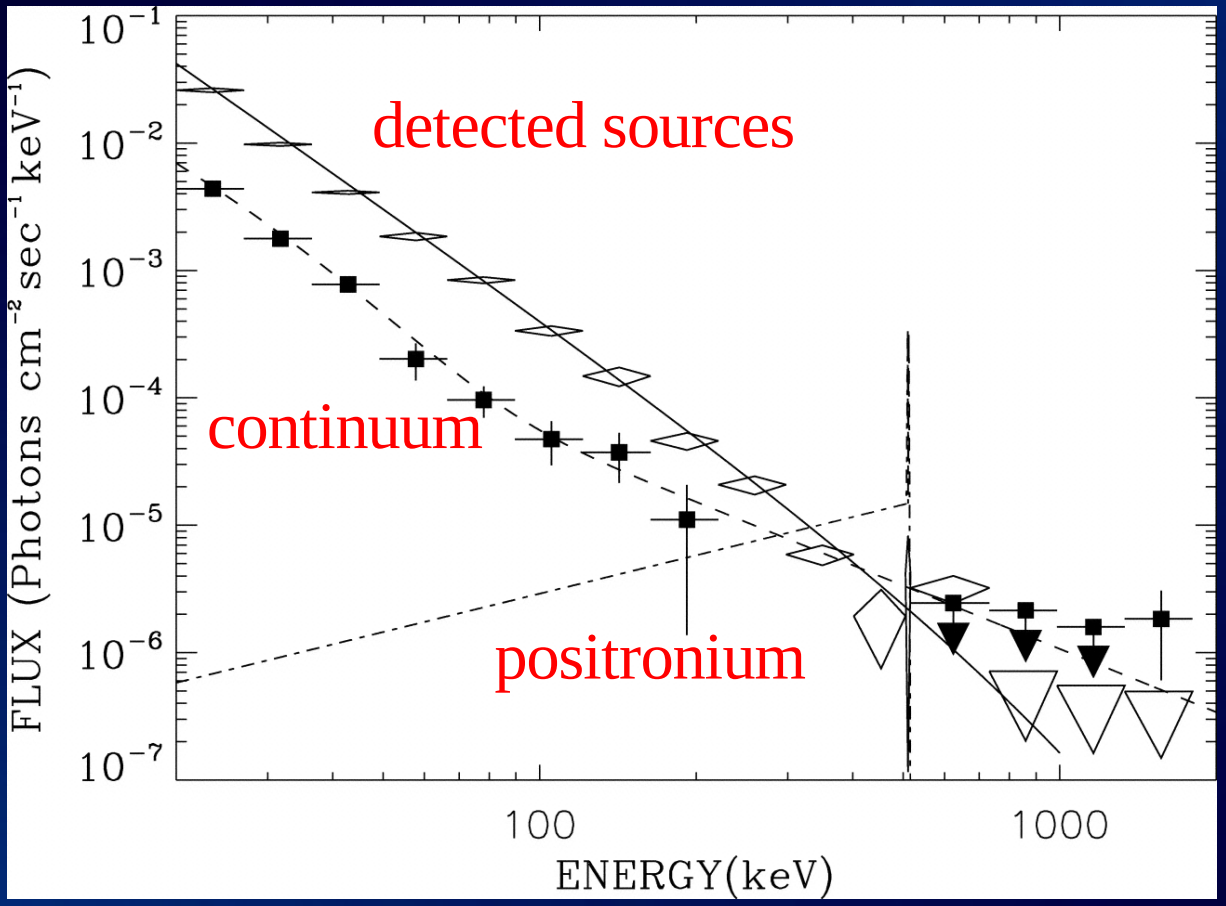
Analyses of the diffuse Galactic continuum

SPI:
Bouchet et al. 2005: *model fitting*
Strong et al. 2005: *model fitting*
Knödlseder et al. 2007: *imaging: total emission only*
Bouchet et al. 2007 model fitting <<<<< NEW

IBIS:
Lebrun et al. 2004: first results – much of 'OSSE diffuse' resolved into sources
Terrier et al. 2004: *model fitting (early results)*
Revnivtsev et al. 2005, Sazonov et al. 2006,Krivonos et al. 2007:
spectrum to 17- 60 keV, *source origin*

in addition for 2 -10 keV at high angular resolution:
Ebisawa et al 2001 (Chandra), Hands et al 2004 (XMM): *interstellar origin*
NEW: Revnivtsev et al. 2007 A&A 473, 857 (Chandra): resolved into sources

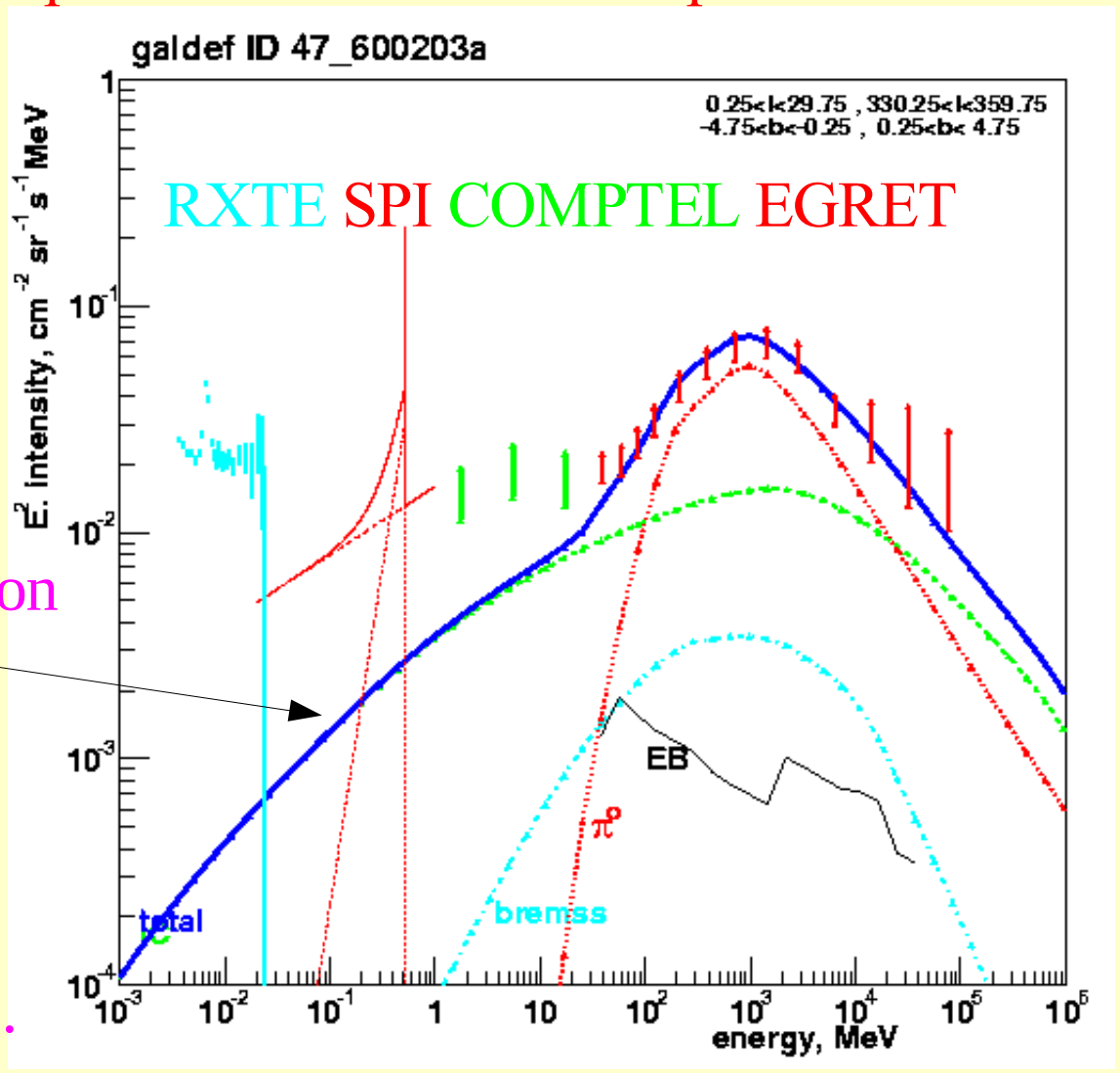
Bouchet et al. 2005



$-50^{o} < l < 50^{o}$, $-25^{o} < b < 25^{o}$

Strong et al. 2005

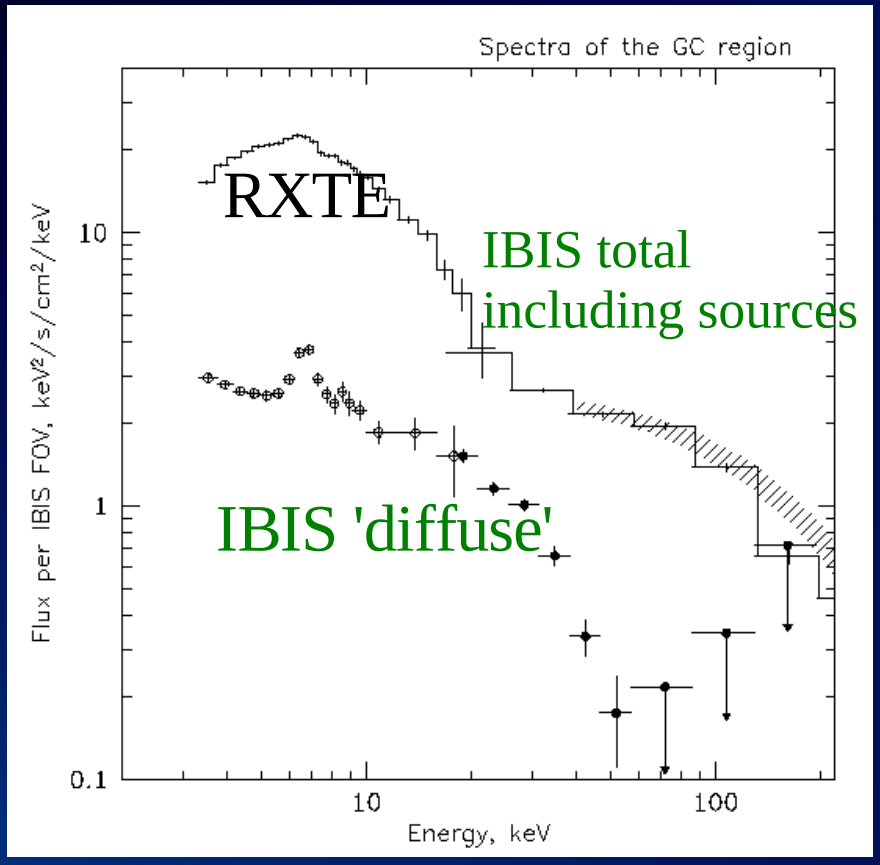
Broadband spectrum of Galactic diffuse emission compared to known emission processes

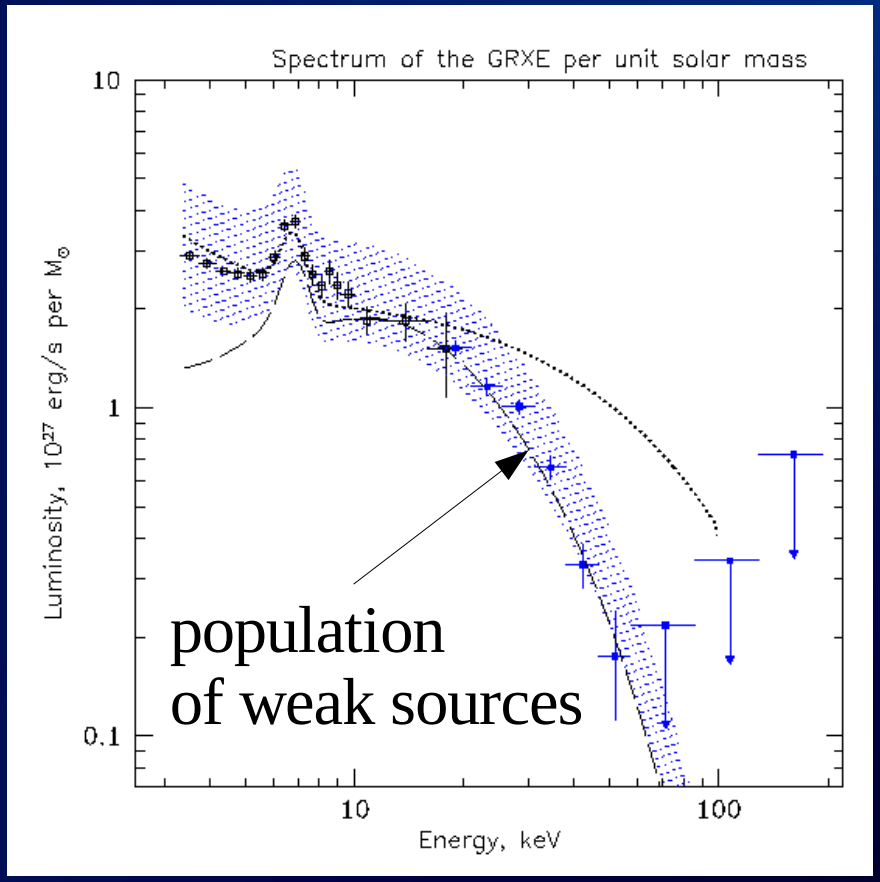


' Inverse Compton cannot explain E < 1 MeV '

but maybe this conclusion was too hasty ....

IBIS: Krivonos et al. 2007





inner Galaxy as seen by an instrument with IBIS FOV, with diffuse traced by 4.9μ DIRBE map

ridge emission < 50 keV is mainly magnetic CV's and coronally active stars

Diffuse ridge emission 50 keV - 1 MeV

explanations were *ad hoc* invented to explain the observations

usually considered *bremsstrahlung* since *inverse Compton* seemed too small

the *bremsstrahlung* 'energy problem':
MeV electrons lose energy too fast via Coulomb losses
requires more than entire SN energy input to low-energy CR electrons !

examples of 'solutions' :

electrons continuously accelerated in SNR or interstellar turbulence (Valinia et al 2000)
in-situ electron acceleration (Dogiel et al 2002)
electrostatic bremsstrahlung (Schroeder et al 2005)
point source populations (e.g. Strong 2006)

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but now we have a simple inevitable explanation

NEW:

SPI data and analysis: Bouchet et al. 2007

3 times as much SPI data,
better source and background handling
(see Laurent Bouchet's talk later in this session)

GALPROP model

intergalactic space

HALO

reacceleration

energy loss

decay

Secondary: ^{10}Be, ^{11}B ...

synchrotron

Secondary: e^+ p

cosmic-ray sources: p, He .. Ni, e^-

B

π^o

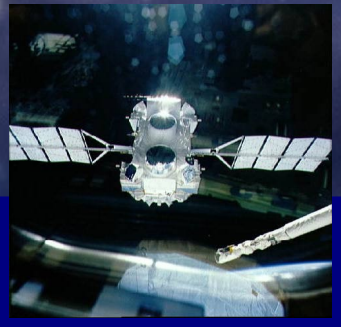
gas

ISRF

bremsstrahlung

inverse Compton

γ – rays



NEW:

theory updates (Igor Moskalenko, Troy Porter, AWS):

new interstellar radiation field

latest GALPROP cosmic-ray propagation/gamma-rays

http://galprop.stanford.edu

iit's mainly about cosmic-ray electrons & positrons !

radio, hard X-rays sensitive to GeV leptons

1 GeV + CMB, FIR => 10-100 keV

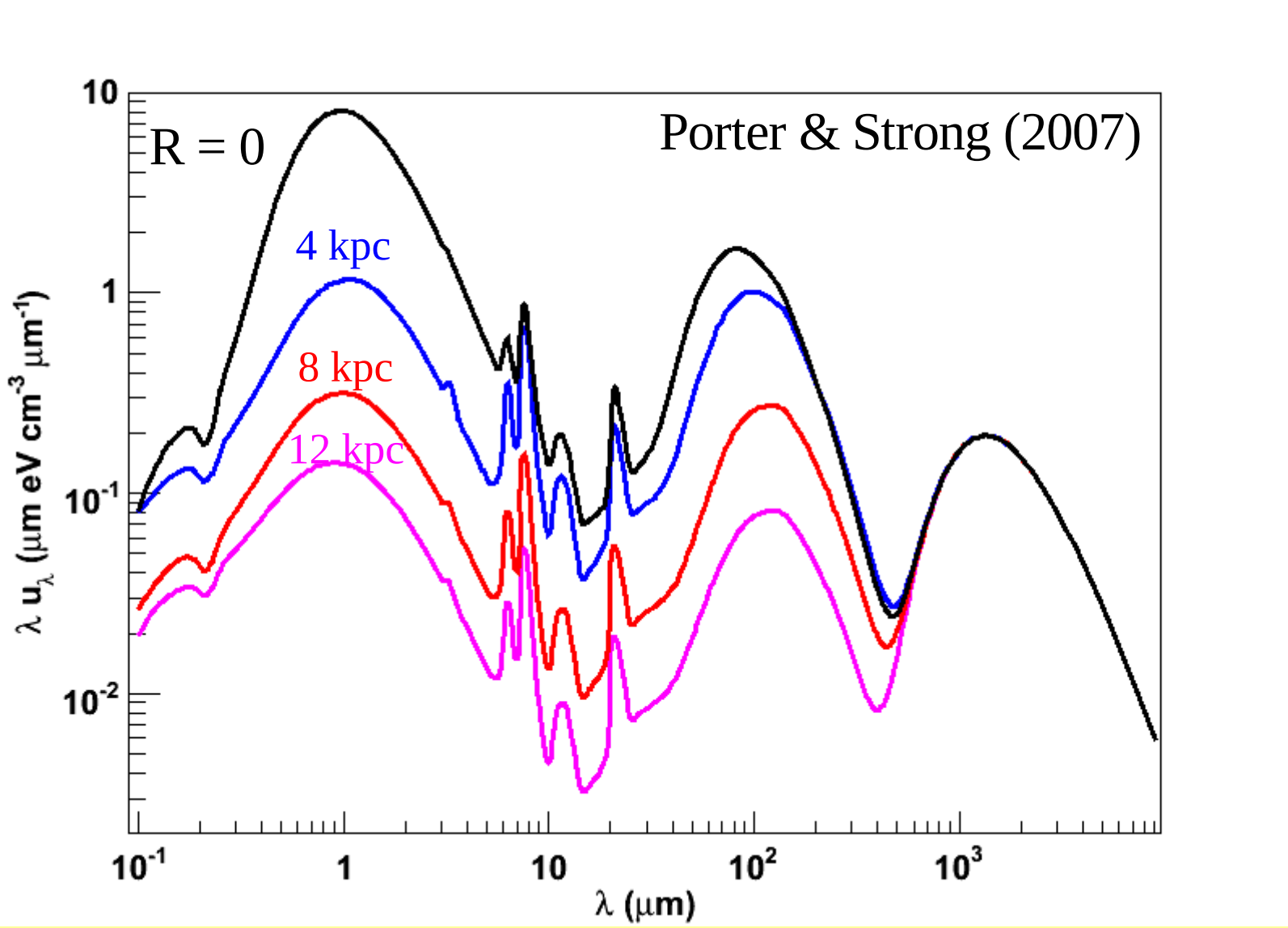
inverse Compton: $E \sim \gamma^2 \varepsilon$

1 GeV + starlight => MeV

1 GeV + 3μG => GHz synchrotron $\nu \sim \gamma^2 B$

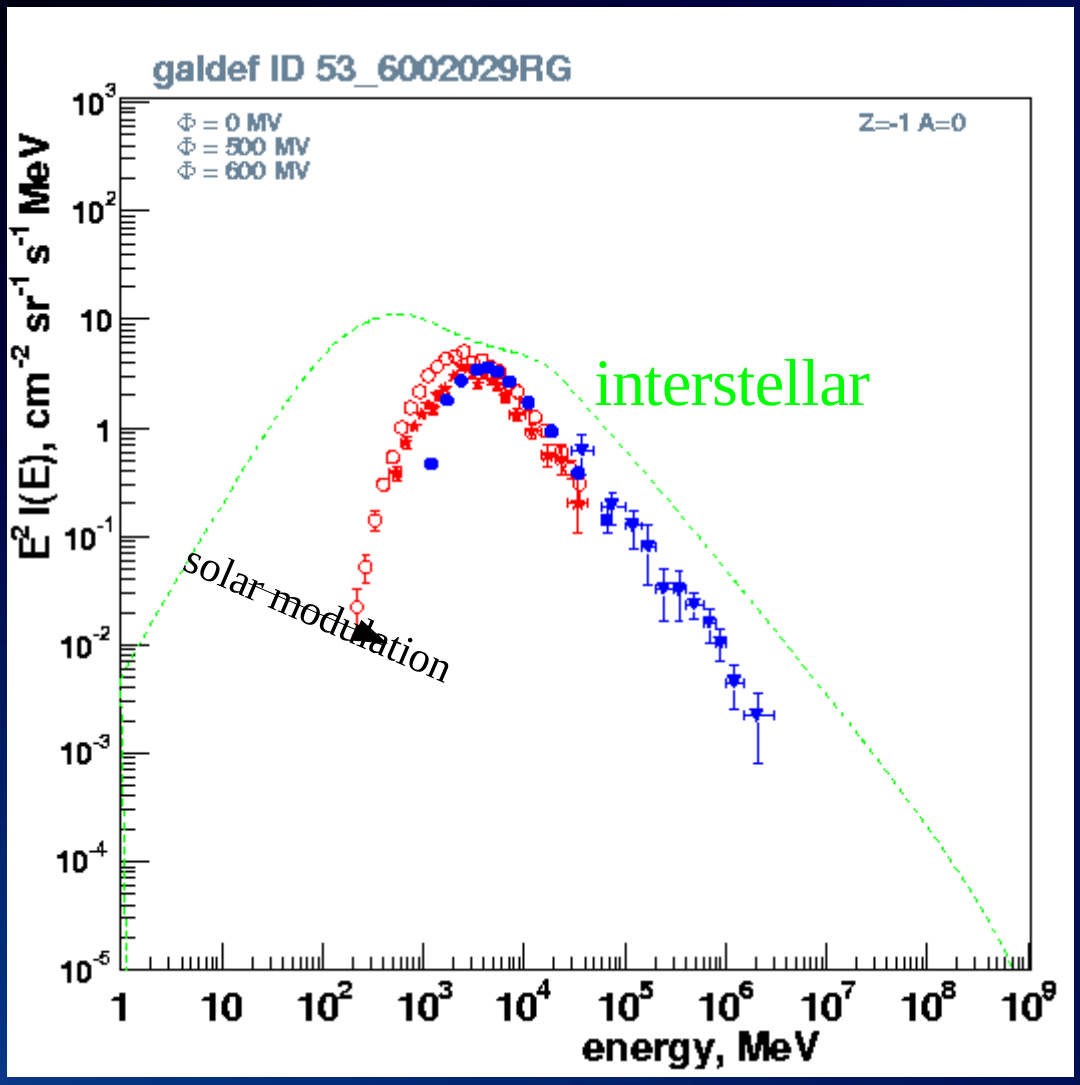
Interstellar Radiation Field (for electron dE/dt, inverse Compton γ-rays): new model *ApJ 640, L155, 2006 (Troy Porter)*

***New** ISRF using much new information e.g. IRAS, COBE, stellar populations, spectral libraries scattering.....*



UV optical IR FIR CMB

primary electrons

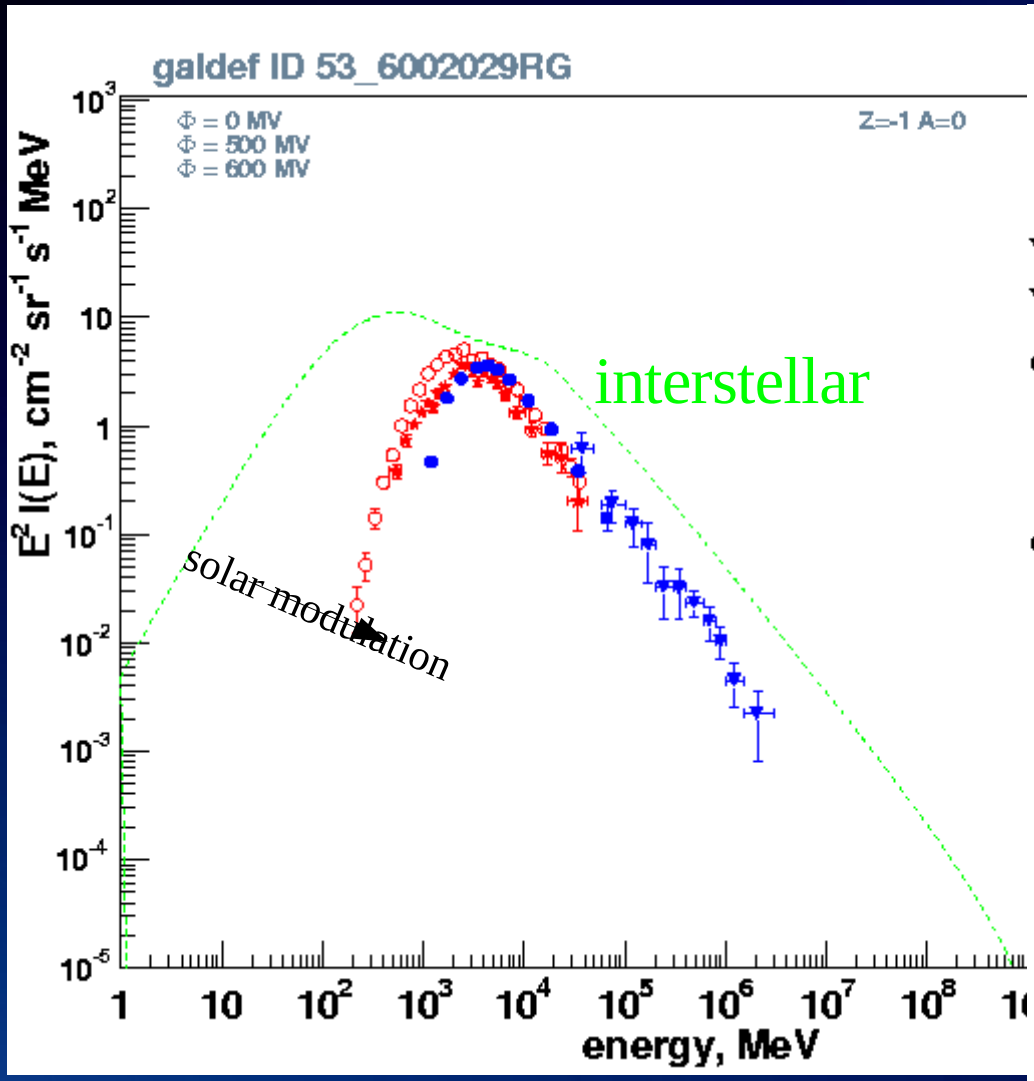


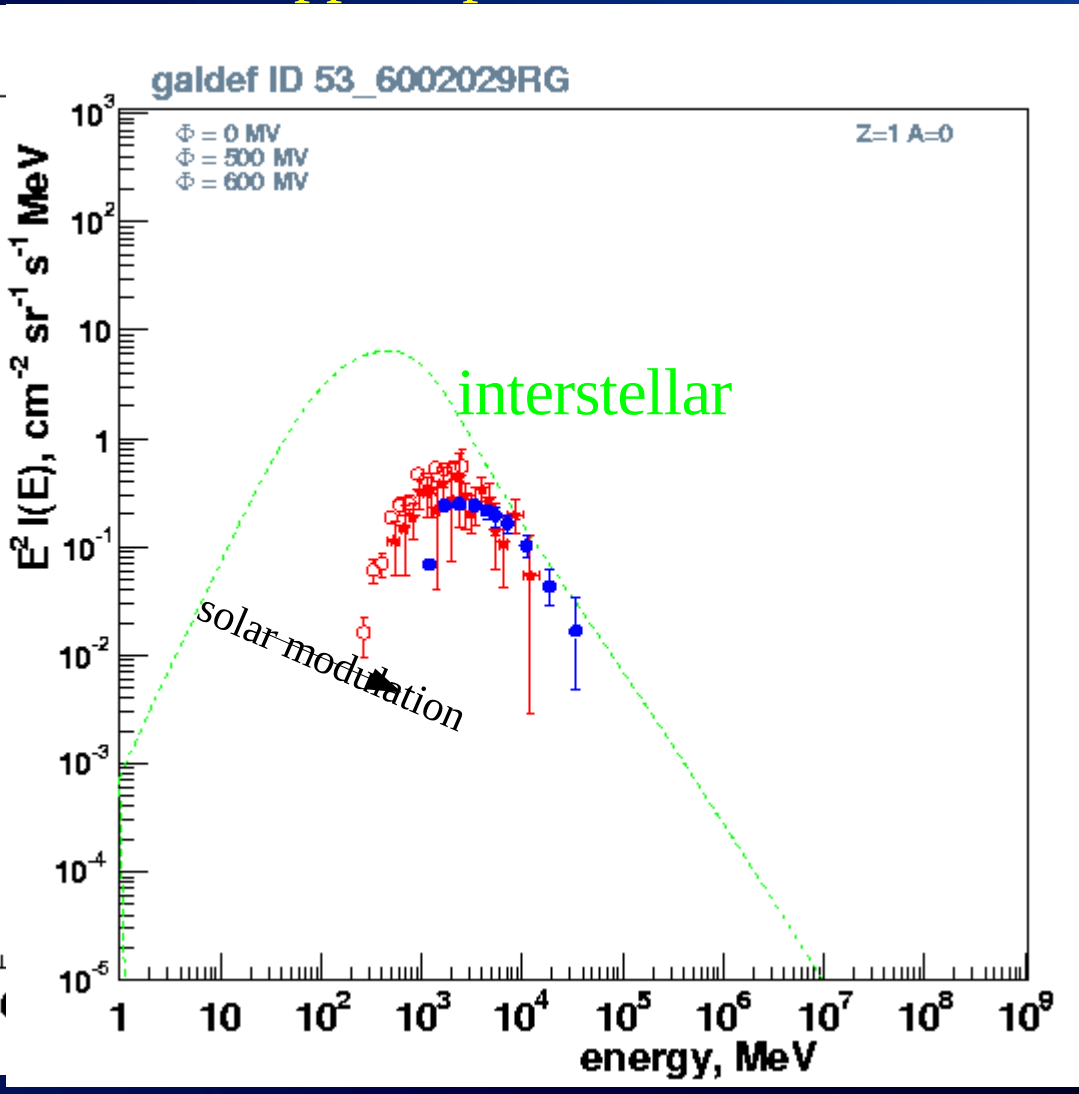
Moskalenko, Porter, Strong, Bouchet 2007 in preparation

primary electrons

secondary positrons

$pp \Rightarrow pn\pi^{+} \Rightarrow e^{+}\nu$





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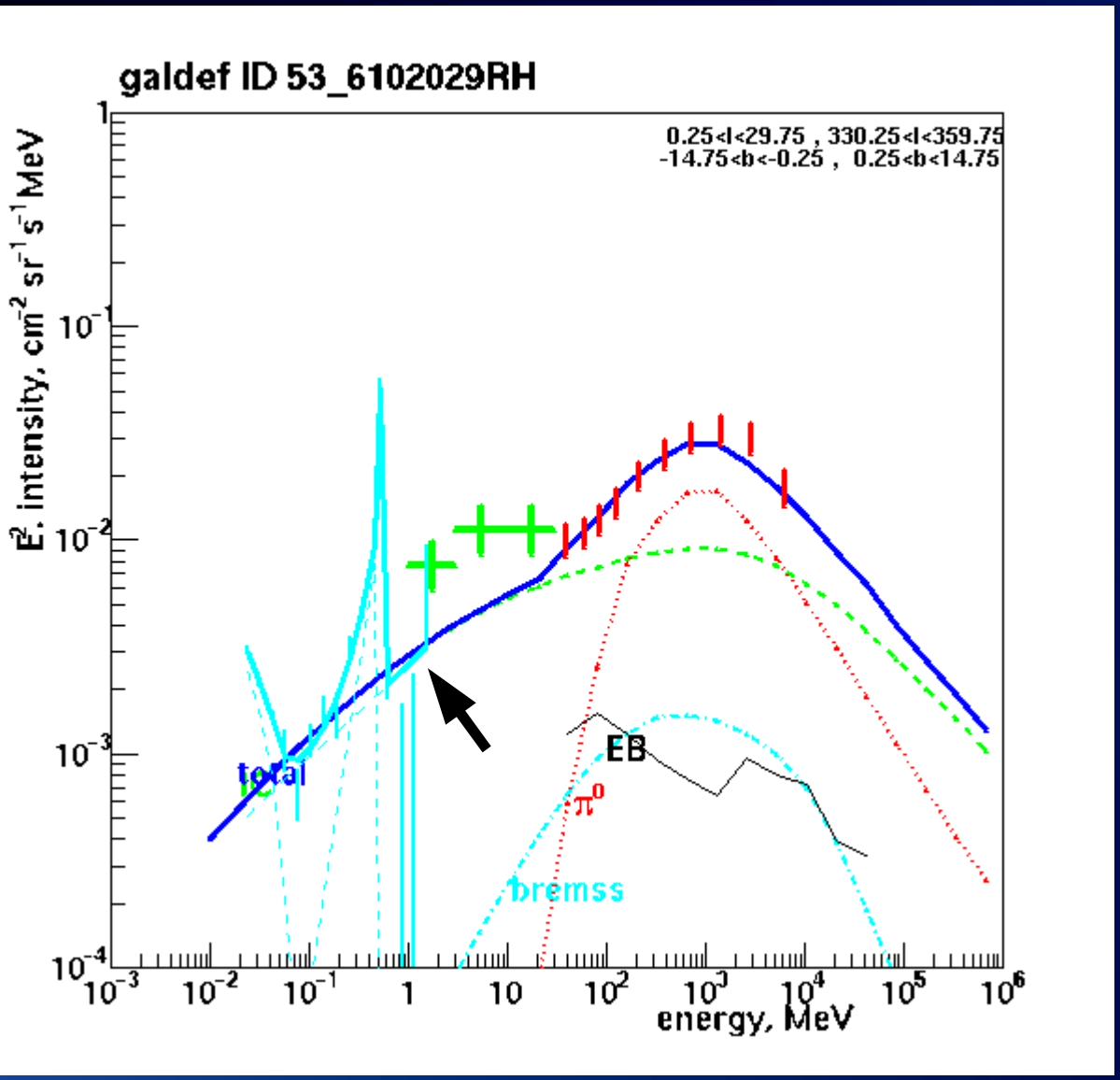
INNER GALAXY DIFFUSE EMISSION

inverse Compton:
primary electrons only

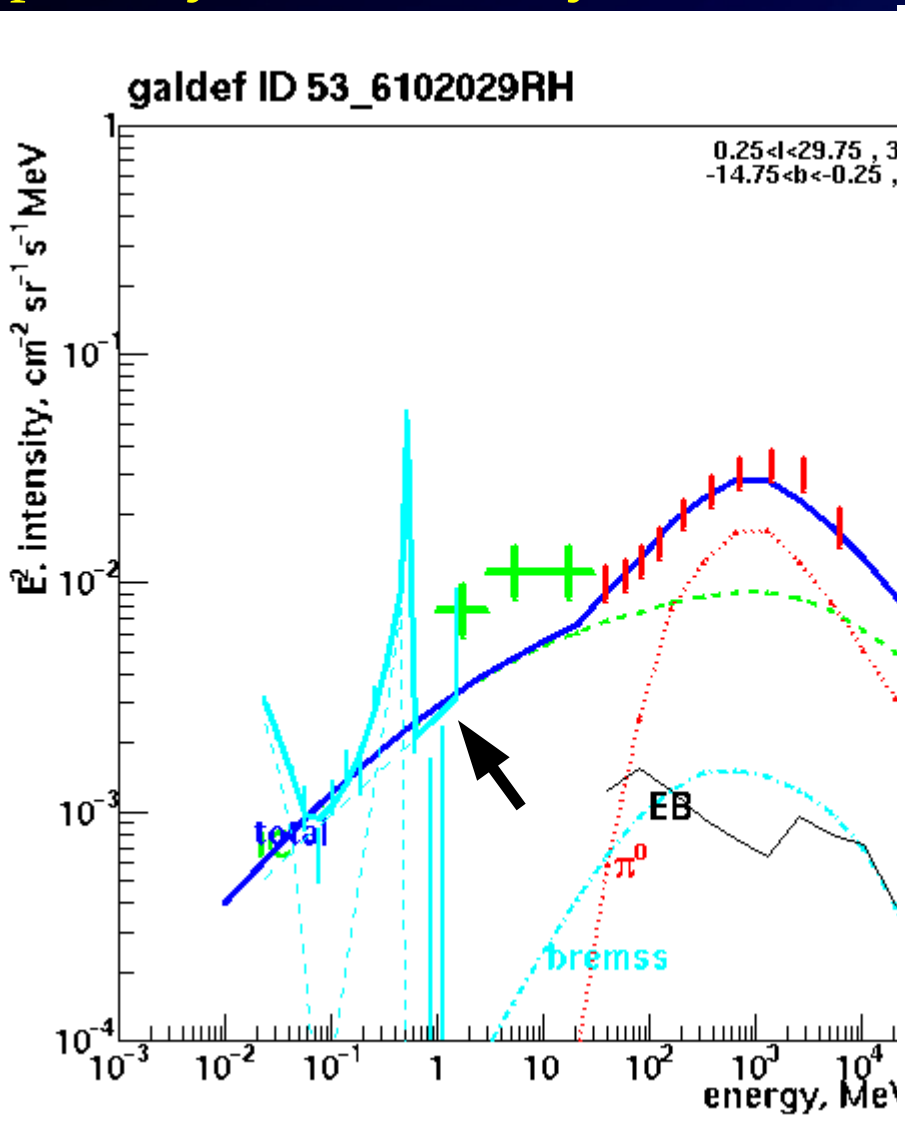


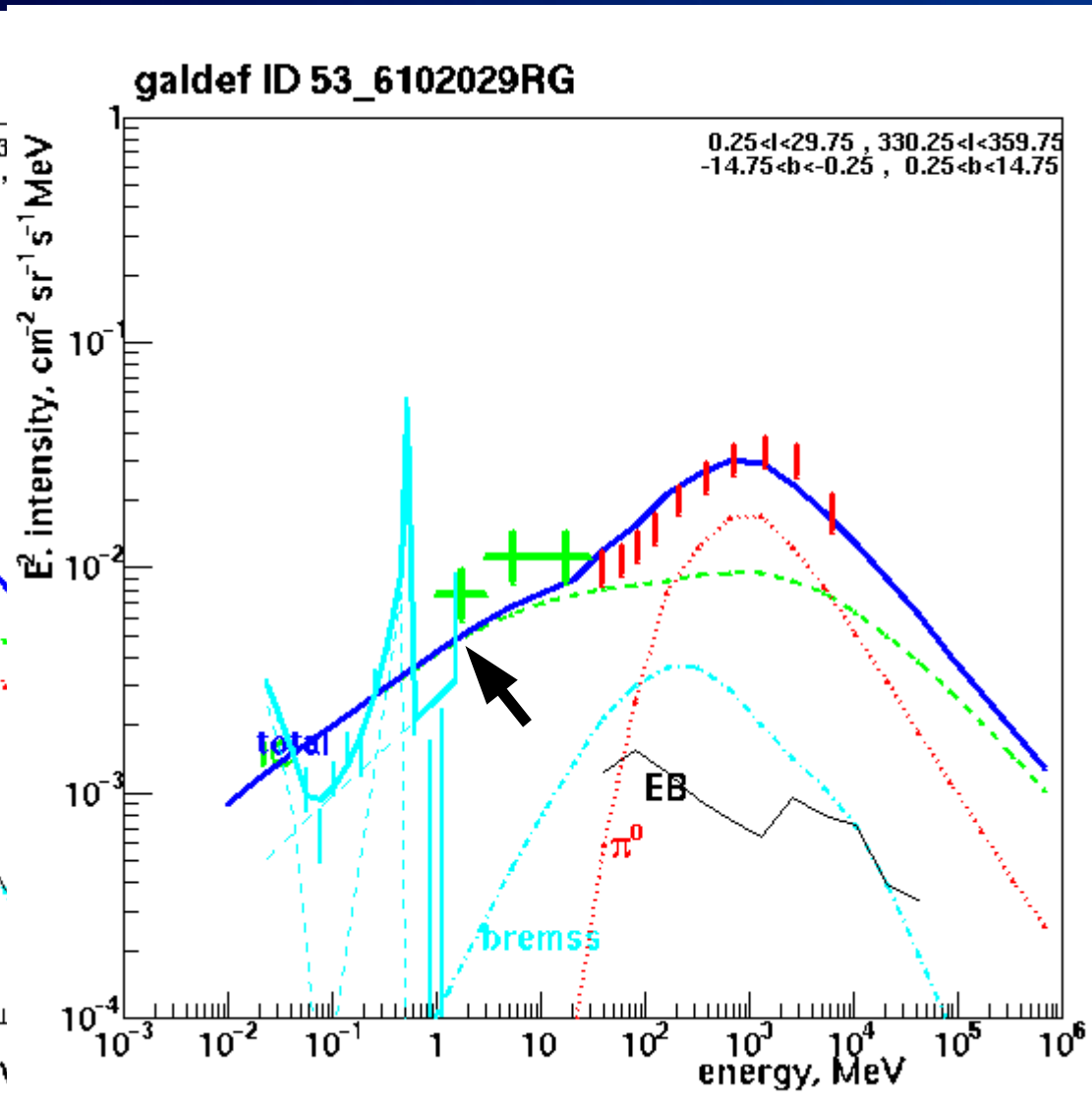
Moskalenko, Porter, Strong, Bouchet 2007 in preparation

INNER GALAXY DIFFUSE EMISSION

inverse Compton:
primary electrons only

+ *secondary* positrons + electrons





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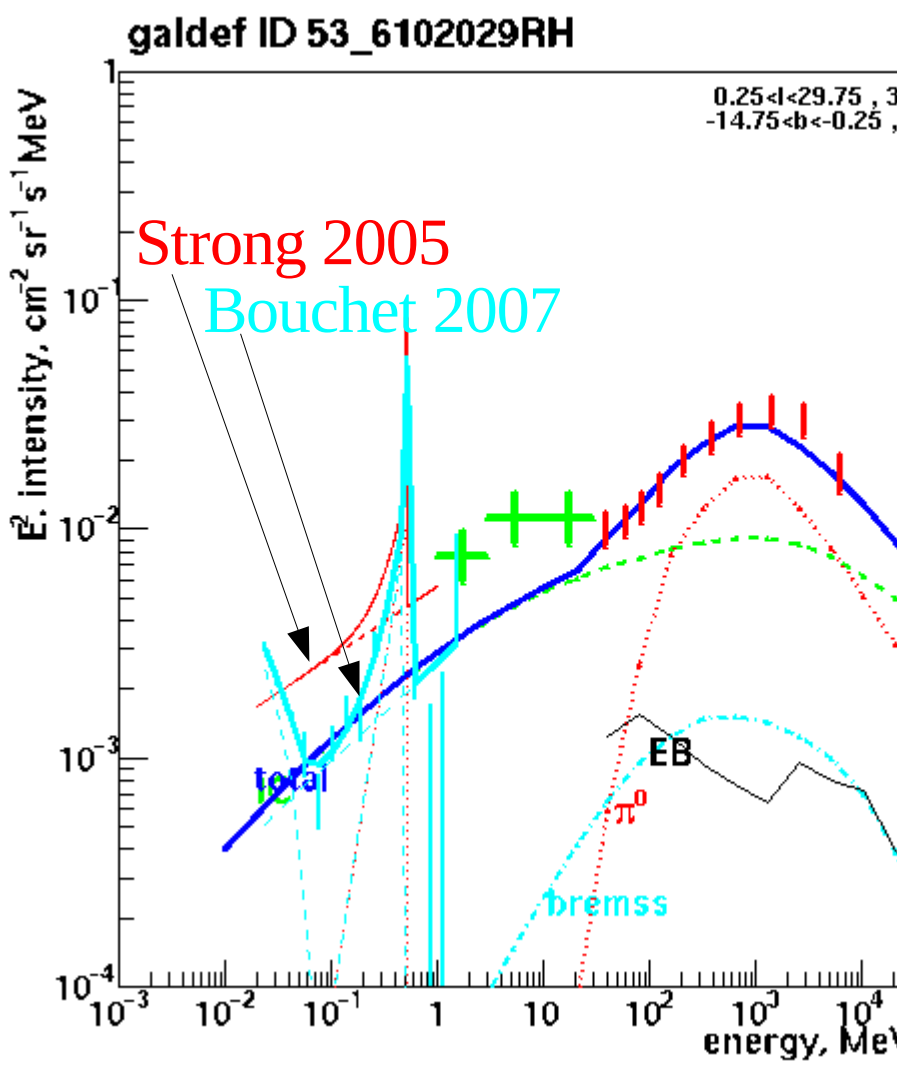
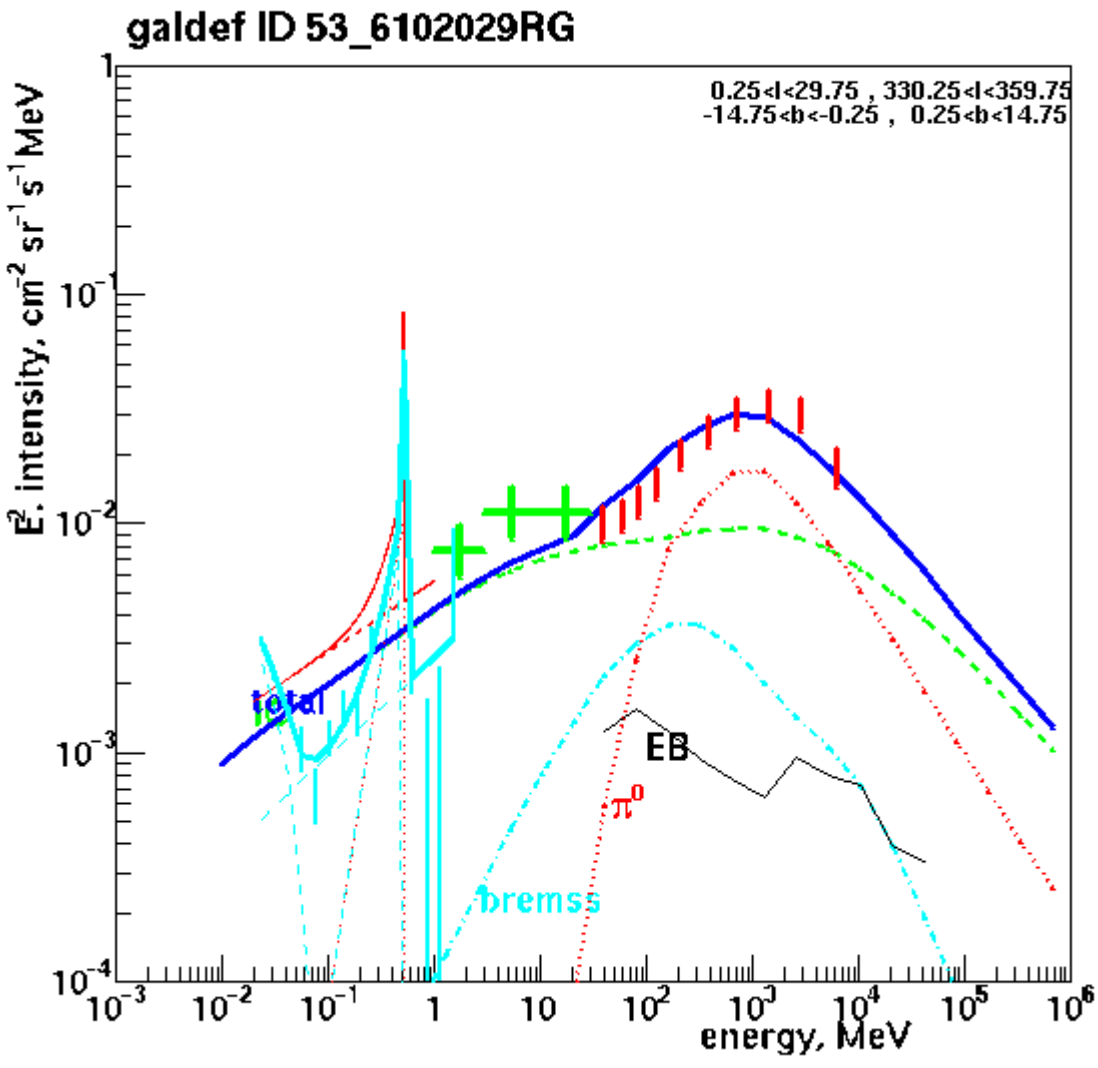




showing also other earlier data: Strong et al. 2005 new prediction lies between data, so conclusion not critically dependent on new data

Moskalenko, Porter, Strong, Bouchet 2007 in preparation

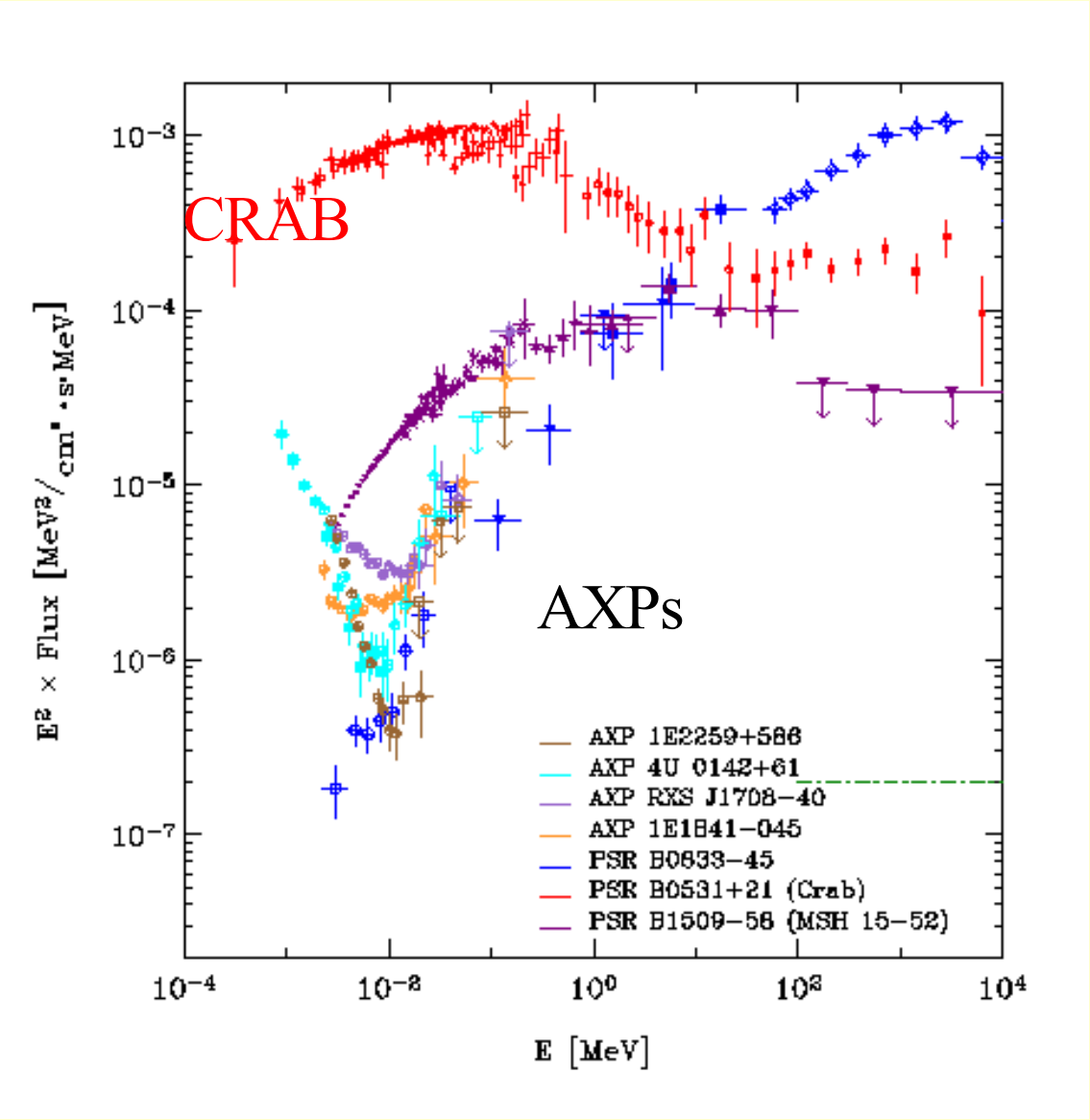
the diffuse emission 50 keV – 1 MeV is inverse Compton !

both the intensity and the *spectral index* are as predicted !

Still perhaps a problem for COMPTEL 1 - 30 MeV
observed fluxes slightly *higher* than predicted

population of hard spectrum sources PSRs / AXPs ?

AXP/PSR spectra: *L. Kuiper et al, ApJ 2006*

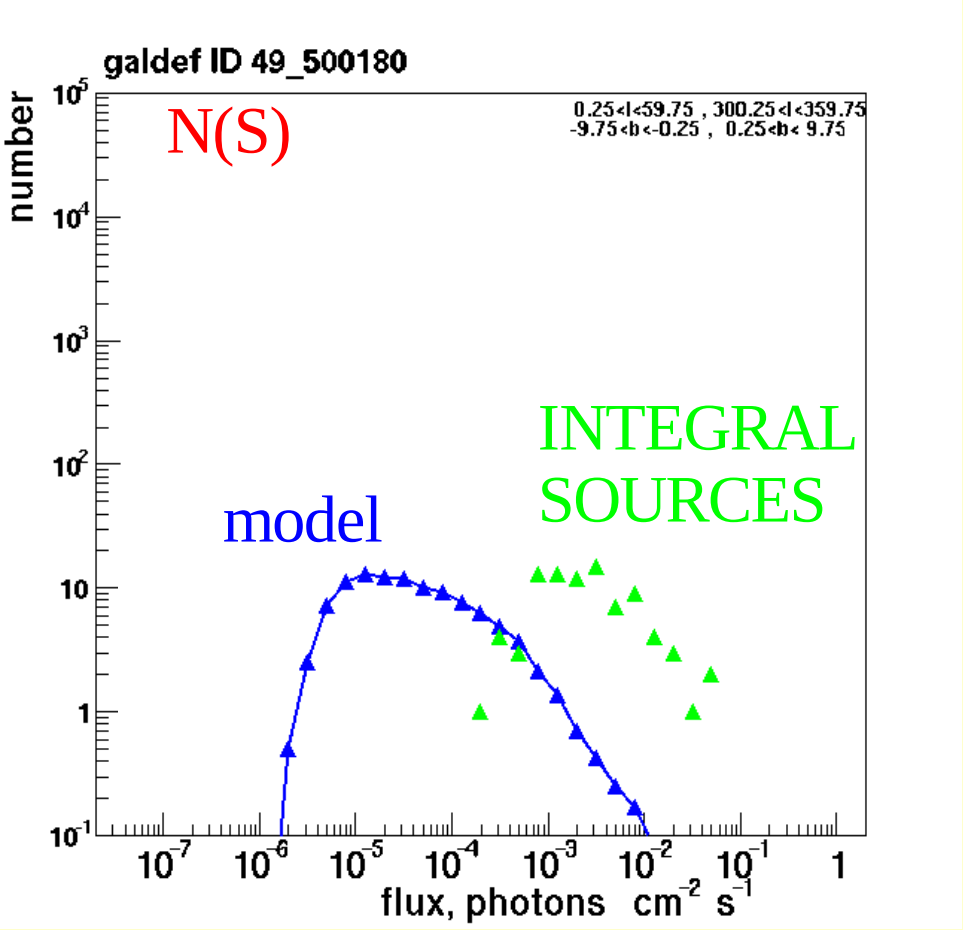


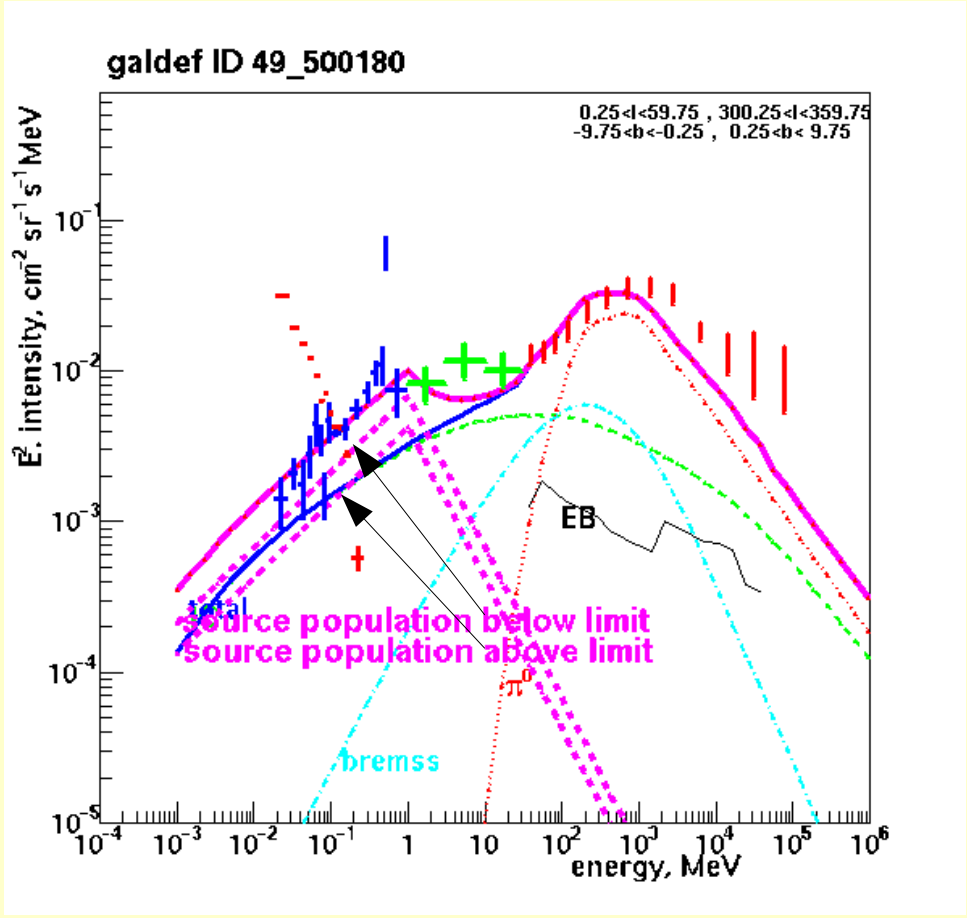
~ 10^{35} erg s^{-1}

AXP and radio pulsar spectra *harder* than E^{-2} : candidates for 'diffuse' emission,

THE *INVISIBLE HARD SPECTRUM* SOURCE POPULATION

$L=10^{41}$-10^{43} ph s^{-1} = 10^{34}-10^{36} erg s^{-1} $N(L) \sim L^{-1.5}$





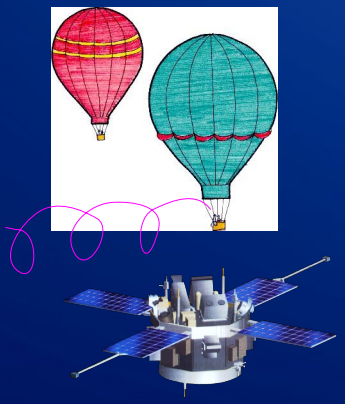
INTEGRAL/SPI 18–28 keV source counts in region H and spectra, for model 6. Shows that unresolved sources of the low-luminosity population can produce the 50–500 keV diffuse emission.

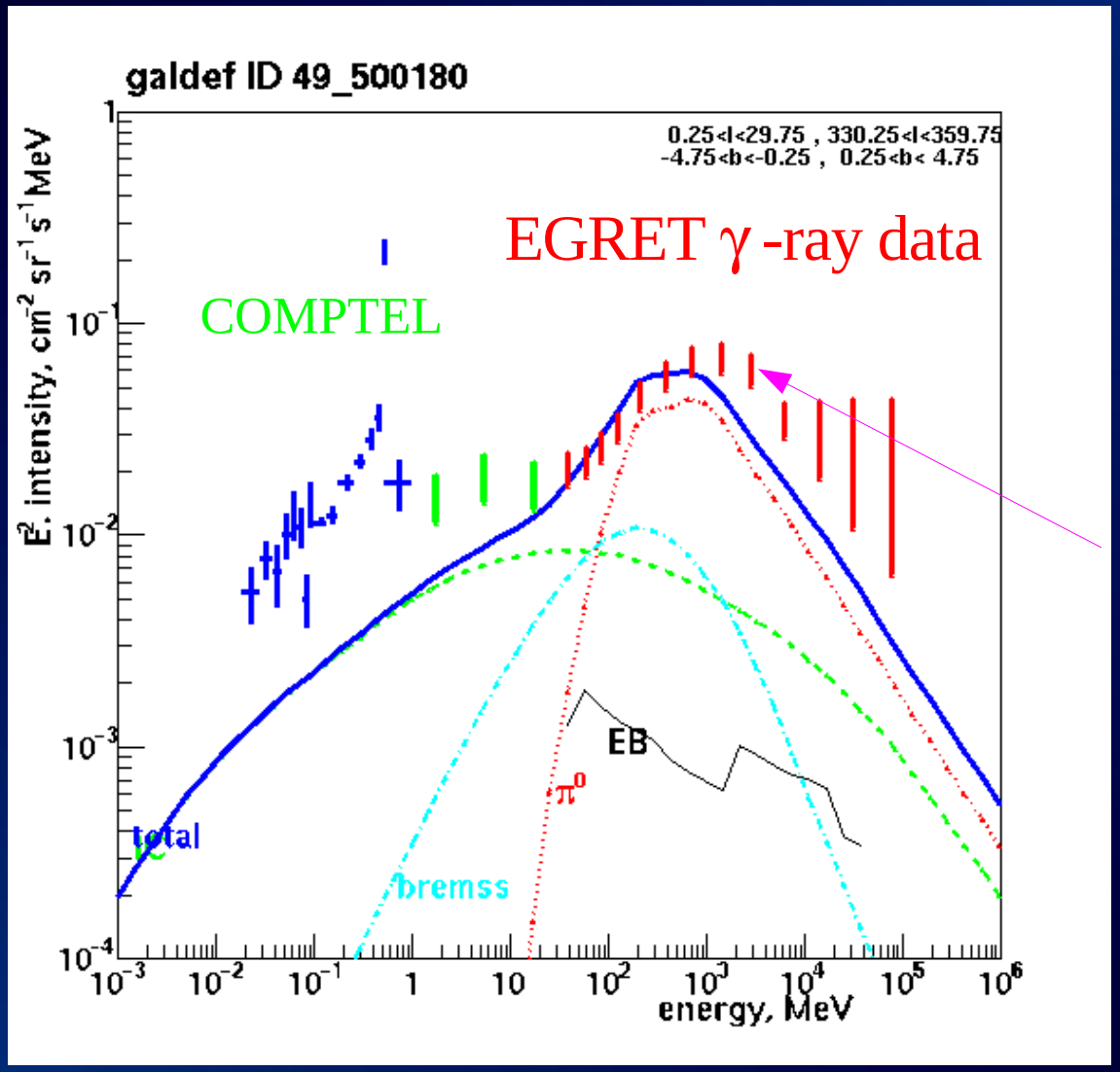
(from Barcelona conf. on unidentified gamma-ray sources, 2006 talk by A. Strong http://www.am.ub.es/bcn06)

the bigger picture :

keV to TeV

Conventional model: cosmic-ray protons and electrons as **directly measured** in balloons and satellites





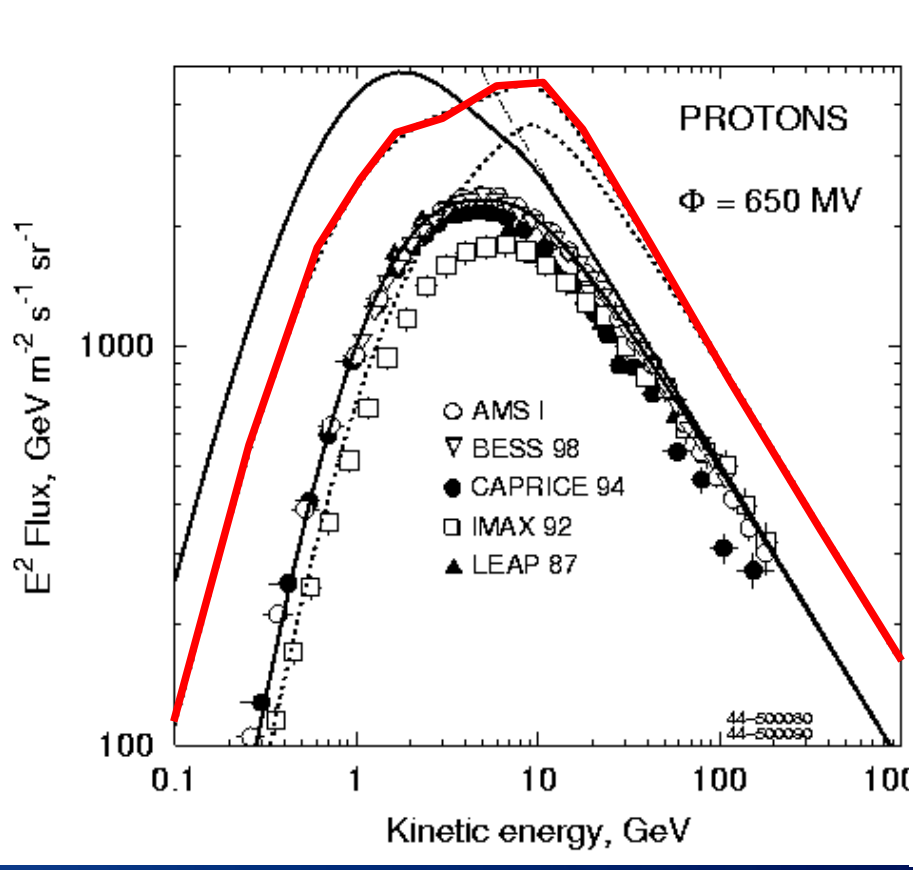
There really IS a big excess !

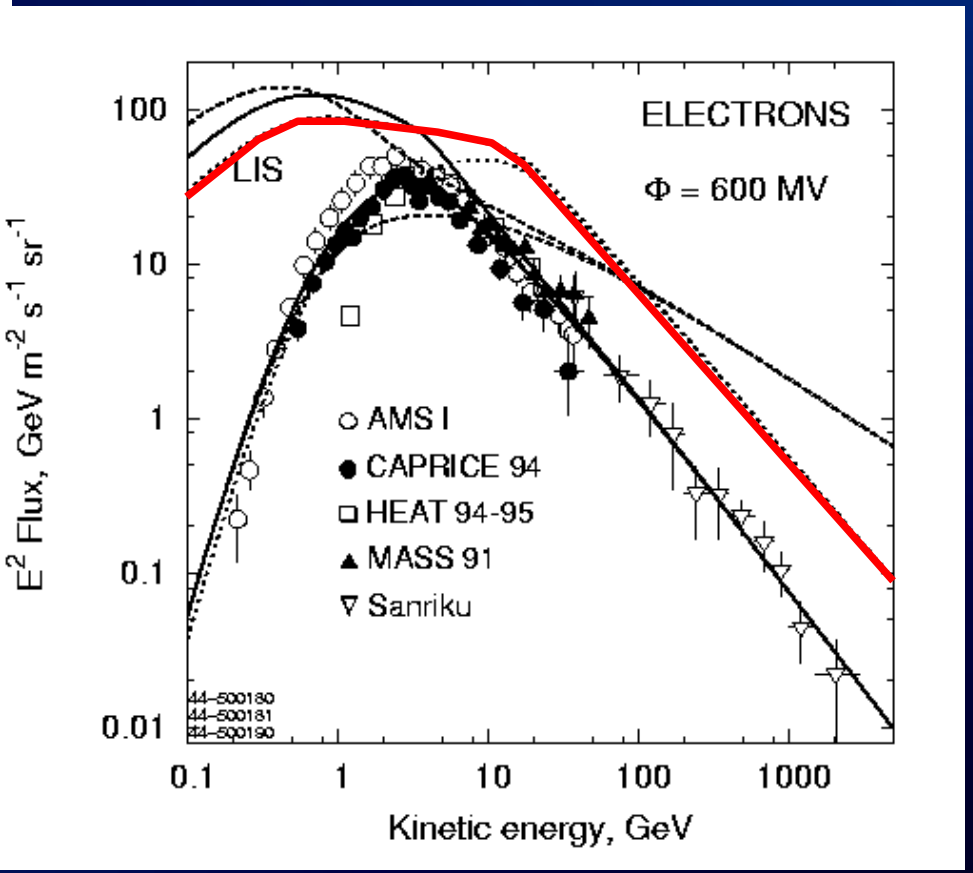
EGRET Calibration problem ? *unlikely* (see http://cosmocoffee.info)

(but await GLAST for the final word)

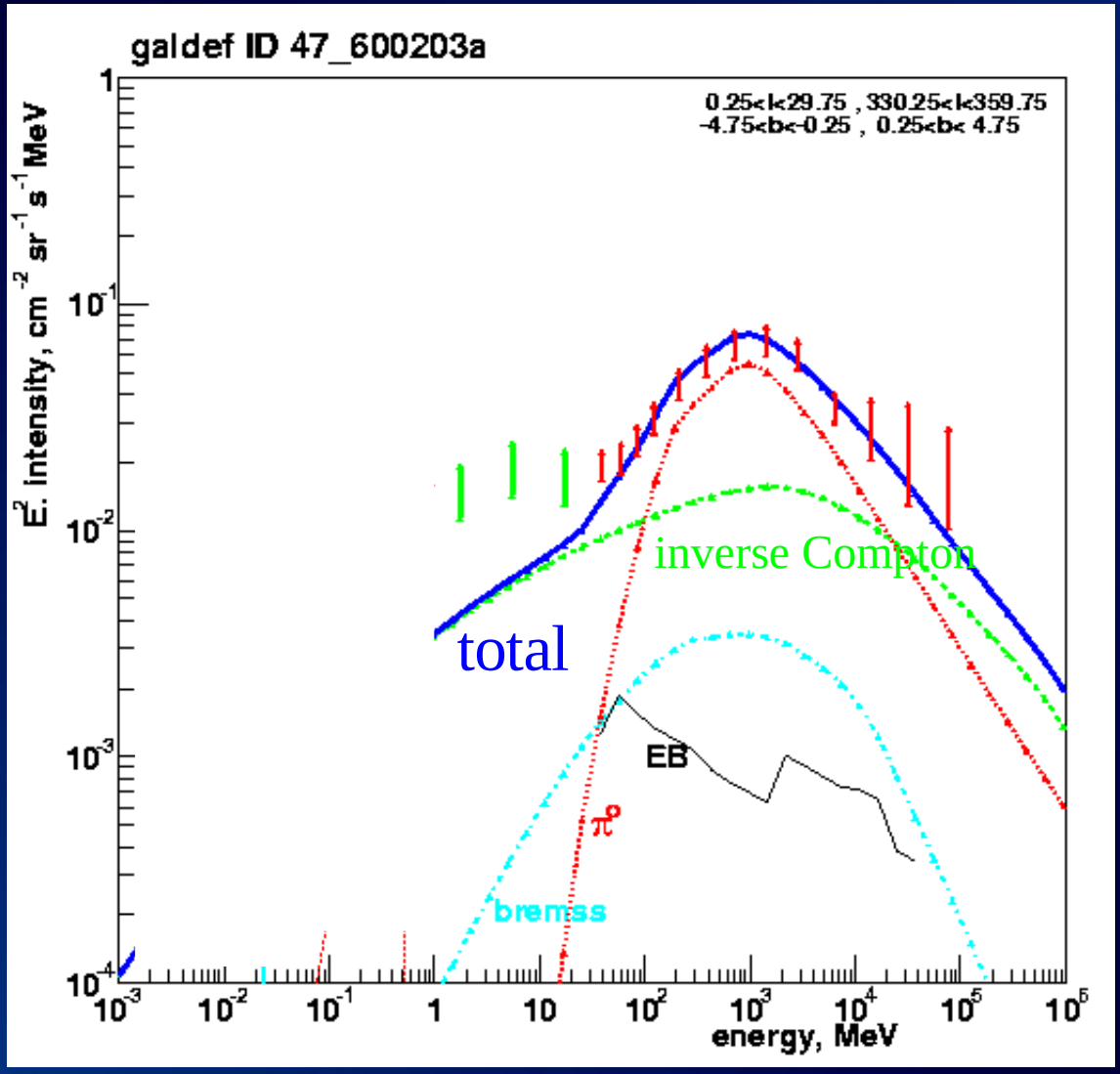
Optimized model:

proton, *electron* spectra factor 2 - 4 higher than measured
(justification: spatial variations due to stochastic nature of sources)





Optimized model: vary proton, electron spectra compatible with expected spatial variations



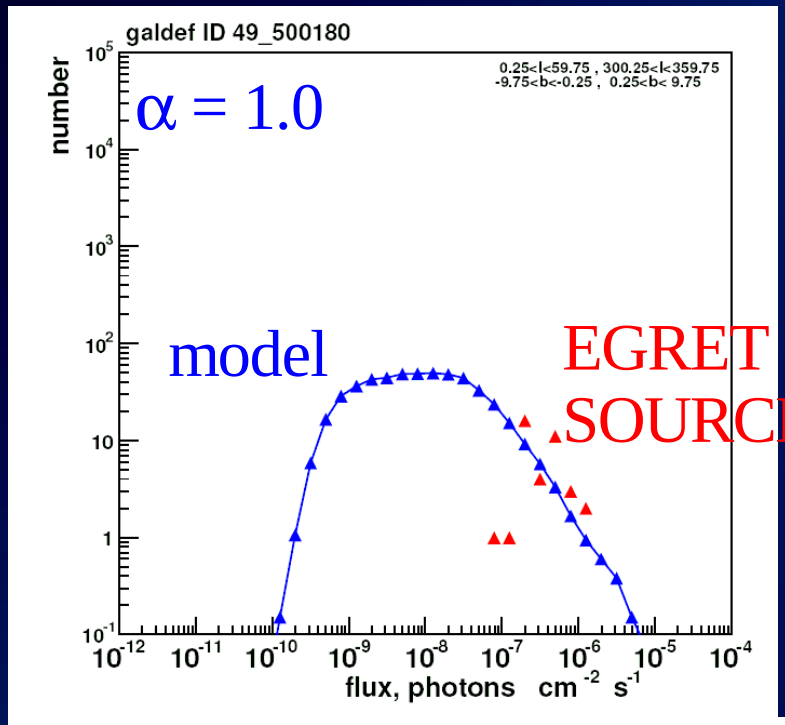
EGRET *Inner Galaxy* Source Counts > 100 MeV

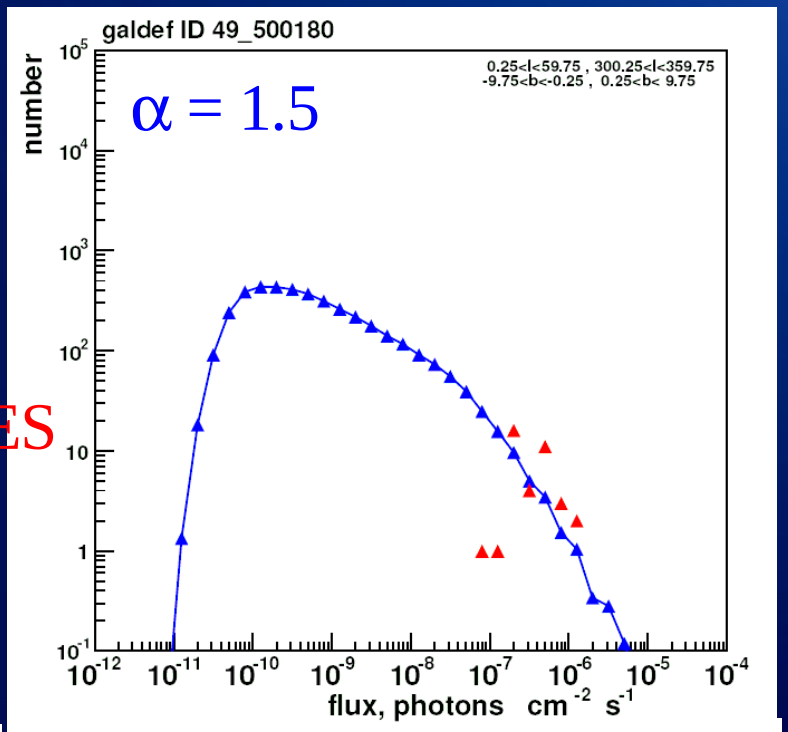
using luminosity function

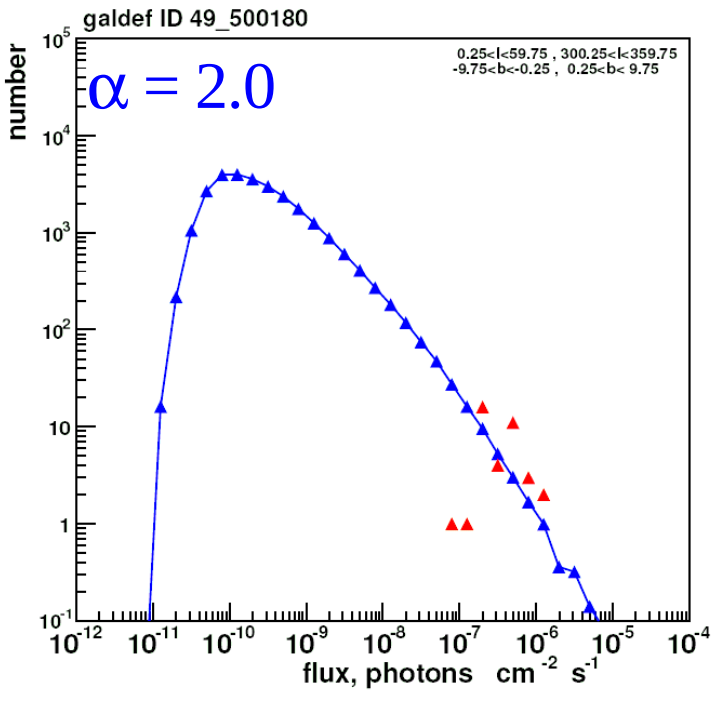
$N(L) \sim L^{-\alpha}$

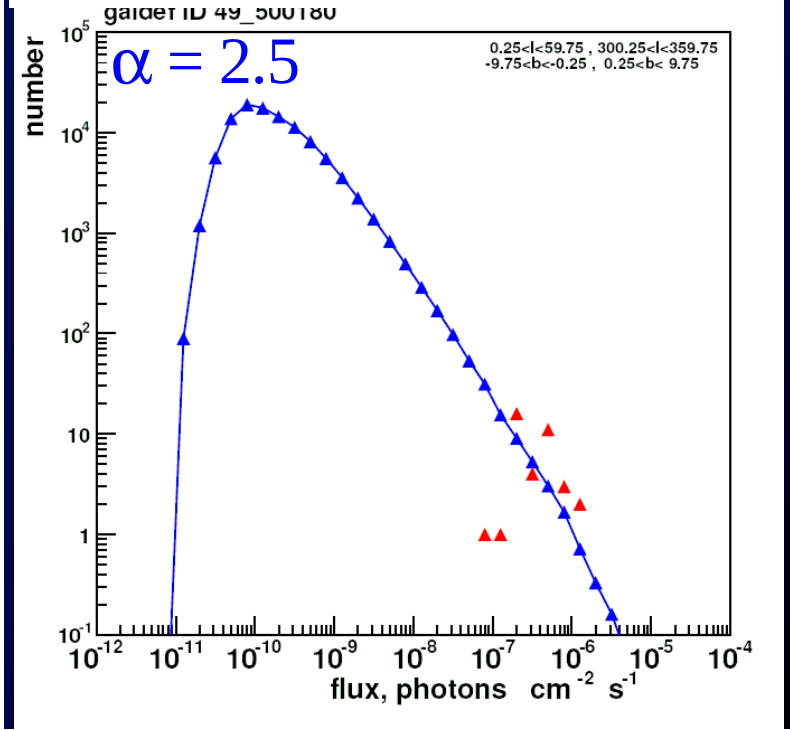
$10^{36} < L < 10^{39}$

photons s^{-1}



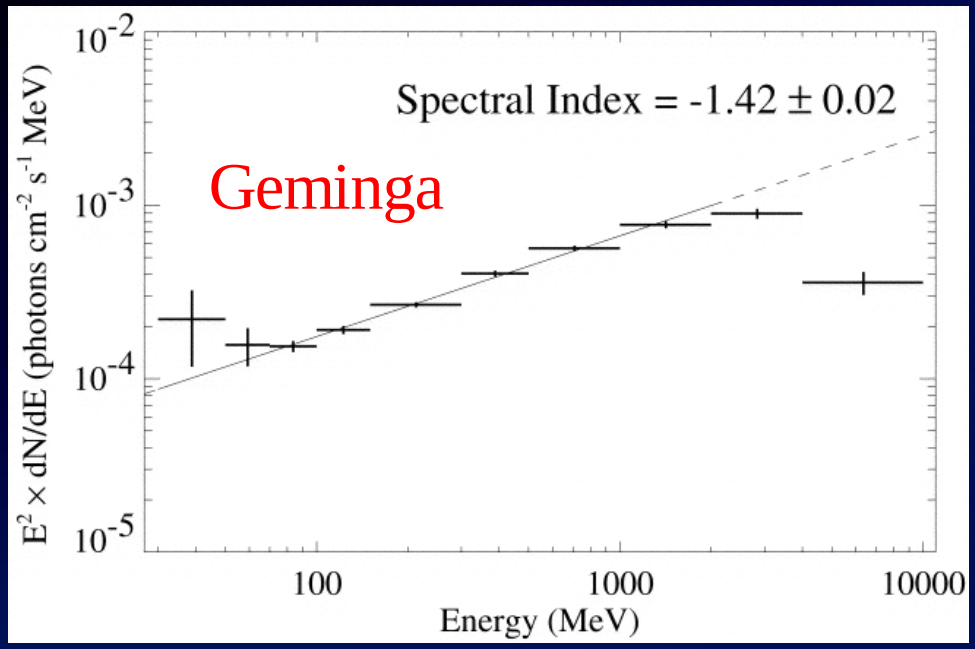


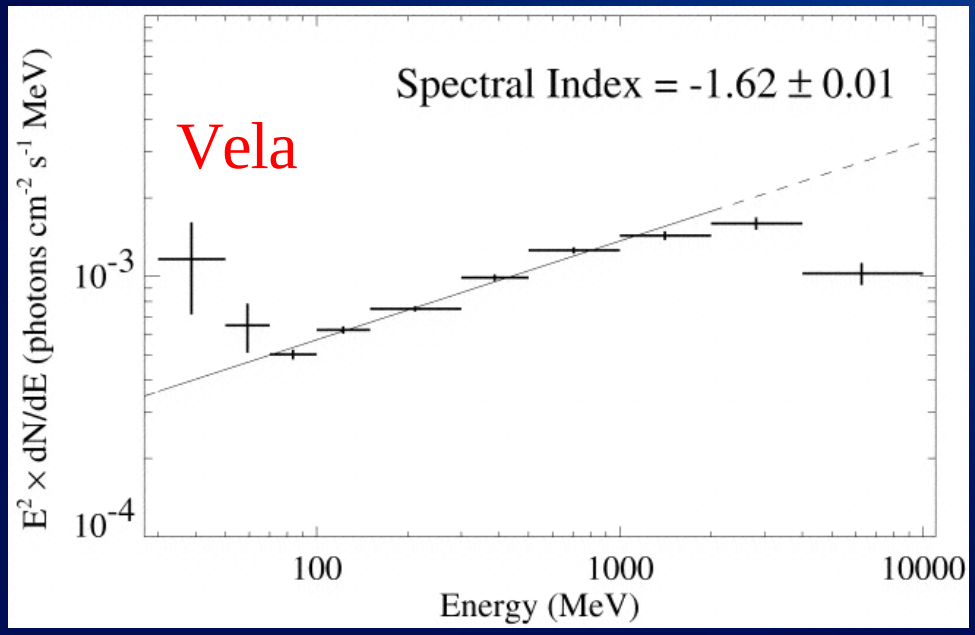




hard spectrum pulsars
Fierro et al. 1998

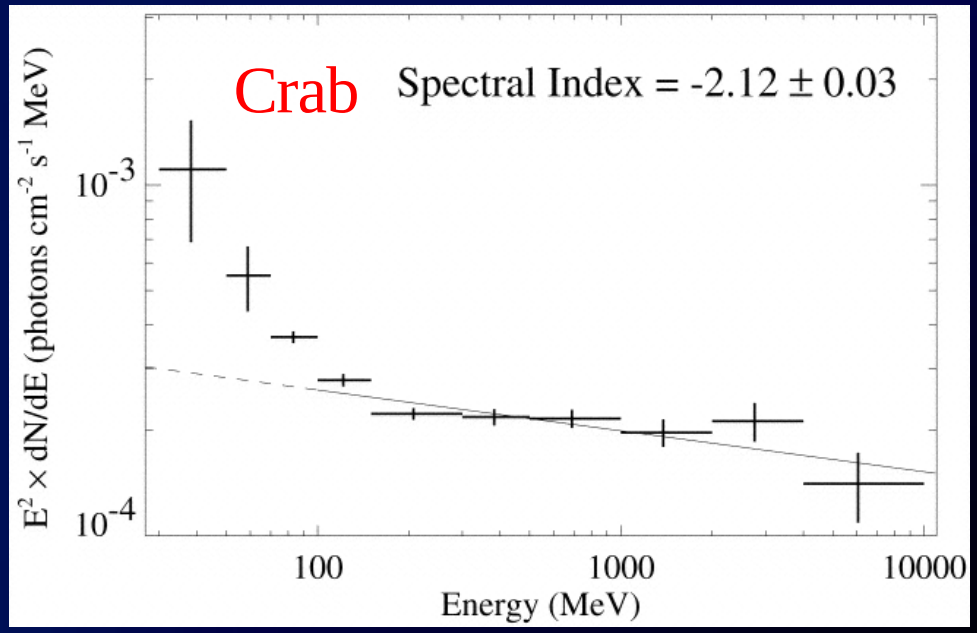
spectrum very reminiscent of the Galactic emission !

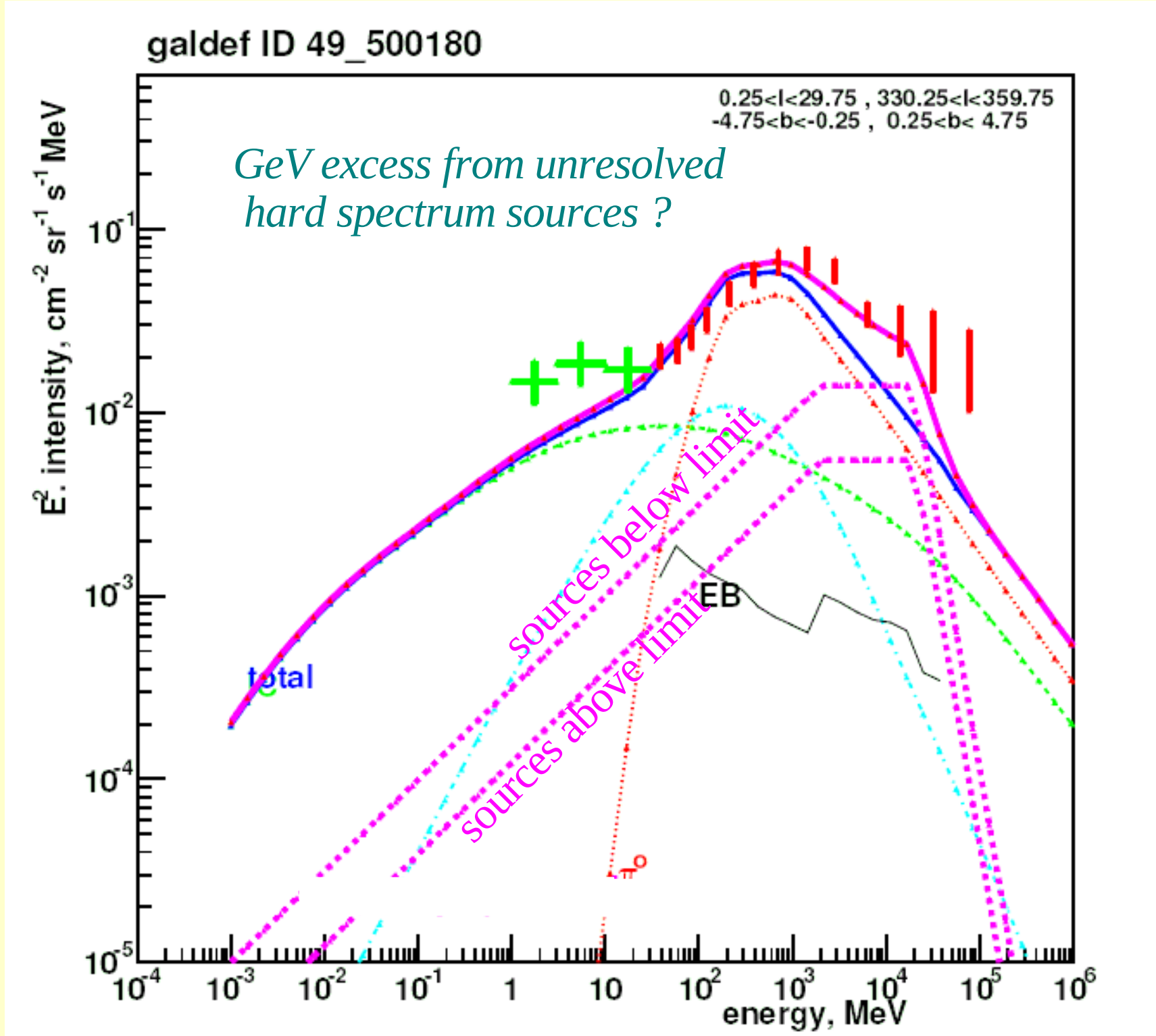




pulsar	index	breaks above
Crab	-2.1	4 GeV
Vela	-1.6	2 GeV
B1706-44	-1.3	1 GeV
B1951+32	-1.9	
Geminga	-1.4	2 GeV
B1055-52	-1.6	1 GeV
B1509-58	-1.7	

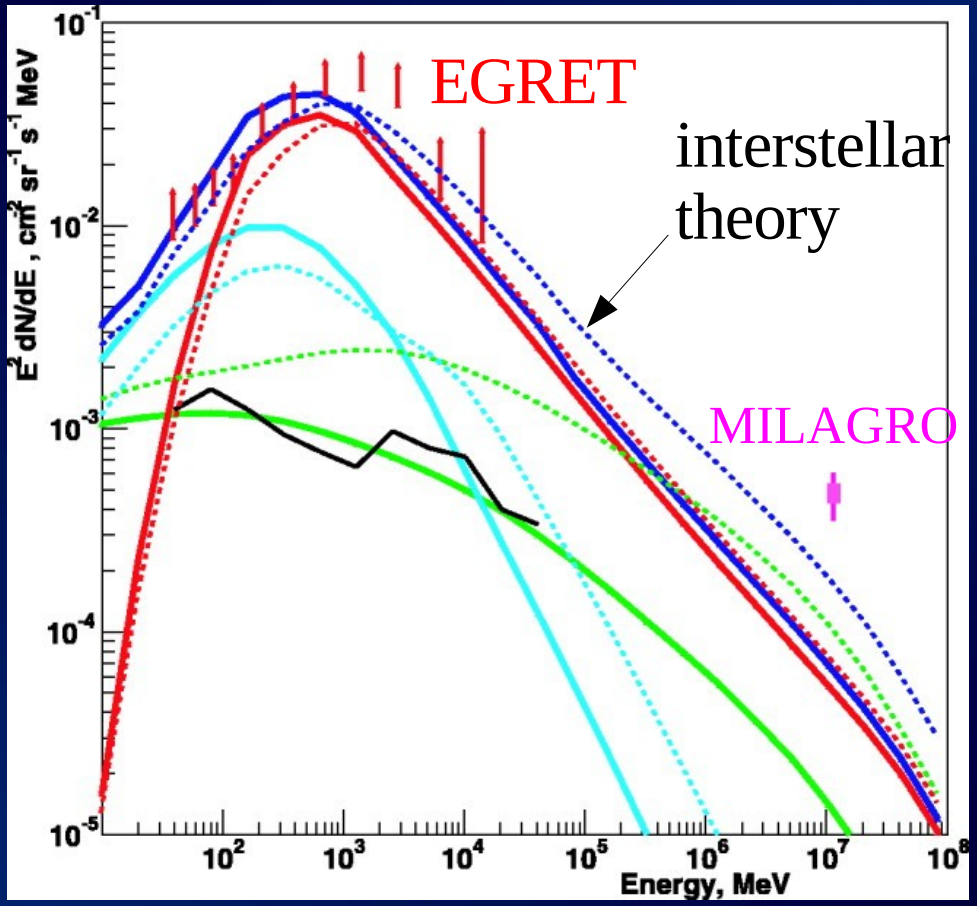
for comparison,
Crab is not so hard:




galdef ID 49_500180
0.25<l<29.75 , 330.25<l<359.75
-4.75<b<-0.25 , 0.25<b< 4.75
GeV excess from unresolved
hard spectrum sources ?
E², intensity, cm⁻² sr⁻¹ s⁻¹ MeV
energy, MeV
total
sources below limit
sources above limit
EB
π⁰

If the GeV excess *is* due to pulsars,
GLAST will detect them and
decide the issue

TeV and beyond : MILAGRO Cygnus region



more
than
expected

sources ?
enhanced
cosmic rays ?

Abdo et al. 2007

CONCLUSIONS

One model for :

cosmic rays: spectrum and propagation
X + γ-rays 50 keV – 20 GeV
secondary e^+ important for IC γ-rays up to 1 MeV

INTEGRAL is a tracer of GeV electrons / positrons !

< 50 keV : source populations *dominate* completely

50 keV - 1 MeV : source population *not* required

1 – 30 MeV : source population (or something else) *is* required

> 1 GeV : source population *might explain* GeV excess

Future : GLAST – PAMELA - PLANCK
+ plenty more from INTEGRAL