High-Energy Emission from Galaxy Clusters
Results from EGRET Observations

GLAST Collaboration Meeting, Sep´03

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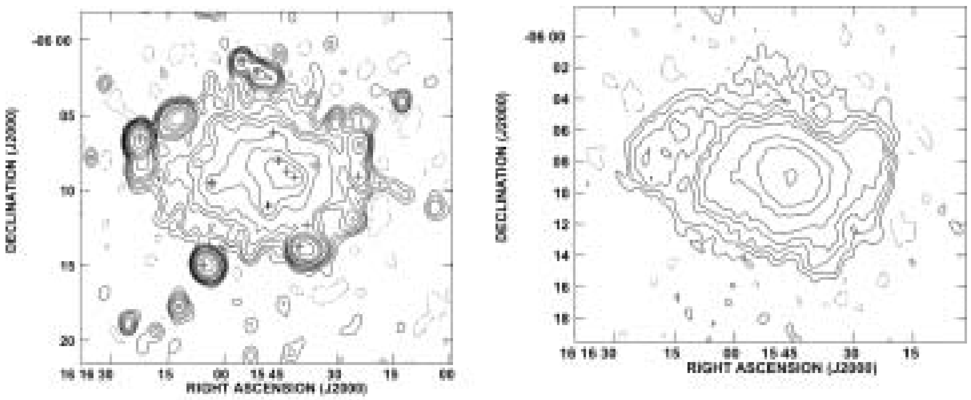
Two general scenarios make us believe to consider clusters of galaxies as potential gamma-ray emitters:

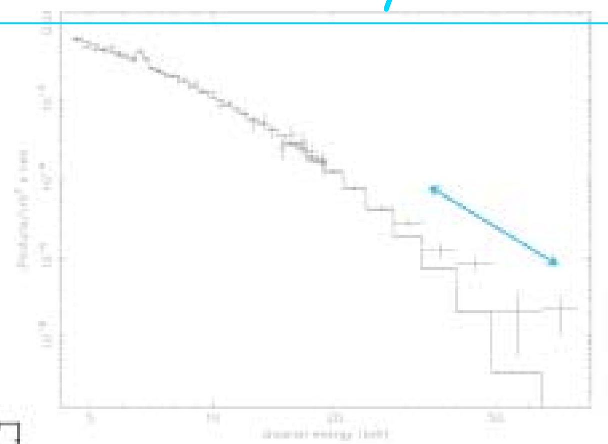
(1) Multifrequency evidence of nonthermal activity



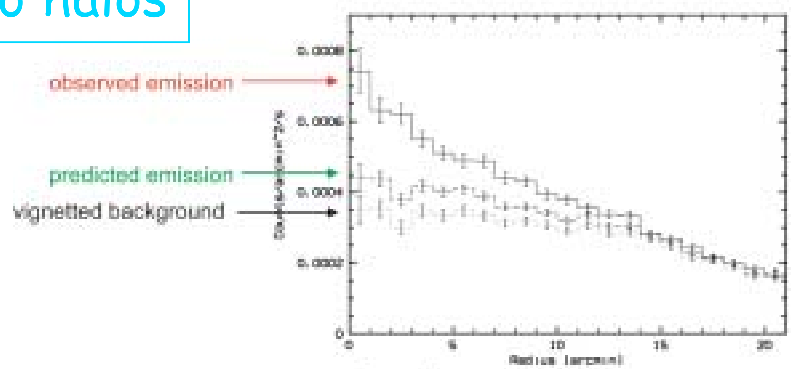
A2163 (Feretti et al. 2001)

diffuse radio halos

nonthermal X-ray emission



BeppoSAX Spectrum of the Coma cluster, fitted with kT = 8.2 keV.
(Rephaeli 2001)

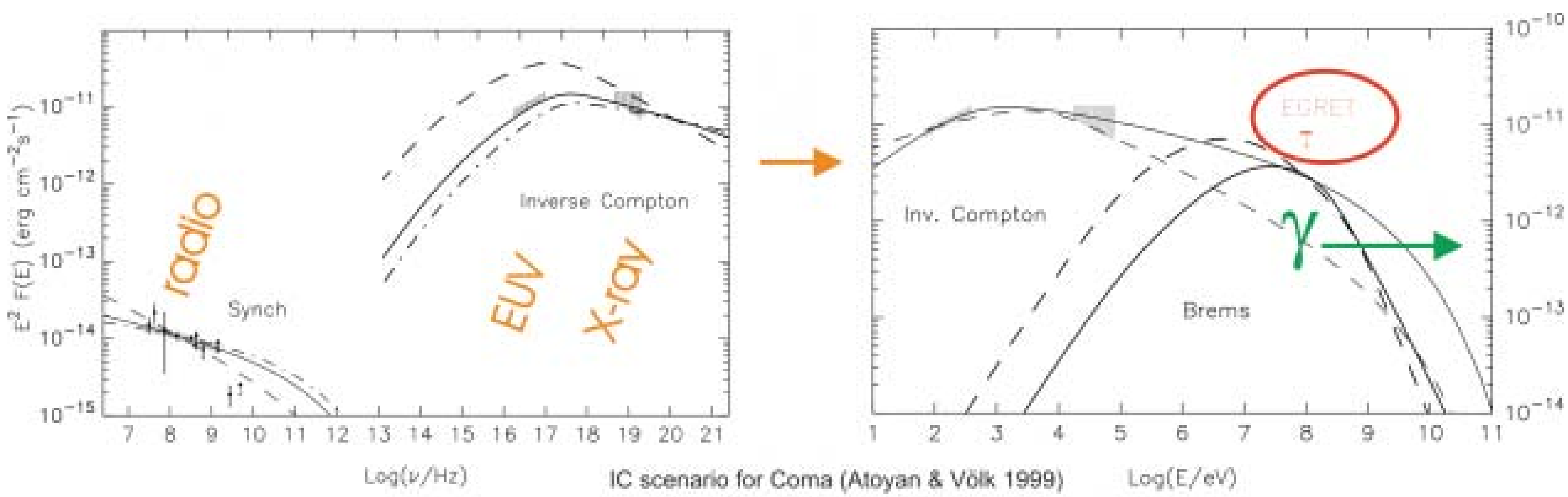


Coma (Bowyer et al. 1999)

EUV excess emission

X-ray emission is IC of the radio emission producing electron by the CMB

- power-law with index simply related to observed radio (synchrotron) emission
- matching spatial emission profiles in X-ray- and radio (halo) images
- multifrequency models require a distinct relativistic particle population



IC scenario for Coma (Atoyan & Völk 1999)

α_{inj} = 2.3 Δt_{inj} = 3 Gyr B = 0.1 μG
α_{inj} = 2.6 Δt_{inj} = 1 Gyr B = 0.15 μG

(2) Large-scale cosmological structure formation

Hierarchical merging scenarios of galaxy clusters:

Larger structures evolve from mergers of adjacent but smaller structures

↓

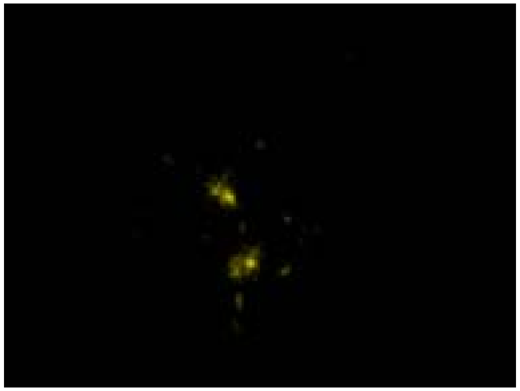
baryonic matter condenses in form of galaxy clusters

↓

dark matter halos interact/merge

↓

1st order Fermi acceleration of particles at the shock fronts



Formation of a galaxy cluster in the tCDM 3D simulation. (Starting z= 2.5) (from Jenkins et al. 1998)

Three ways to detect galaxy clusters at gamma-rays

Direct detection of gamma-ray emission in unambiguous positional coincidence with an candidate galaxy cluster
-> „pointing" approach

Spatial-statistical correlation between still unidentified gamma-ray sources and a candidate object population
-> „correlation study"

Unresolved gamma-ray emission through localized enhancements in the extragalactic background
-> „background contribution studies"

@ diffuse day:

Special emphasis on the diffuse fore- and background involved in galaxy cluster analysis

-> NO discussion of individual cluster observations

(McGlynn, Vestrand & Jennings: 22 Abell clusters -> u.l.)
(Sreekumar et al. 1996: Virgo, Coma -> u.l.)
(Reimer et al. 2003: 58 nearby X-ray bright Abell clusters -> u.l.)

-> NO dicussion of spatial-statistical correlation work

(Kolatt & Piran 1996: Abell clusters <-> GRBs)
(Marani et al. 1997: rich, nearby Abell clusters <-> GRBs)
(Hurley et al. 1997: Abell clusters <-> GRBs)
(Gorosabel & Castro-Tirado 1997: Abell <-> GRBs)
(Burenin, Sunyaev et al. 1997: Abell <-> GRBs)
(Hurley et al. 1999: Abell clusters <-> GRBs)
(Colafranceso 2001,2002: Abell clusters <-> EGRET unIDs)
(Kawasaki & Totani 2002: possible merging clusters <-> EGRET unIDs)
(Reimer et al. 2003: nearby X-ray bright Abell <-> EGRET unIDs)

Galaxy clusters as explanation of the extragalactic diffuse gamma-ray background (EGDB)

... a long record as well:

Strong & Bignami 1983: NGC 1275 & Perseus cluster possible sources of γ-ray enhancement measured by COS-B

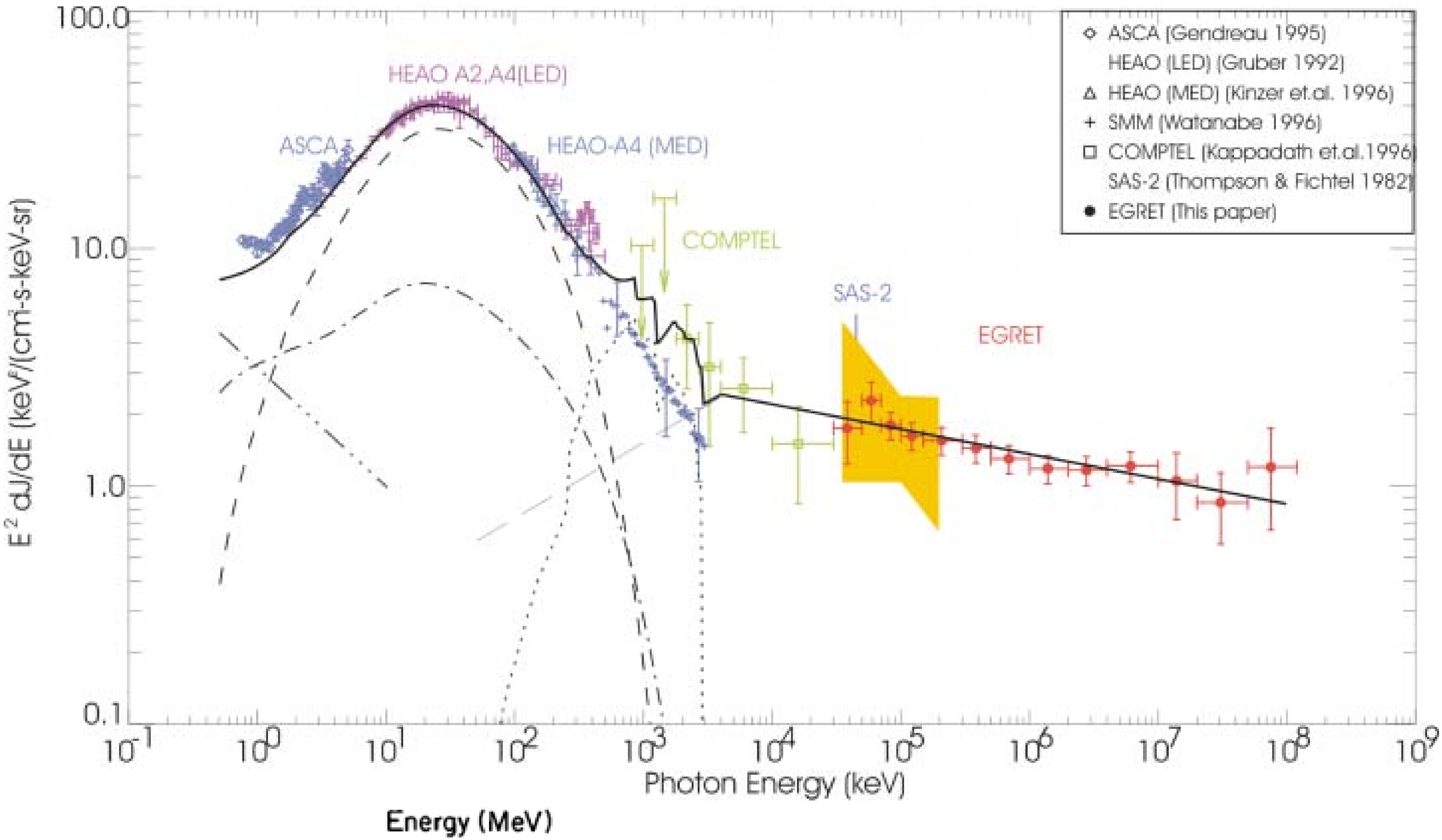
and subsequently:

Houston et al. 1984: cosmic ray interactions with intergalactic gas within groups and clusters of galaxies produced EGDB

but: respective COS-B fluxes not confirmed by CGRO

Dar & Shaviv 1995: Cosmic Ray Origin of EGDB, essentially 100% (!)

Coma, Perseus, Virgo ~ 10^{-7} cm^{-2} s^{-1} (!)



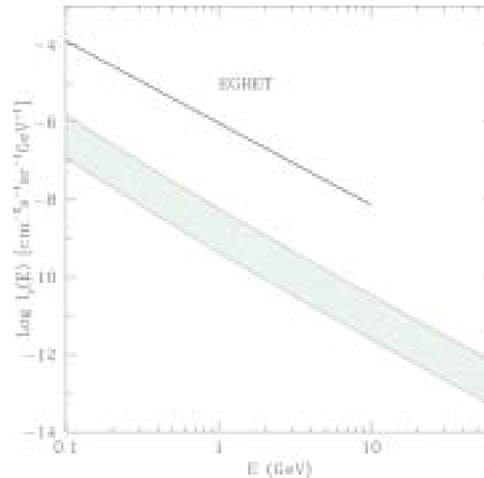
-> EGRET EGDB

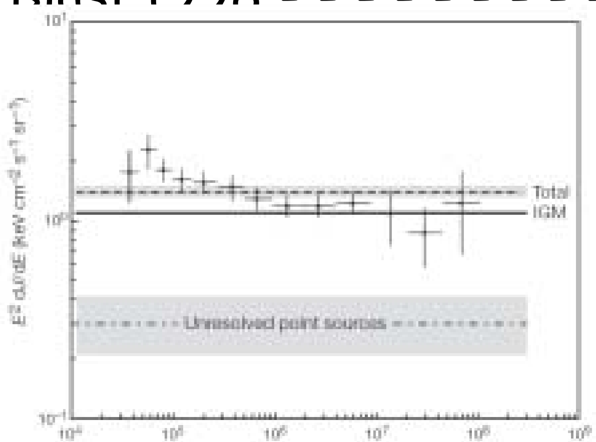
(Sreekumar et al. 1998) !

Predictions of the contribution from clusters to the EGDB

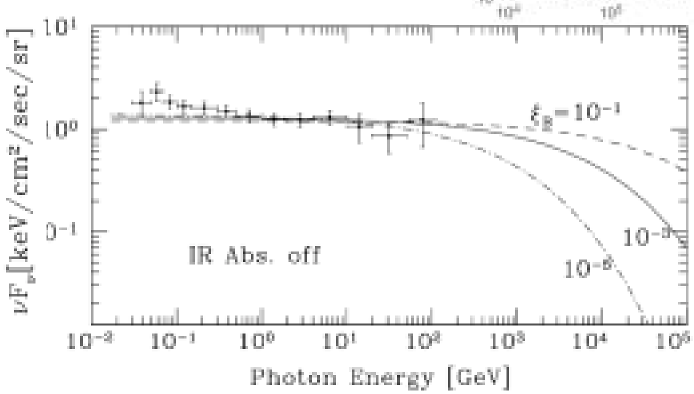
Berezinsky, Blasi & Ptuskin 1997 -> not detectable by current instrumentation

Colafrancesco & Blasi 1998 - - - - - - - - - - ->





<- Waxman & Loeb 2000



<- Totani & Kitayama 2000

Scharf & Mukherjee 2002

BULK SOURCE OF UNIVERSE'S GAMMA RAYS IDENTIFIED, SCIENTISTS SAY

Scientists at Columbia University and Barnard College have found that *the majority of the gamma rays outside of our galaxy are likely emitted by galaxy clusters* and other massive structures. This may resolve a 30-year-old mystery as to the origin of the Universe's gamma-ray background. ... "This result not only *resolves the question of where all these gamma rays are coming from*, but provides a new probe of the gravity-driven picture of structure formation in the Universe"...

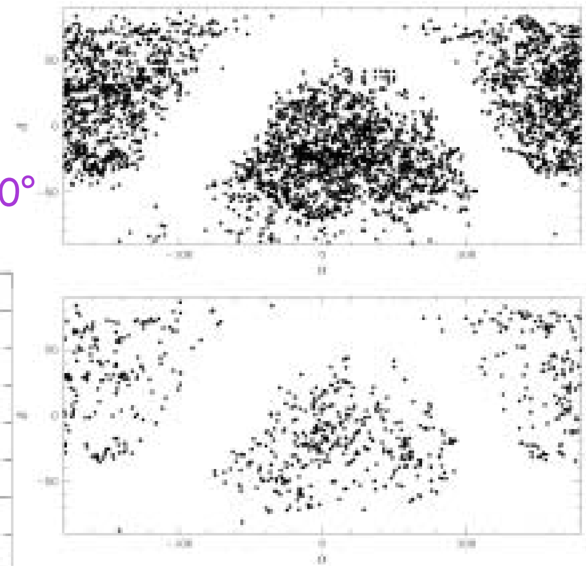
Statistical Detection of Galaxy clusters in EGRET data -> unresolved sources -> EGDB

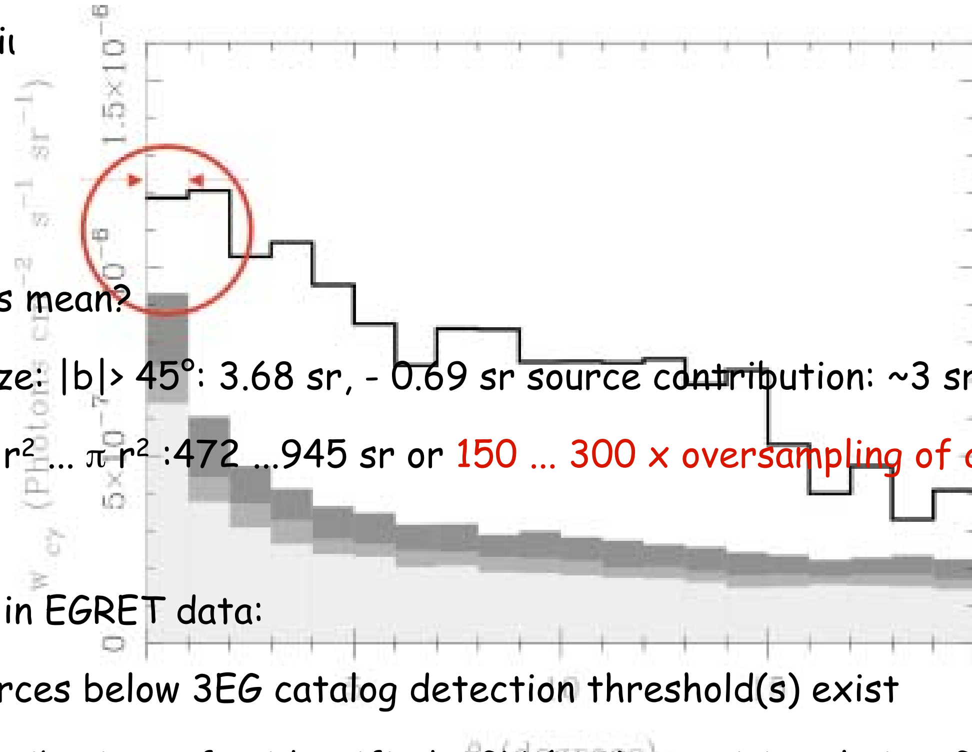
Method: annular binning of EGRET intensity data

|b|> 45°, 2.7° cut around 100 identified EGRET sources

sample: positions of 2469 Abells, 447 Abell (R ≥ 2), stacked out to 20°

average indivi





What does this mean?

sample size: |b|> 45°: 3.68 sr, - 0.69 sr source contribution: ~3 sr

1/2 π r^2 ... π r^2 :472 ...945 sr or 150 ... 300 x oversampling of a bin in EGRET intensity map

residuals in EGRET data:

sources below 3EG catalog detection threshold(s) exist

+ contributions of unidentified AGN (unIDs awaiting their AGN identification)

+ contributions of identified sources with psf-extension of > 2.7° (the psf tails!),

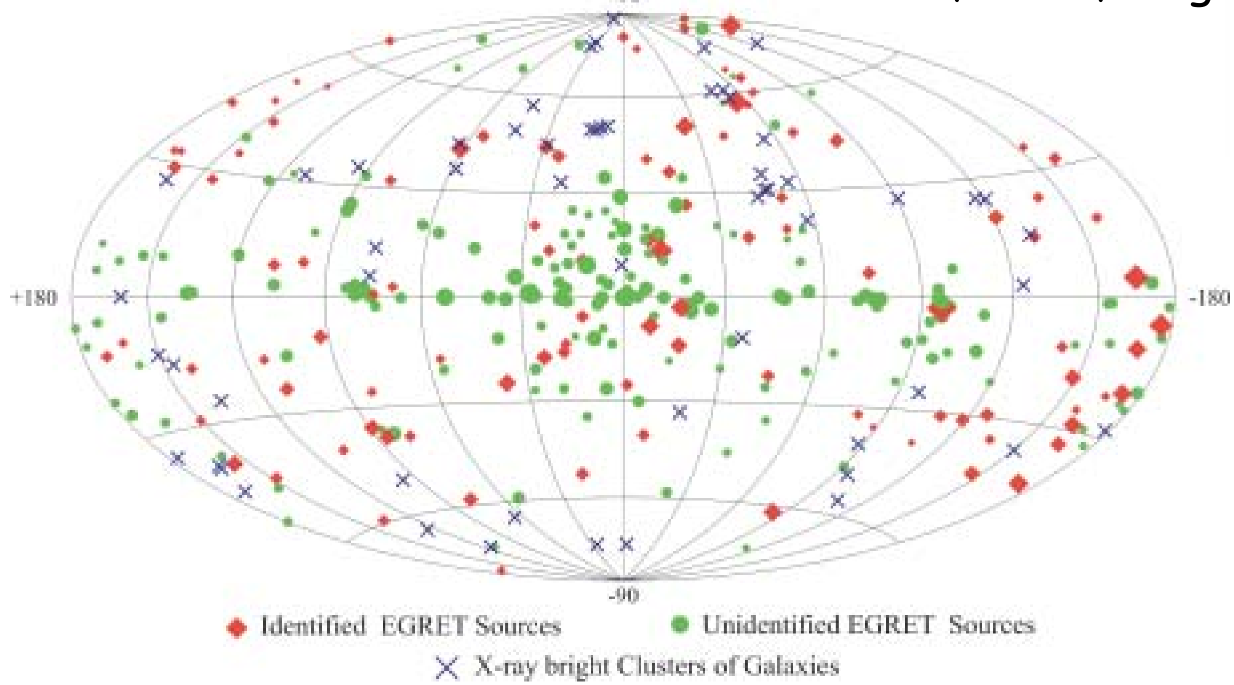
+ plain diffuse galactic foreground (unadapted GALDEF !)

Reimer et al. 1999 (ICRC ´99), 2001 (γ2001), 2003 (ApJ 588)

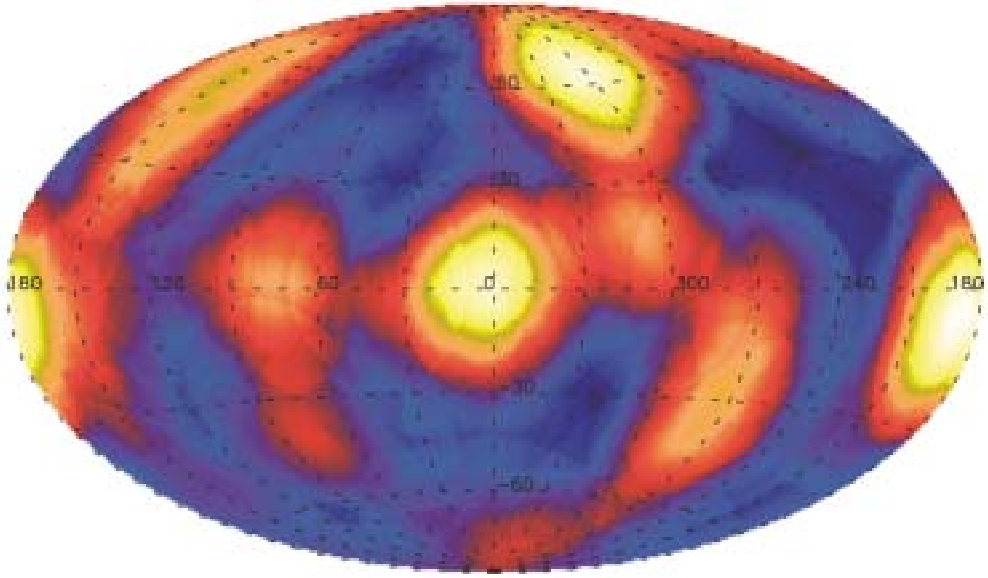
58 of the X-ray brightest clusters, nearby (z < 0.14)

individually analyzed as well as in **superposition**

naturally included := best-observed clusters: EUV excess; hard X-ray emission; most of the radio halo clusters; Perseus, Coma, Virgo



The superposition: a highly



-> stacking of data of all in

(~ 650 indiv. vp's) in clus

-> usage of an appropriate

model for exactly *this* sample

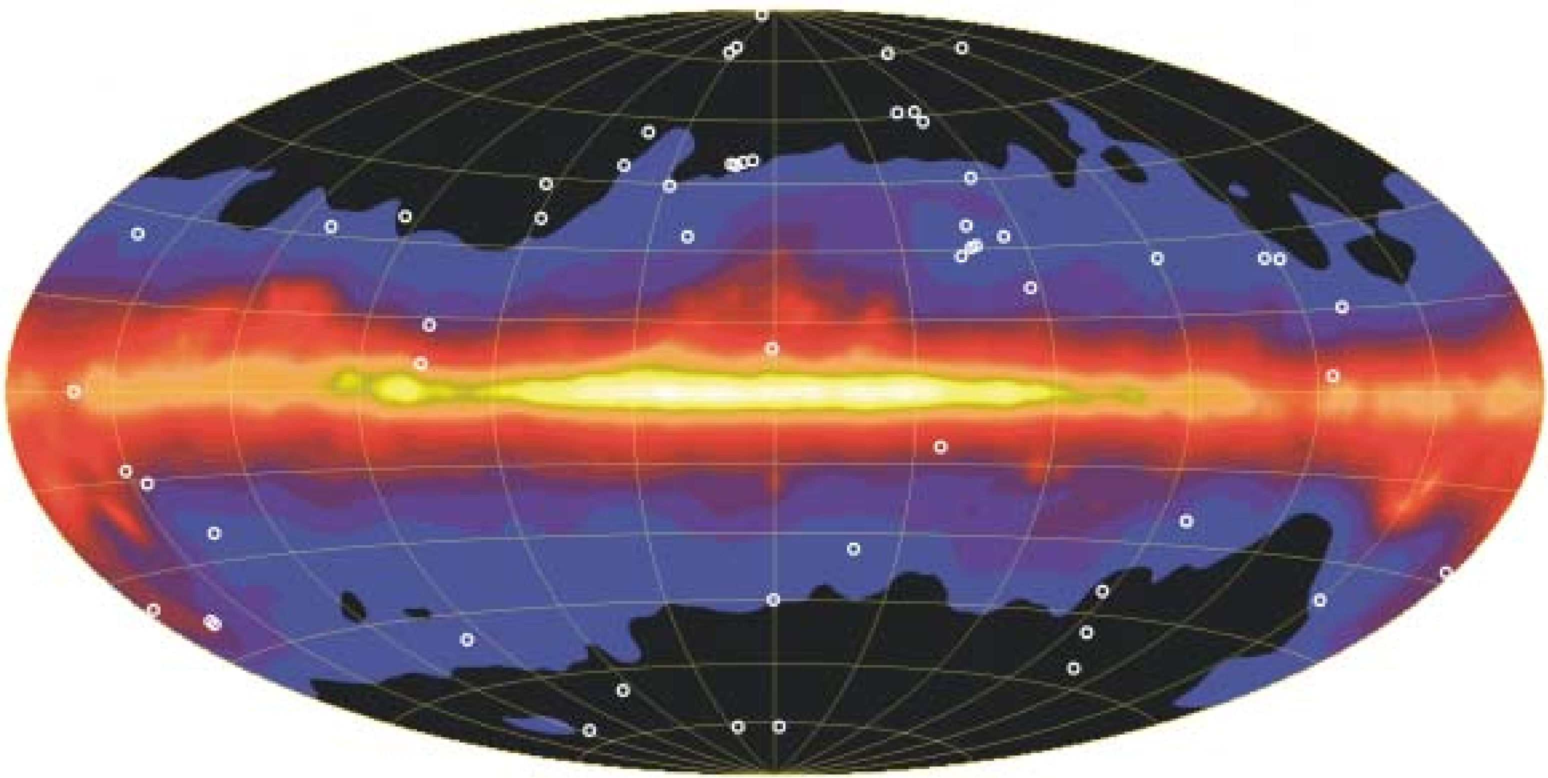
-> correction for different foreground expectations to account

for unequal exposures

$$\mathrm{DF}_{\mathrm{tot}} = \frac{1}{\varepsilon_{\mathrm{tot}}} \sum_i c_i = \frac{1}{\varepsilon_{\mathrm{tot}}} \sum_i \varepsilon_i \mathrm{DF}_i \,, \qquad \varepsilon_{\mathrm{tot}} = \sum_i \varepsilon_i \,.$$

-> max lh algorithm

-> flux determination at image center

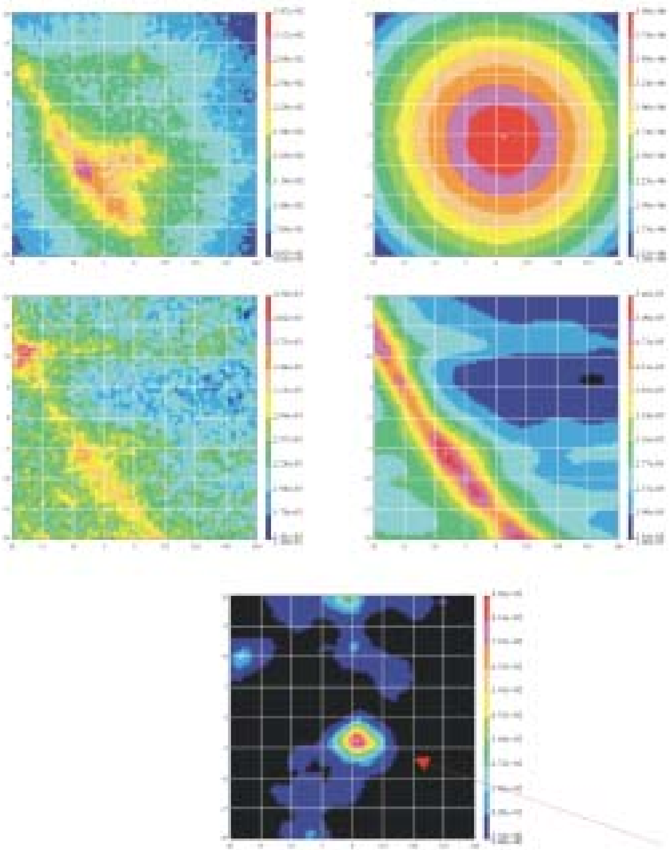


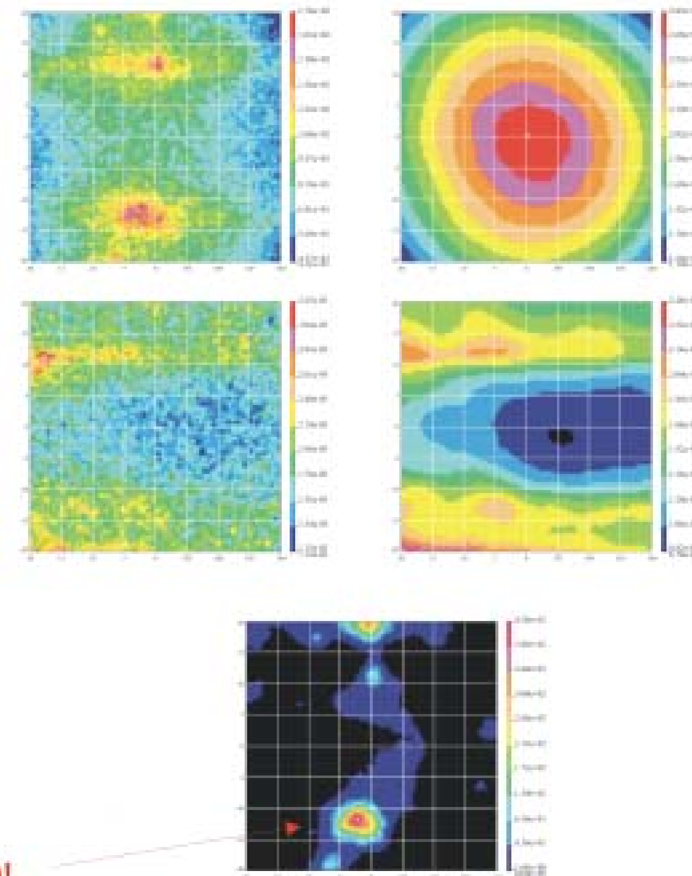
Galactic diffuse model as used in likelihood application (Hunter et al. 1997)

here incl. positions of considered clusters; E > 100 MeV; gmult = 1, gbias = 0

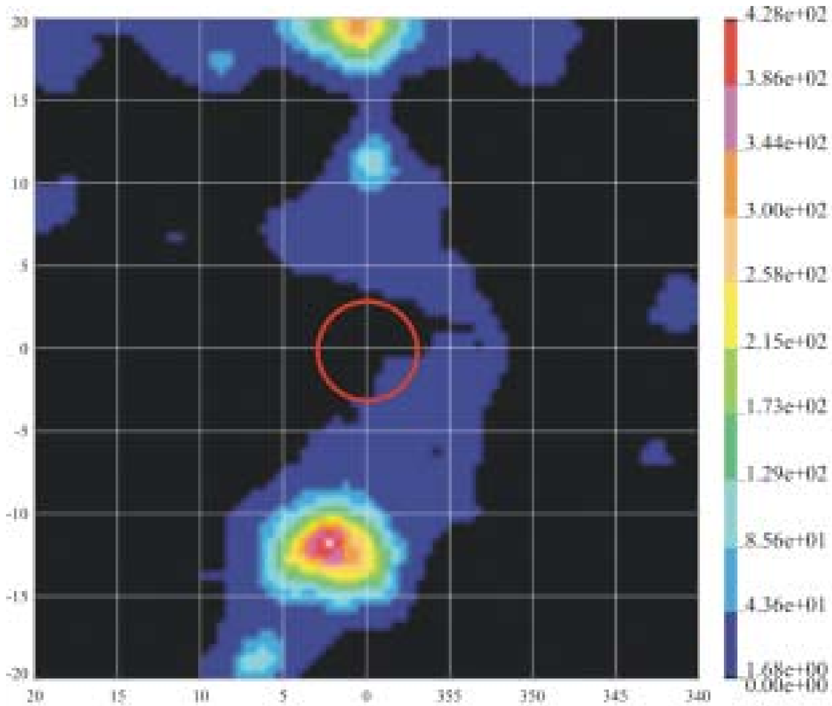
the complete sample (58)

the reduced sample (50) (predominant identified point sources or galactic plane at image center -> removed!)





3C279!



NO DETECTION !

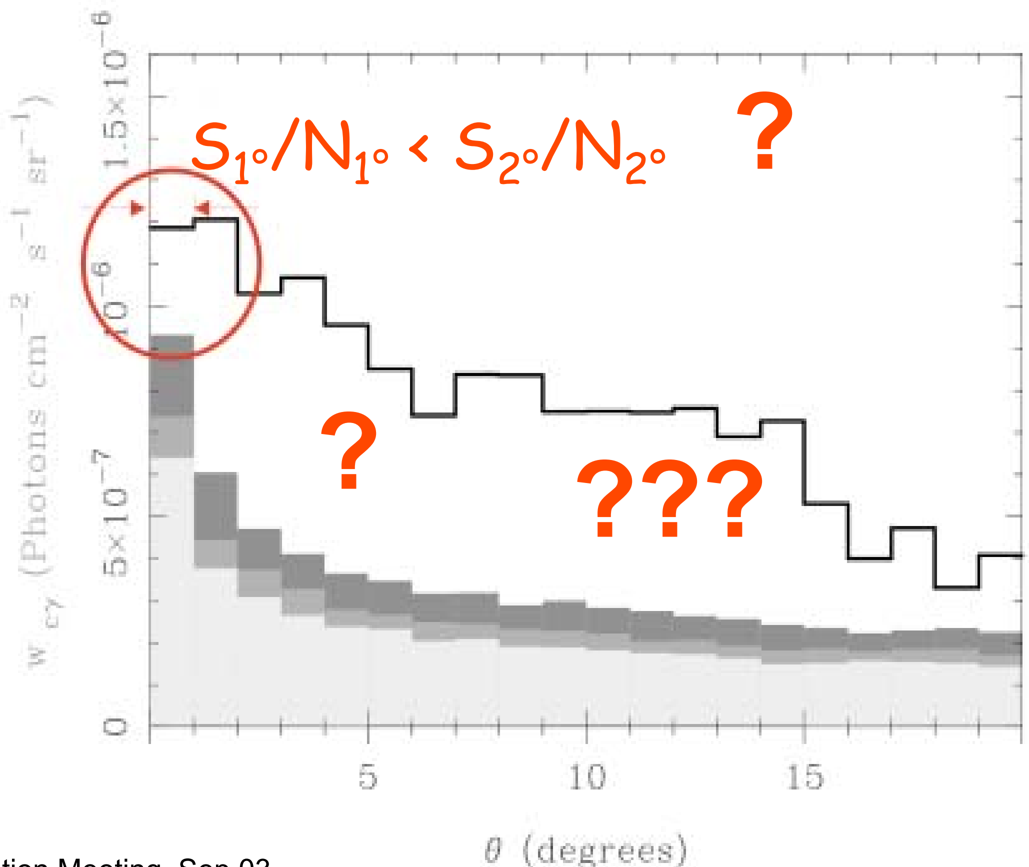
combined exposure: 3.5 x 10^{10} cm^2 s

upper limit (50 cluster sample): 5.9 x 10^{-9} cm^{-2} s^{-1}

energy averaged psf (E > 100 MeV) 6 **wrong** ure

68% in 3.1° aperture, 1° corresponds only 24% flux enclosure

	claim	recalc using correct psf	conclusion
$r=1°$:	1.14×10^{-9} cm^{-2}s^{-1}	4.7×10^{-9} cm^{-2}s^{-1}	marginally inconsistent
$r=2°$?	9.6×10^{-9} cm^{-2}s^{-1}	our u.l.: 5.9×10^{-9} cm^{-2}s^{-1}	clearly inconsistent !!



main result figure from S&M 2002

Conclusions:

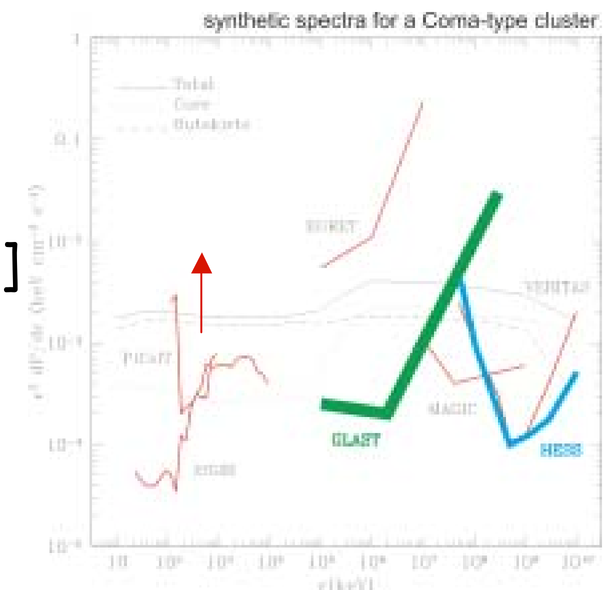
No observational evidence for the contribution of galaxy clusters at high-energy gamma-rays yet.

Analysis requires precise handling of diffuse foreground, instrumental response, observational pecularities, and statistical assessments (noise expectations)
... but EGRET was *just* not sensitive enough here

[as for radio galaxies & Seyferts (Cillis, Hartman & Bertsch 2003, in submission), Starburst galaxies (Blom et al. 1999) and Normal Galaxies (Pavlidou & Fields 2001)]

Conclusions 2:

Confirmation of this negative observational result from most recent publications:



Miniati 2002, 2003:
[20...30% EGDB, but accounted for p & e]

Keshet et al. 2003 [~ 10% EGDB]

Gabici & Blasi 2003 [< 10% EGDB, following cluster merger evolution]

Berrington & Dermer 2003 [Only minor contribution to EGDB, which is featureless power law of 2.1]

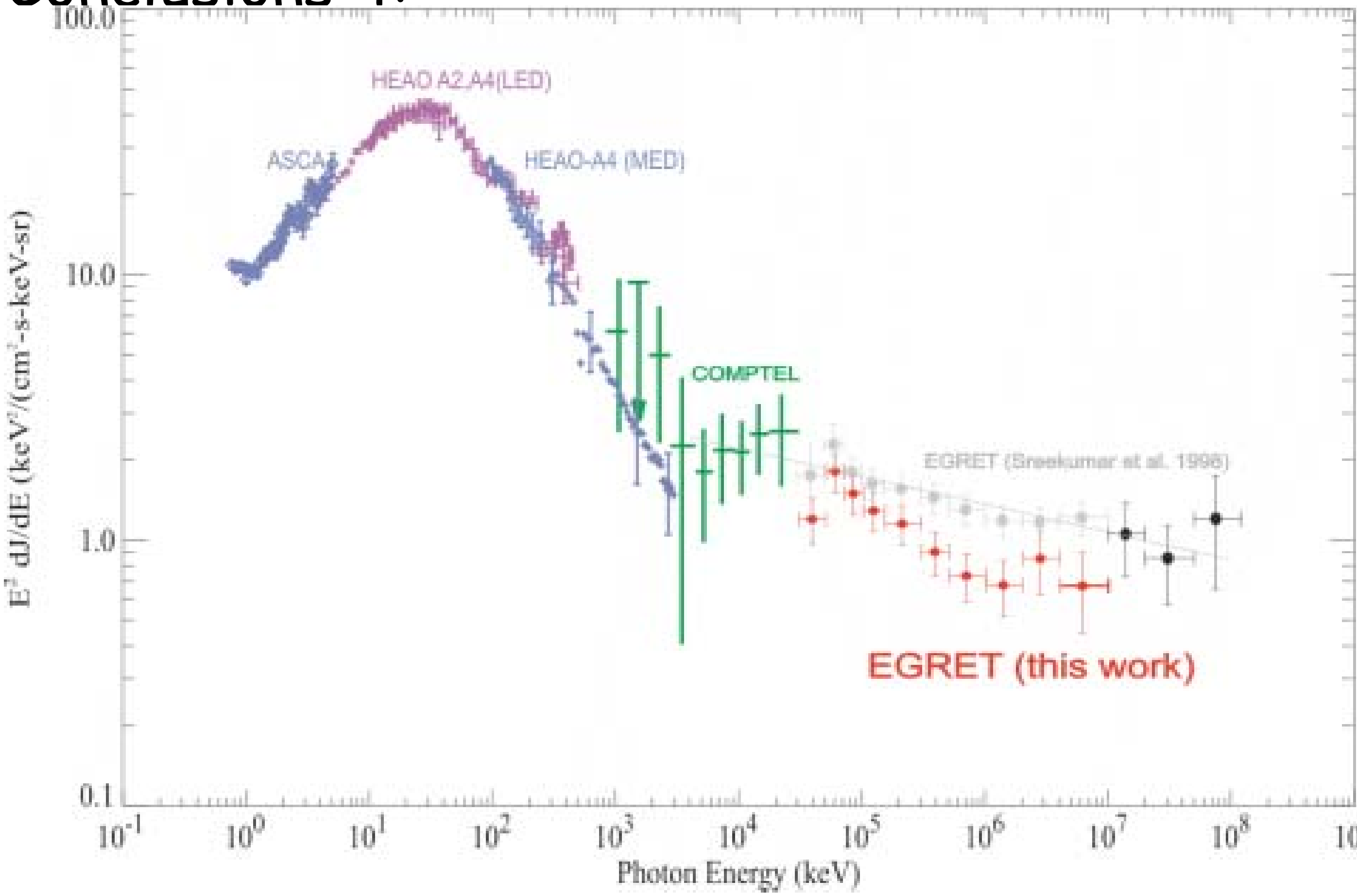
Conclusions 3:

When a cluster will be detected at gamma-rays (by GLAST), predictions on the EGDB contribution will be more precisly determined/verified.

We were presumable close to the required instrumental sensitivity in EGRET, so it's a very appropriate science case for GLAST.

Predictions exist already! (see literature)

Conclusions 4:



reevaluated!

rom EGRET Data

nation of EGDB

-> improved modelling of high-latitude γ-rays based on IC halo emission

Stay tuned!