Cosmic Gamma-Ray Background Radiation

--- AGNs, and more? ---

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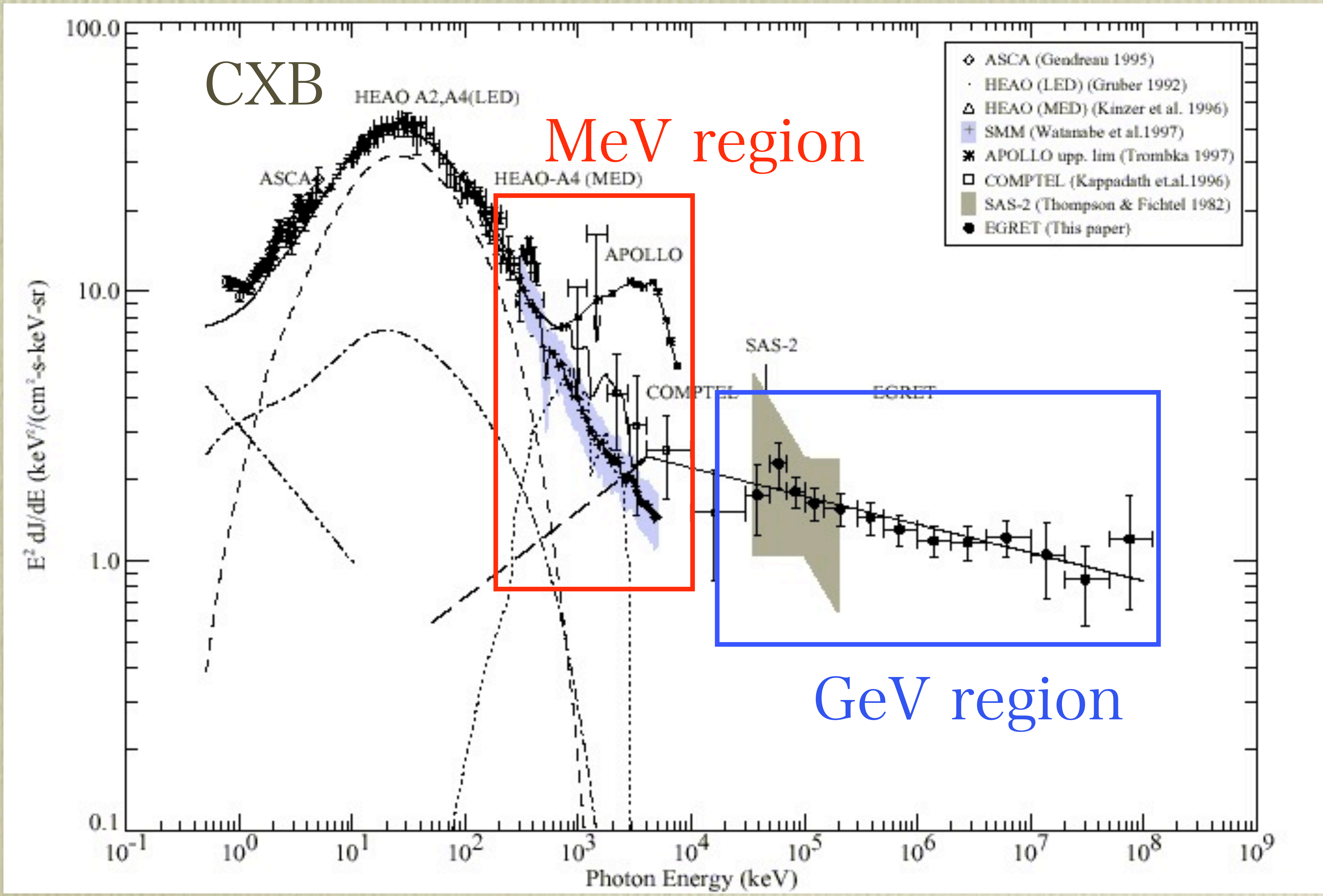
The Next Generation of Physics, Spun from Universality & Emergence

Outline

- Origin of the Cosmic Gamma-Ray Background:
  - MeV and GeV regions
- Origin of MeV background
  - non-thermal “tail” from X-ray background by AGNs
- Origin of GeV background
  - the minimum contribution from blazars
- Do we need another contribution than the minimum contribution from AGNs? e.g., DM annihilation?

Cosmic X-ray & gamma-ray background (CXB, CGB)



Sreekumar et al. 1998

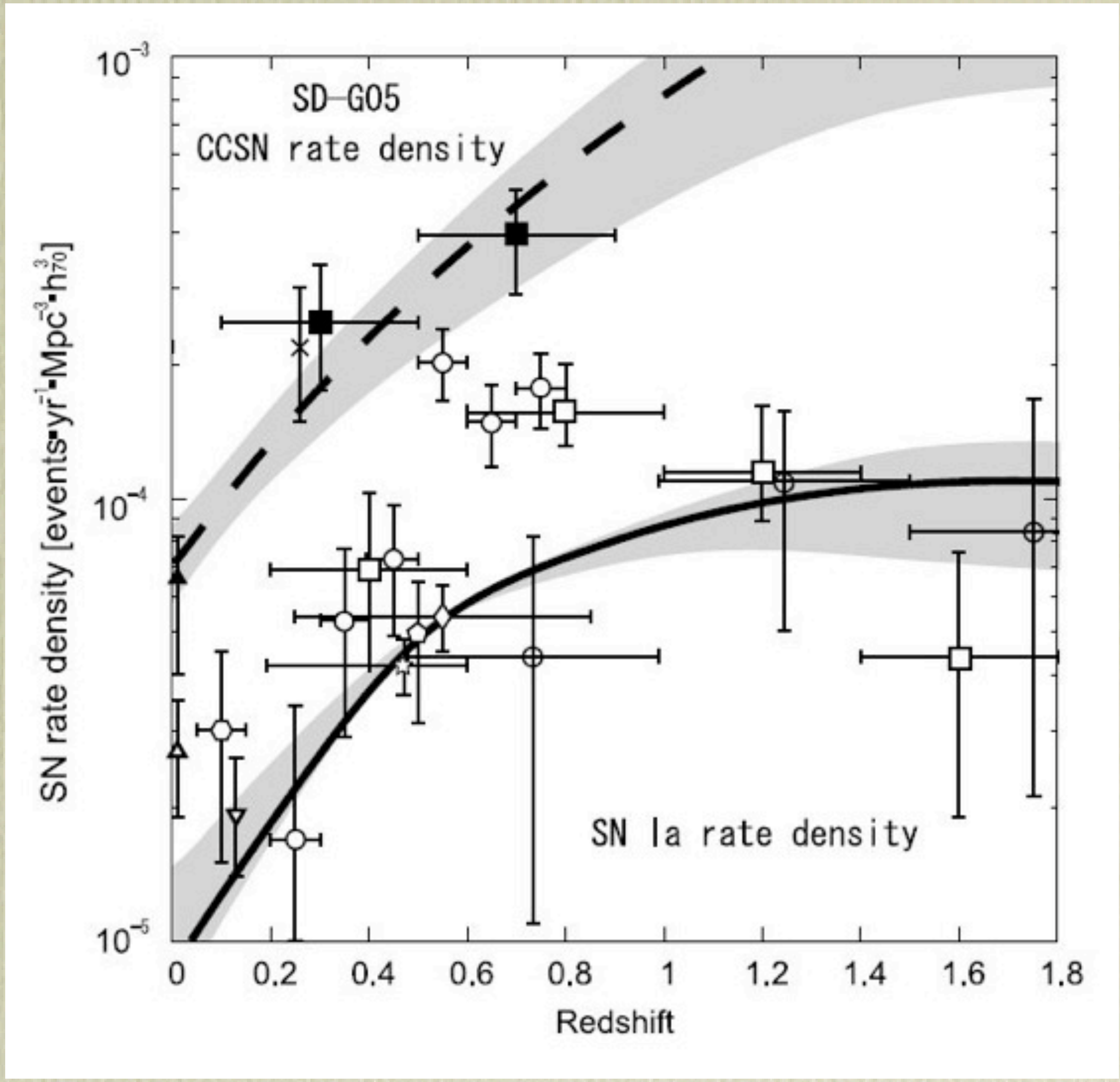
Origin of MeV Background

- Cosmic X-ray background (CXB)
  - can be explained by integration of normal X-ray AGNs
  - has mostly been resolved into discrete sources

- MeV background
  - AGN? ("conventional" AGN models for CXB cannot explain)
  - SN Ia? (rate not sufficient)
    - Clayton & Ward '75; Zdziarski '96; Watanabe+'99
  - MeV-mass dark matter annihilation!?
    - Ahn+Komatsu '05a; Rasera+'06

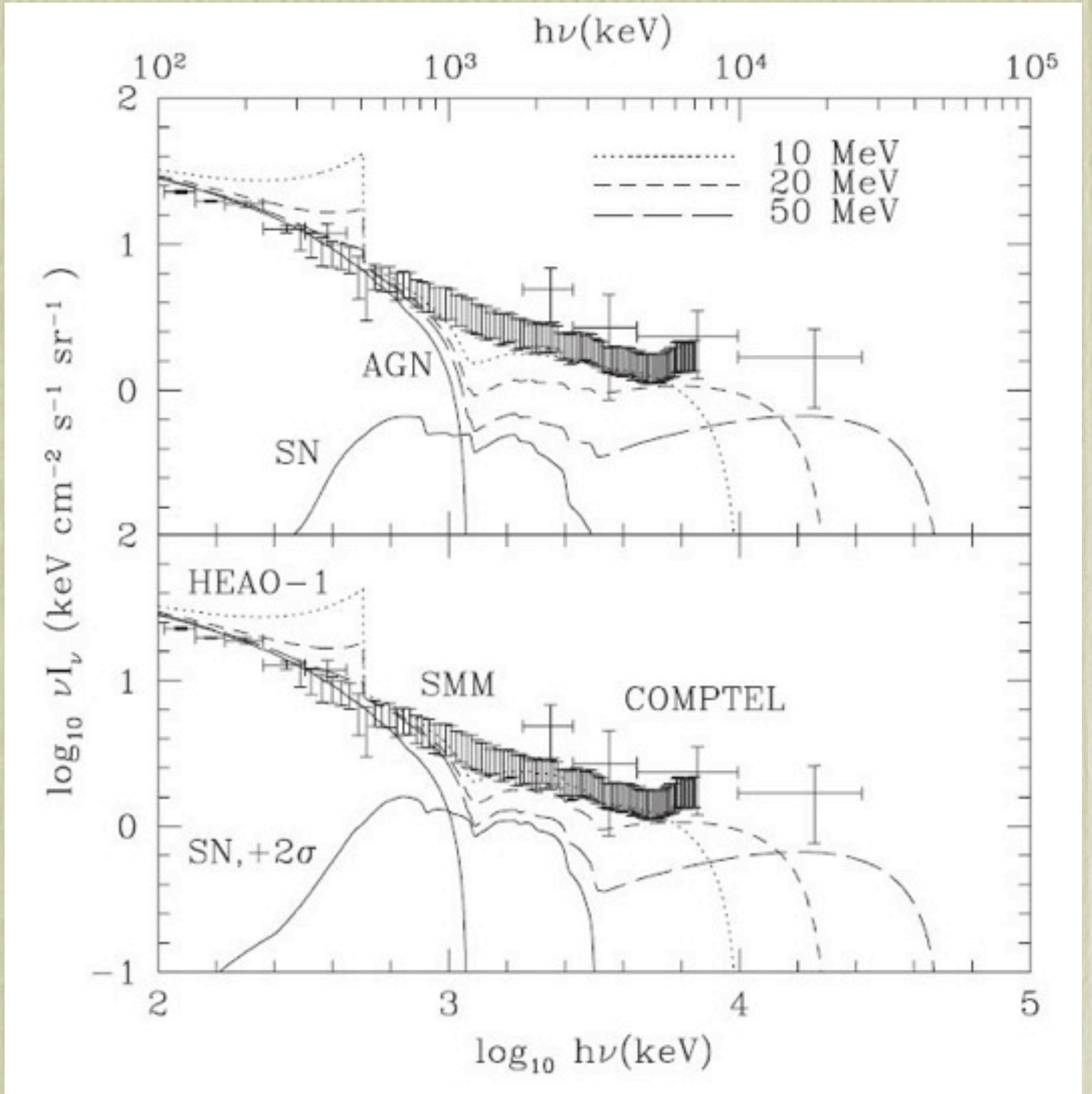
Cosmic SN Rate Evolution

- SN Ia rate evolution to z~1 now well known
- ~10 times short to explain MeV background from SNe Ia (Ahn+ ’05; Strigari+ ’05)



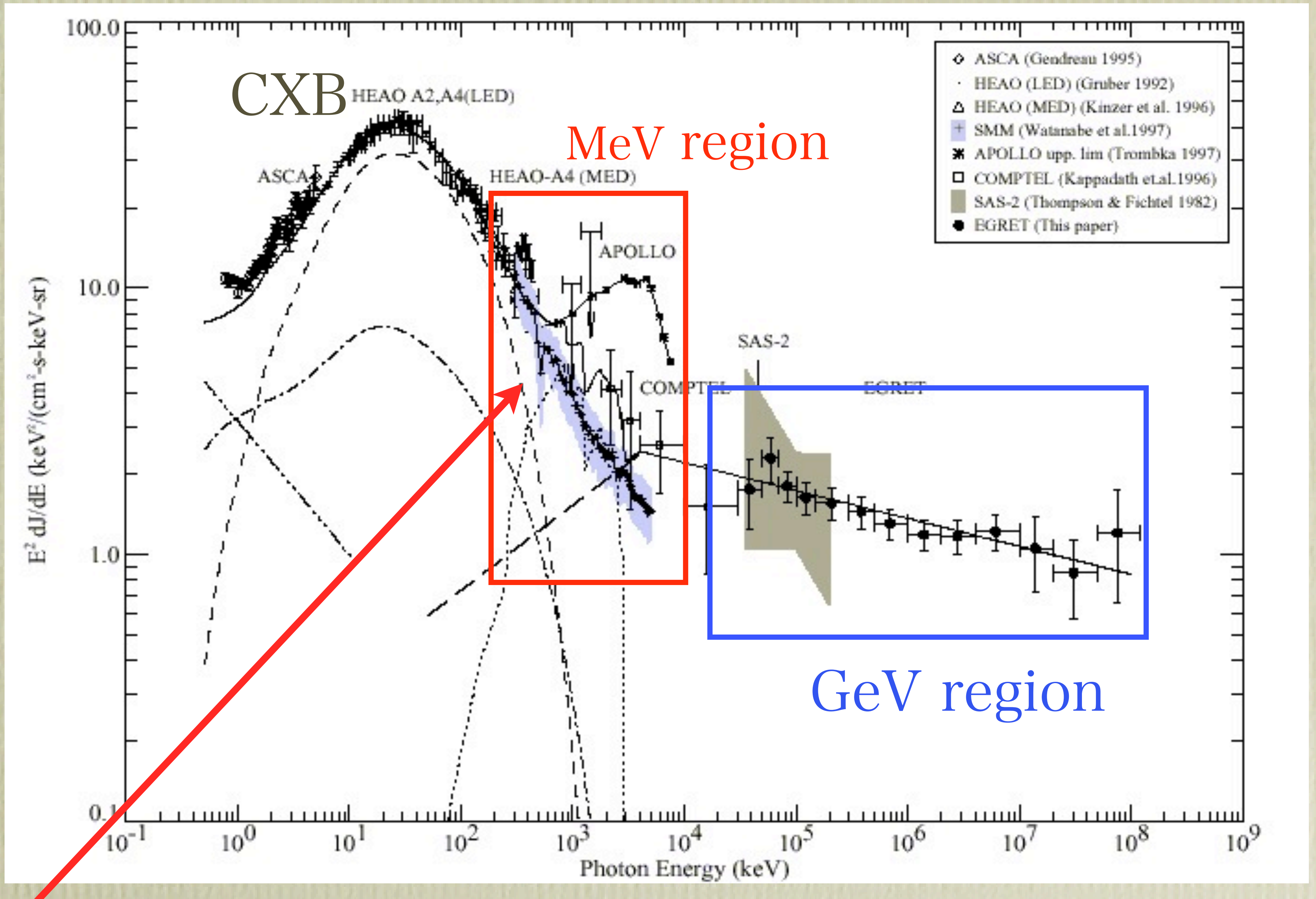
Oda+’08

MeV Dark Matter?



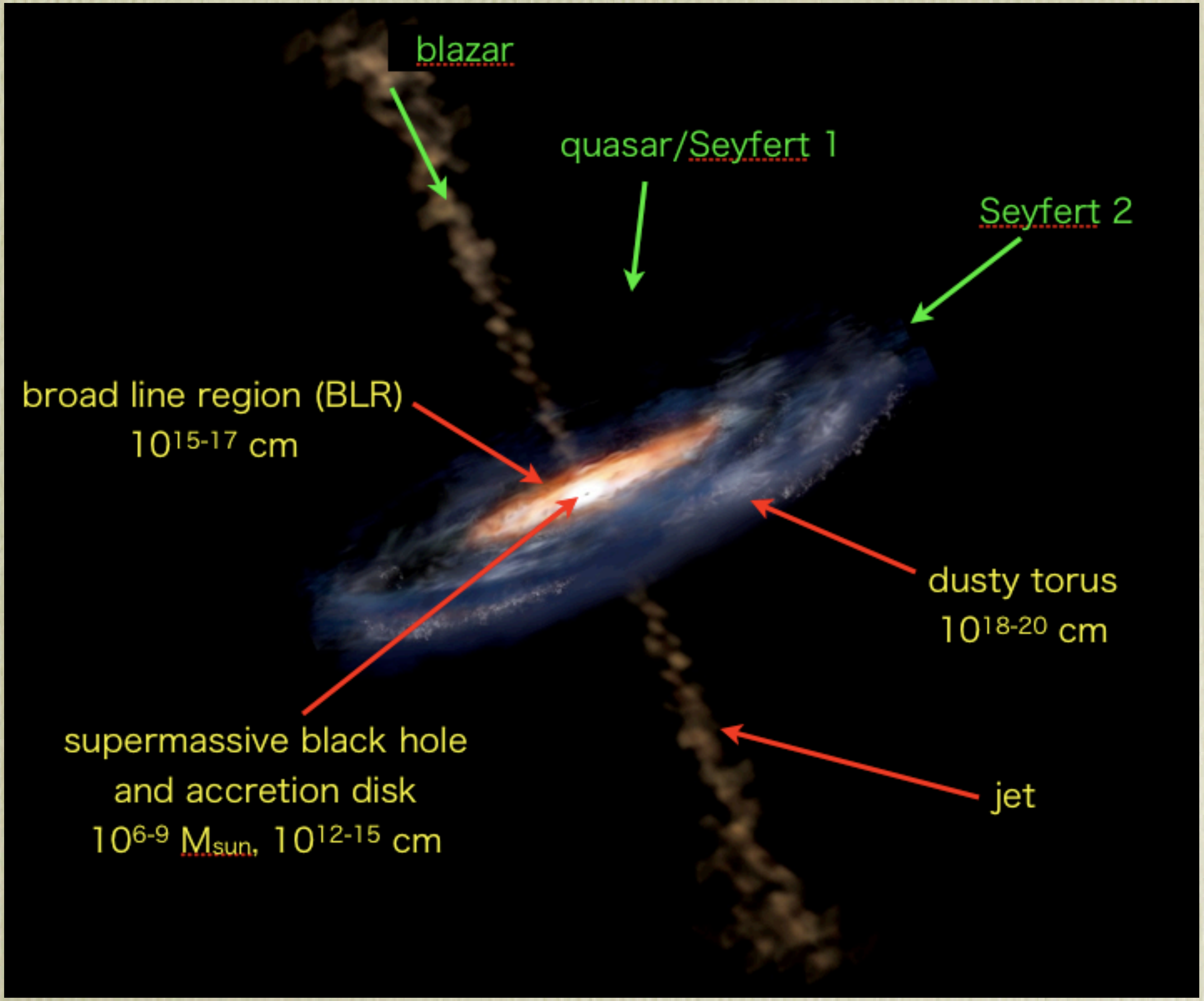
- Ahn+Komatsu ’05

Why not AGNs!?



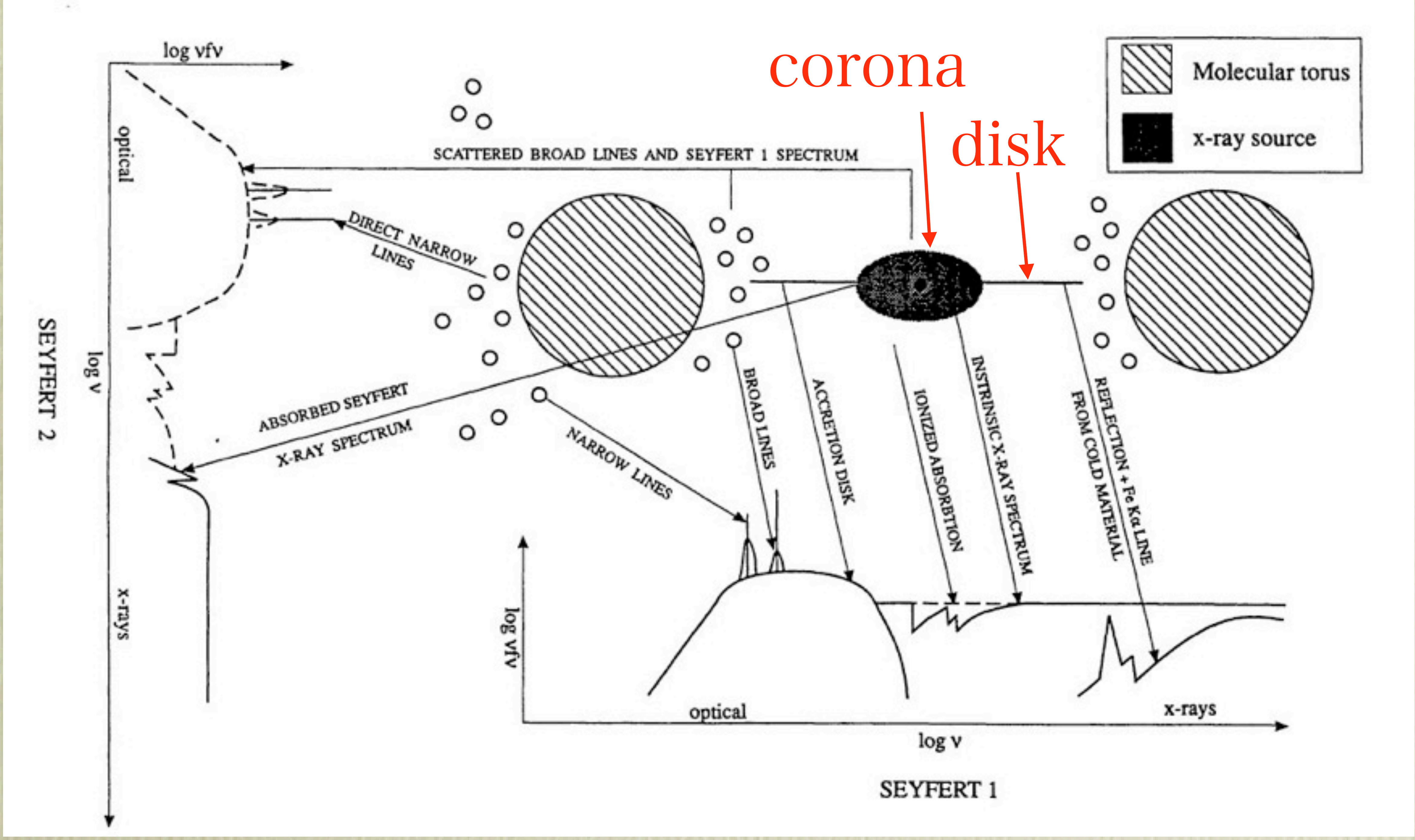
- conventional AGN X-ray model predicts "exponential cut-off"
- However, MeV component "smoothly" connects to CXB!

Active Galactic Nuclei



The Picture of AGN X-ray Spectra

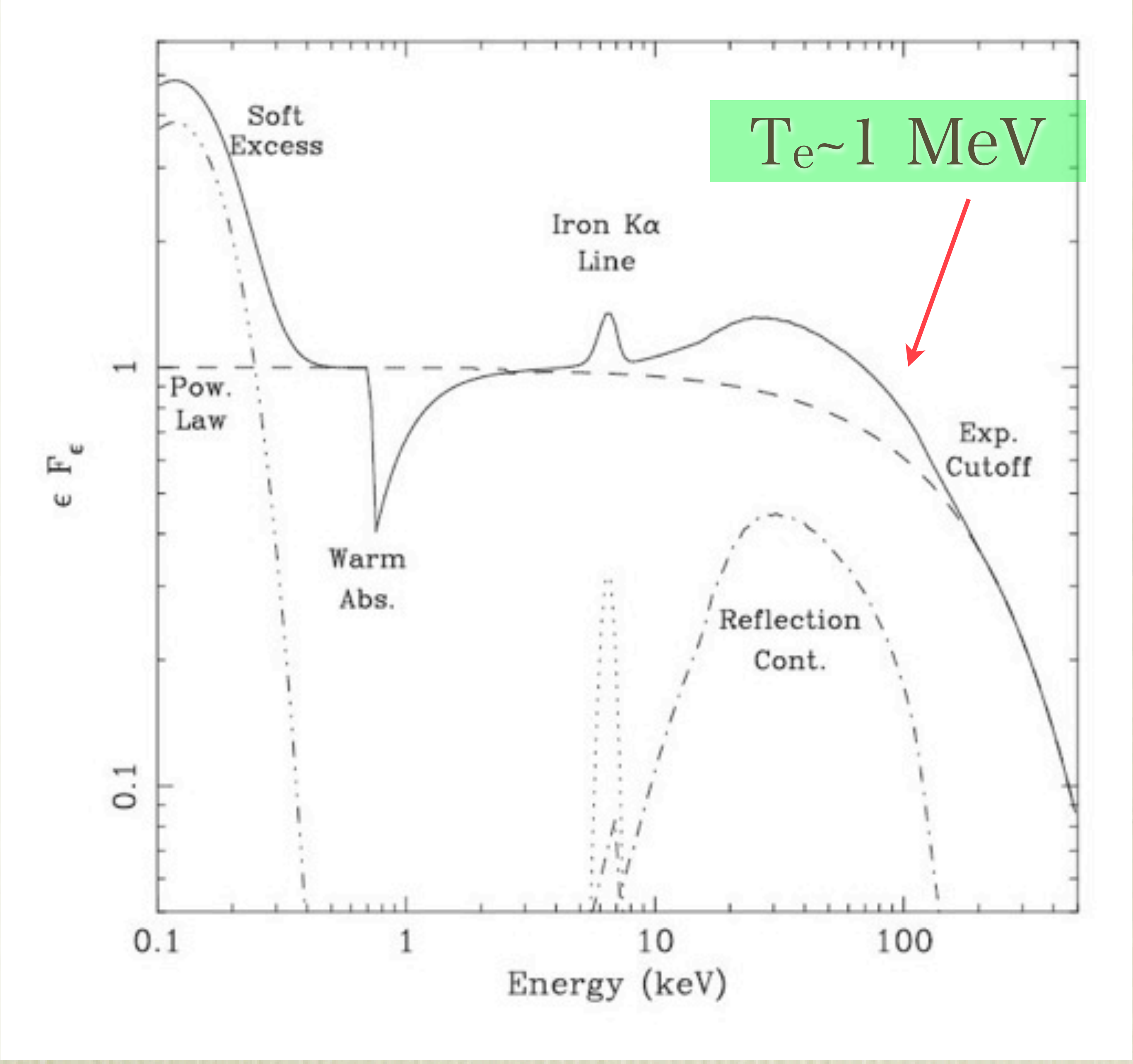
- picture of normal X-ray AGNs (e.g., Seyferts)



Mushotzky et al. 1993

AGN X-ray Spectrum

- X-rays are produced by Compton up-scatter of UV disk photons by hot electrons in corona
- "the exponential cut-off" comes from "assumption" of thermal electron distribution in corona
- what if a small amount of non-thermal electrons exist?



schematic AGN spectrum
Fabian 1998

MeV background by AGNs with nonthermal coronal electrons

- Comptonization calculation by Yoshi Inoue, TT, & Y. Ueda 2008, ApJ, 672, L5
- Energy fraction 3.5%, $dN_e/dE_e \propto E_e^{-3.8}$ will explain MeV background
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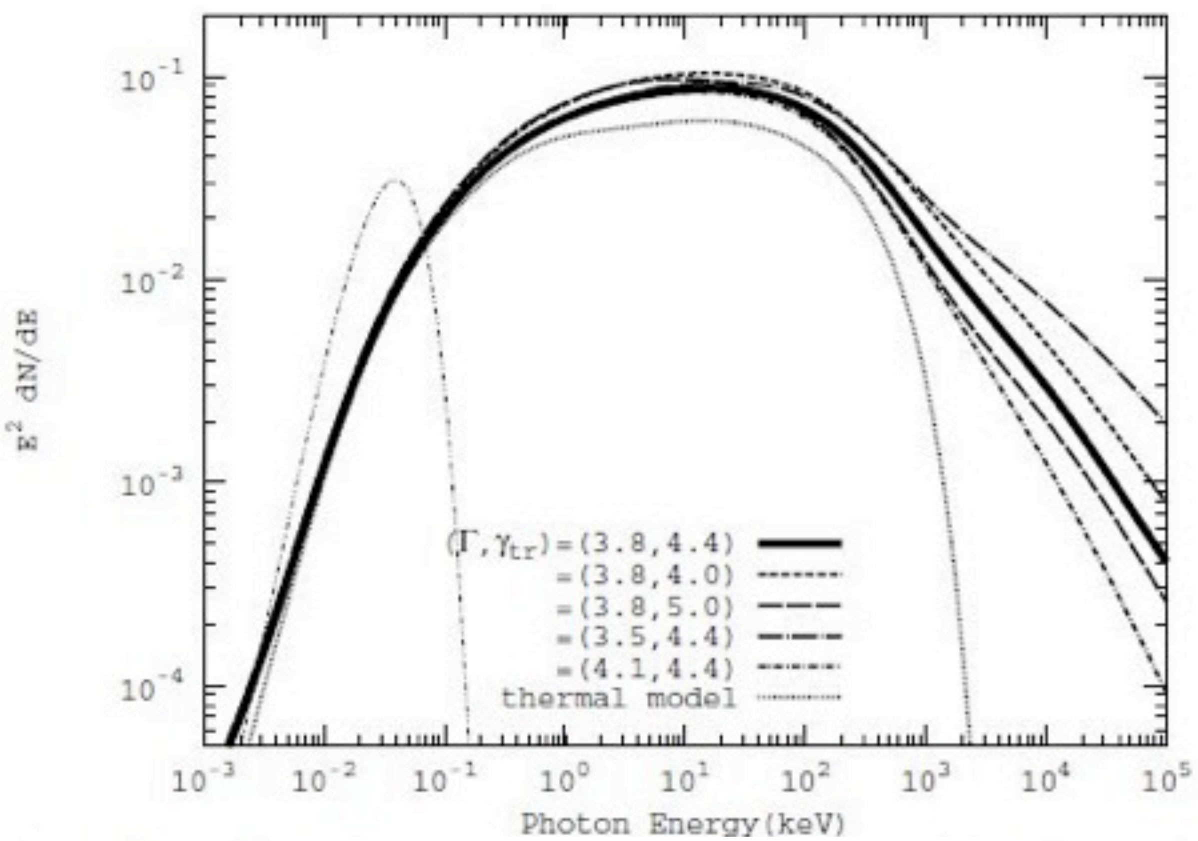
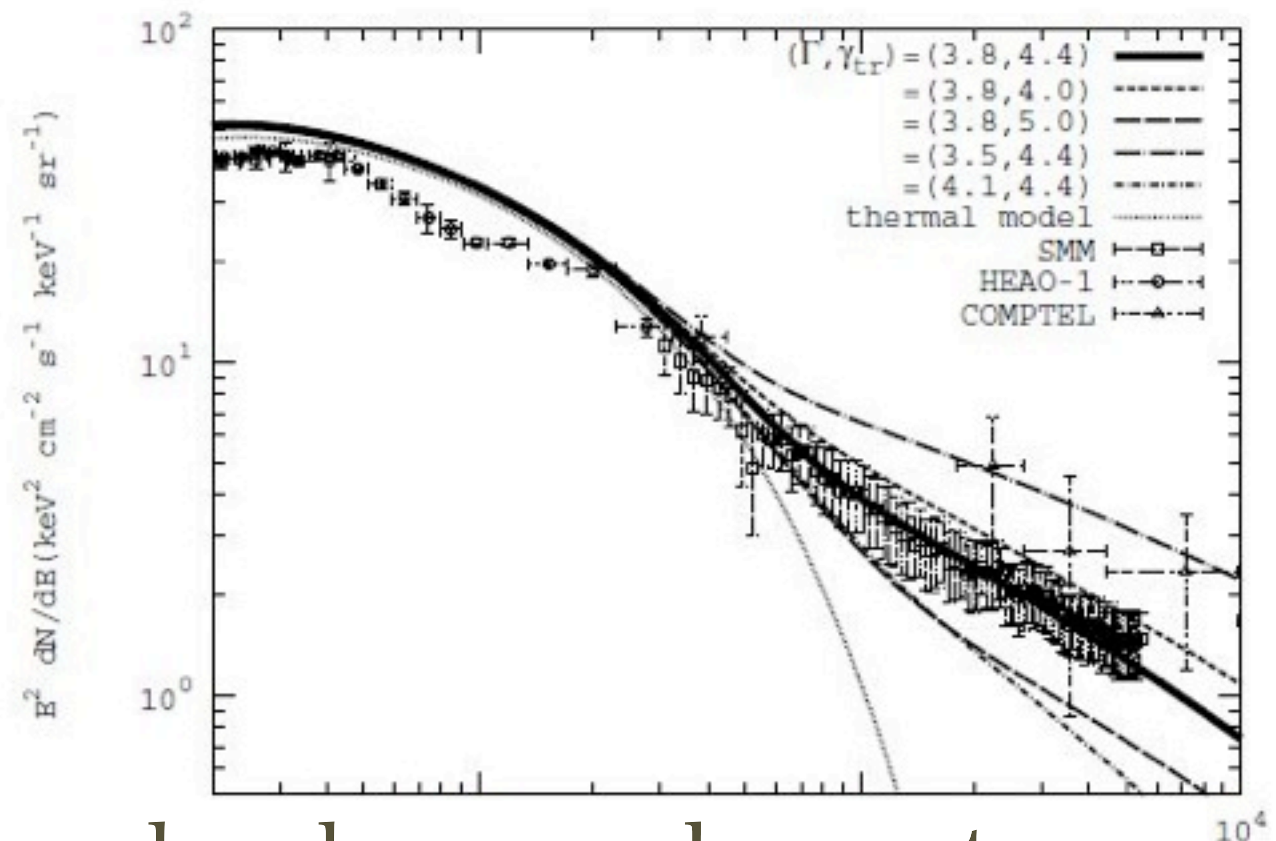


AGN spectrum

FIG. 1.— The ... ds calculated by our model. T... /dE, where dN/dE is a differential photon spectrum. They are Comptonization of UV seed photons without taking into account the reflection component and the absorption effect. The thick solid curve is our standard spectrum with $\Gamma = 3.8$ and $\gamma_{tr} = 4.4$. The other thick curves are for the cases of different model parameters as indicated in the figure. The thick dotted curve is the spectrum only with the thermal component ($kT_e = 256$ keV). The thin dotted curve is the input UV spectrum (a black body with $T_d = 10$ eV).



background spectrum

FIG. 2.— The spectrum of the cosmic background radiation in X-ray and gamma-ray bands, predicted by our model of AGN spectra shown in Fig. 1. For each line-marking, the corresponding AGN spectrum in Fig. 1 is used for the calculation. The data points of HEAO-1 (Gruber et al. 1999) SMM (Watanabe et al. 1999), and COMPTEL (Kappadath et al. 1996) experiments are also shown.

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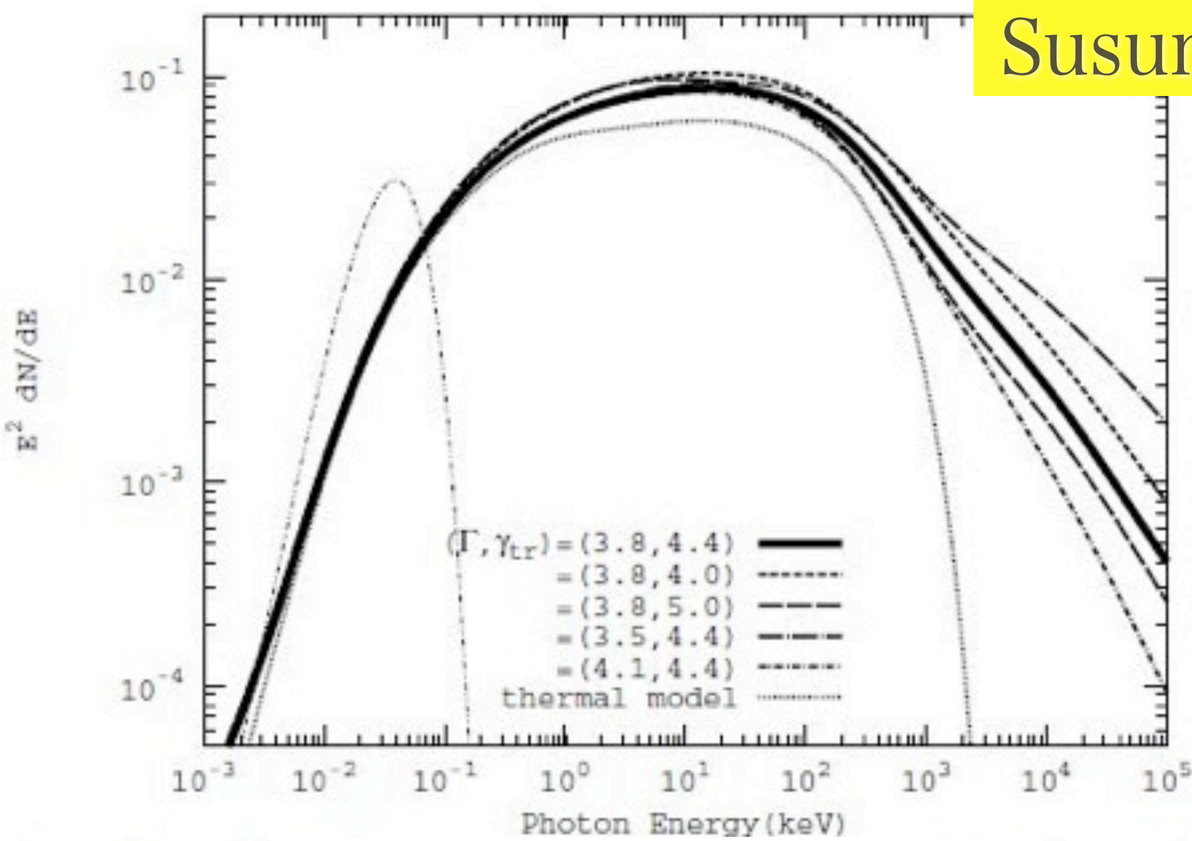

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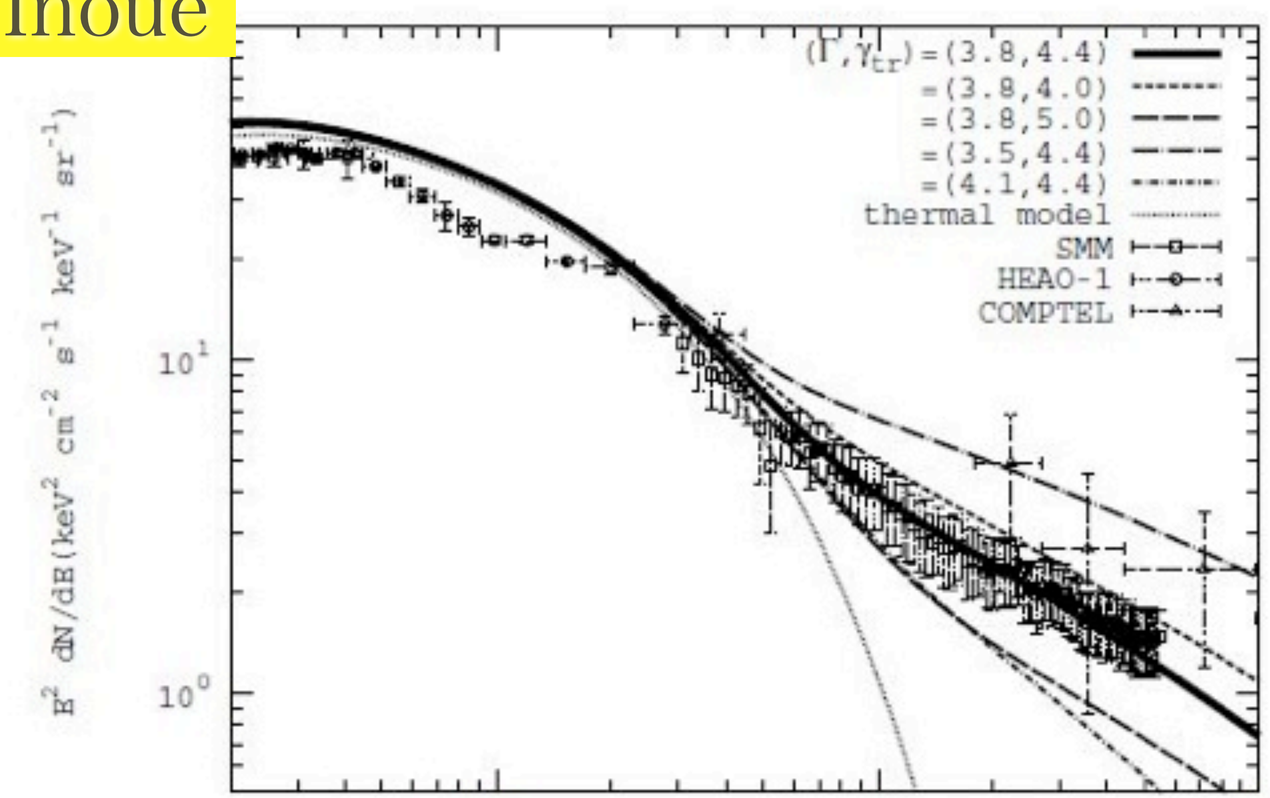

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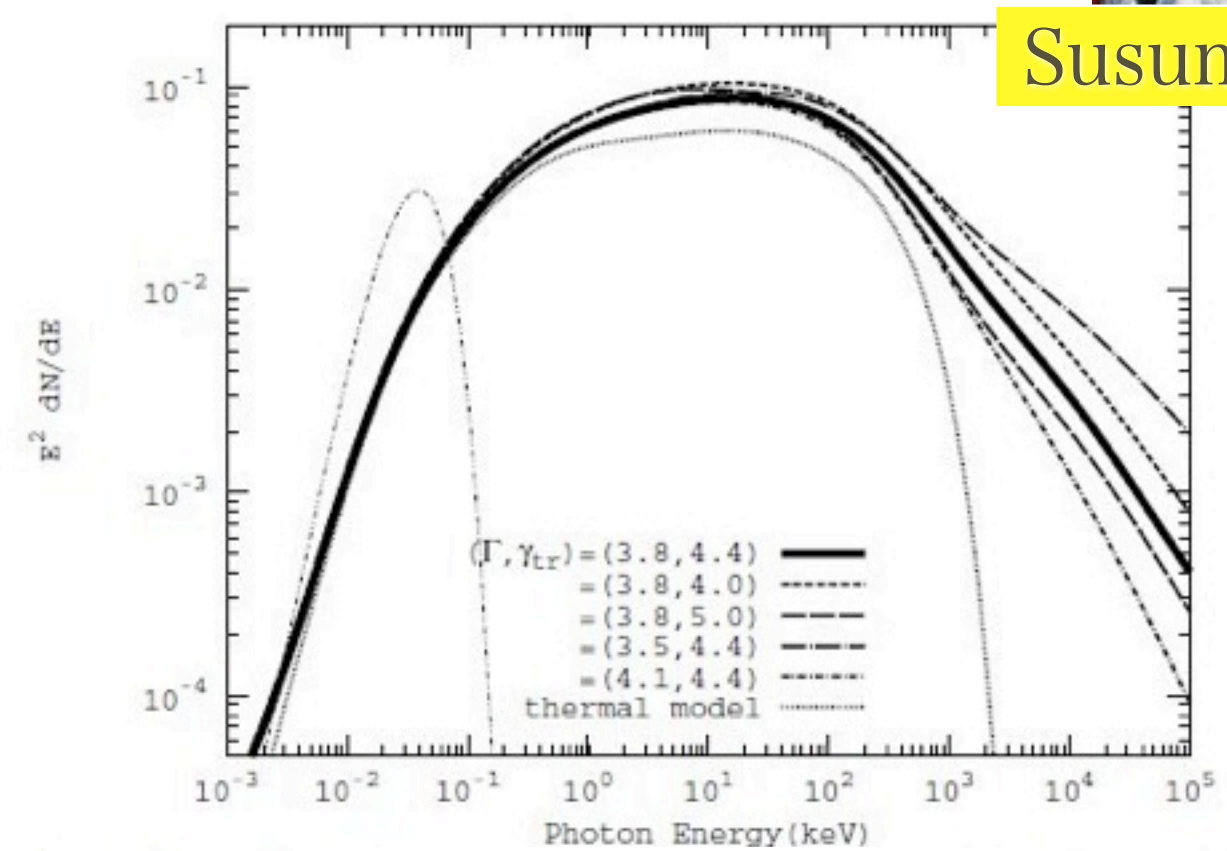

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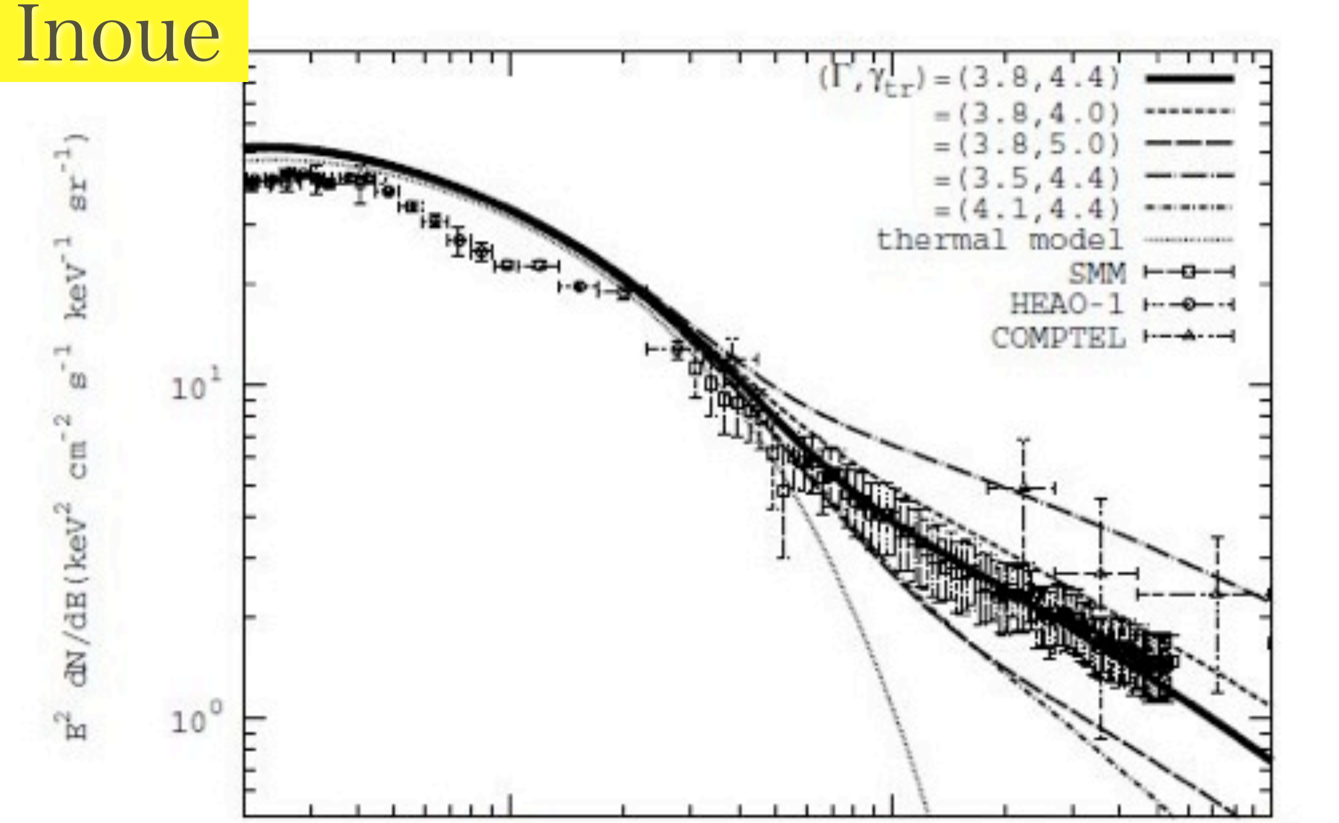

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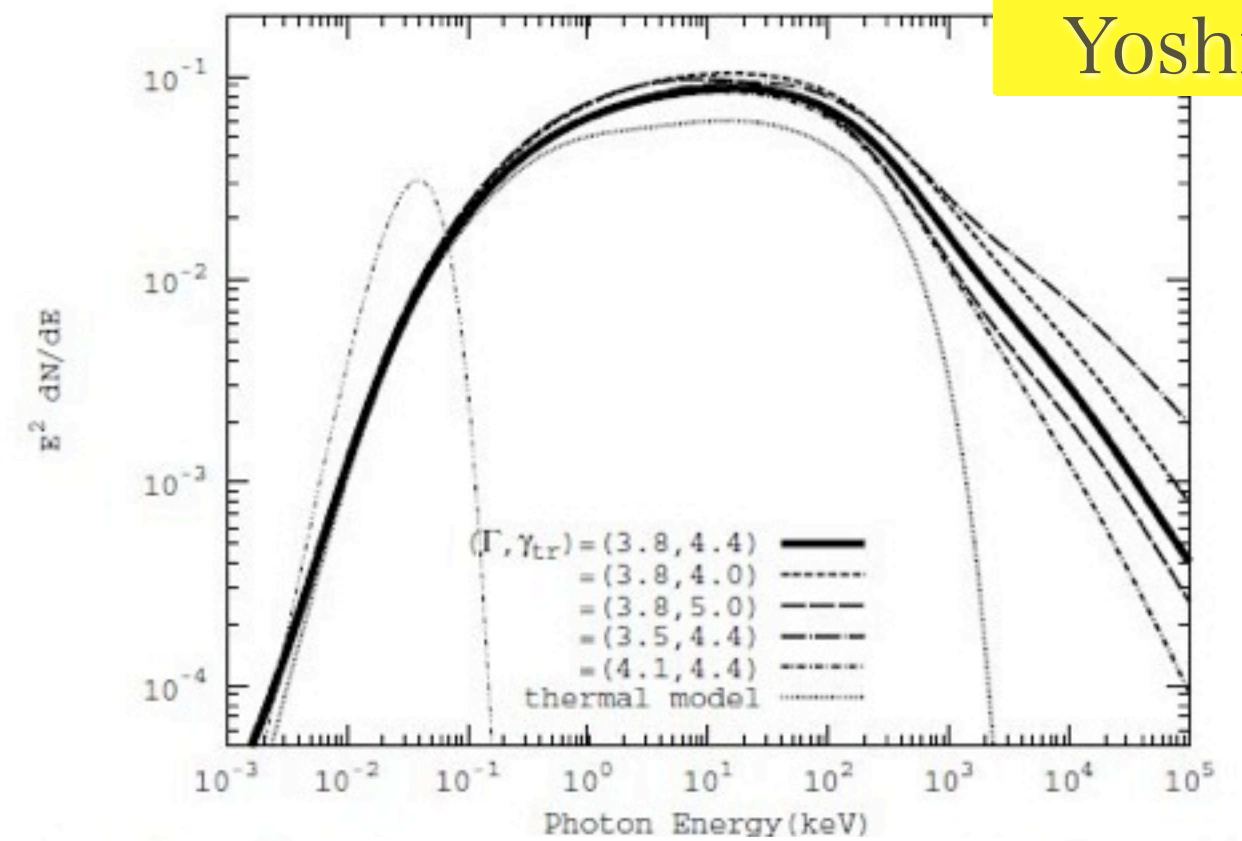

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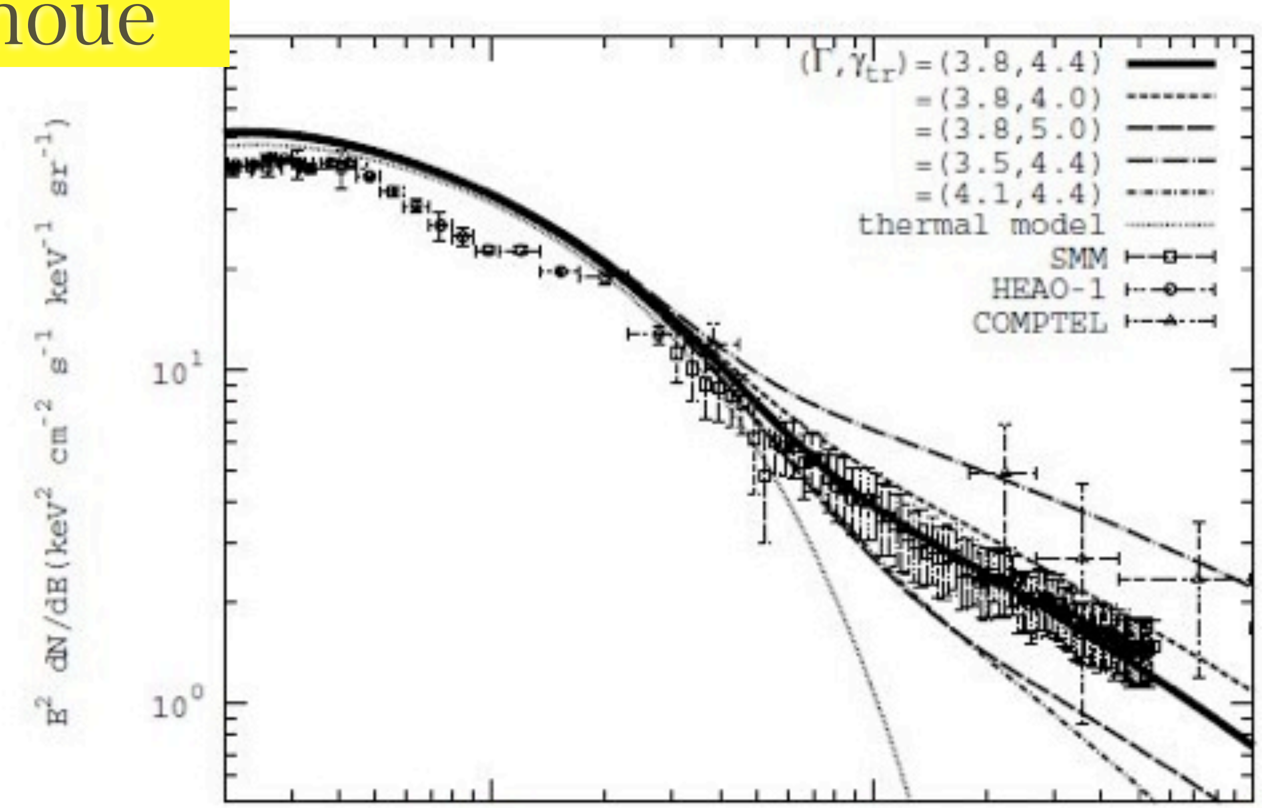

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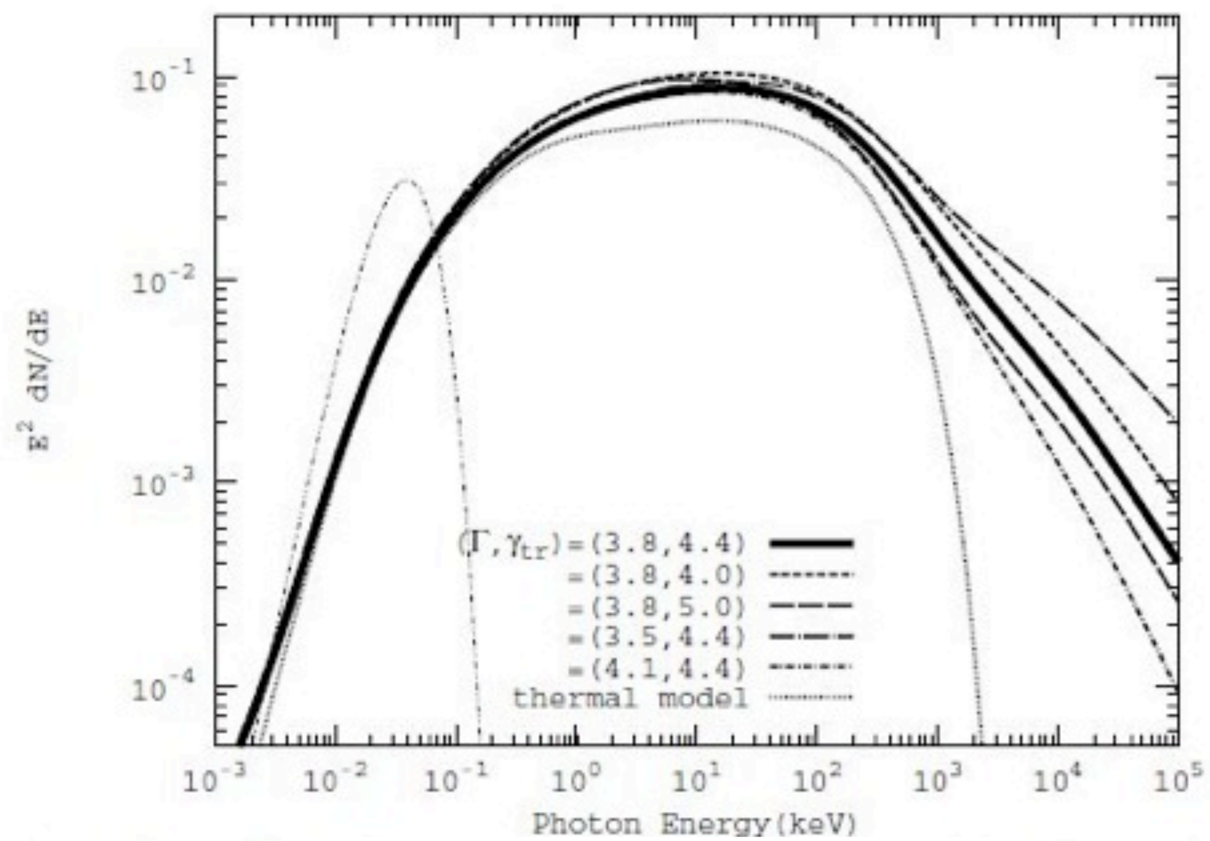

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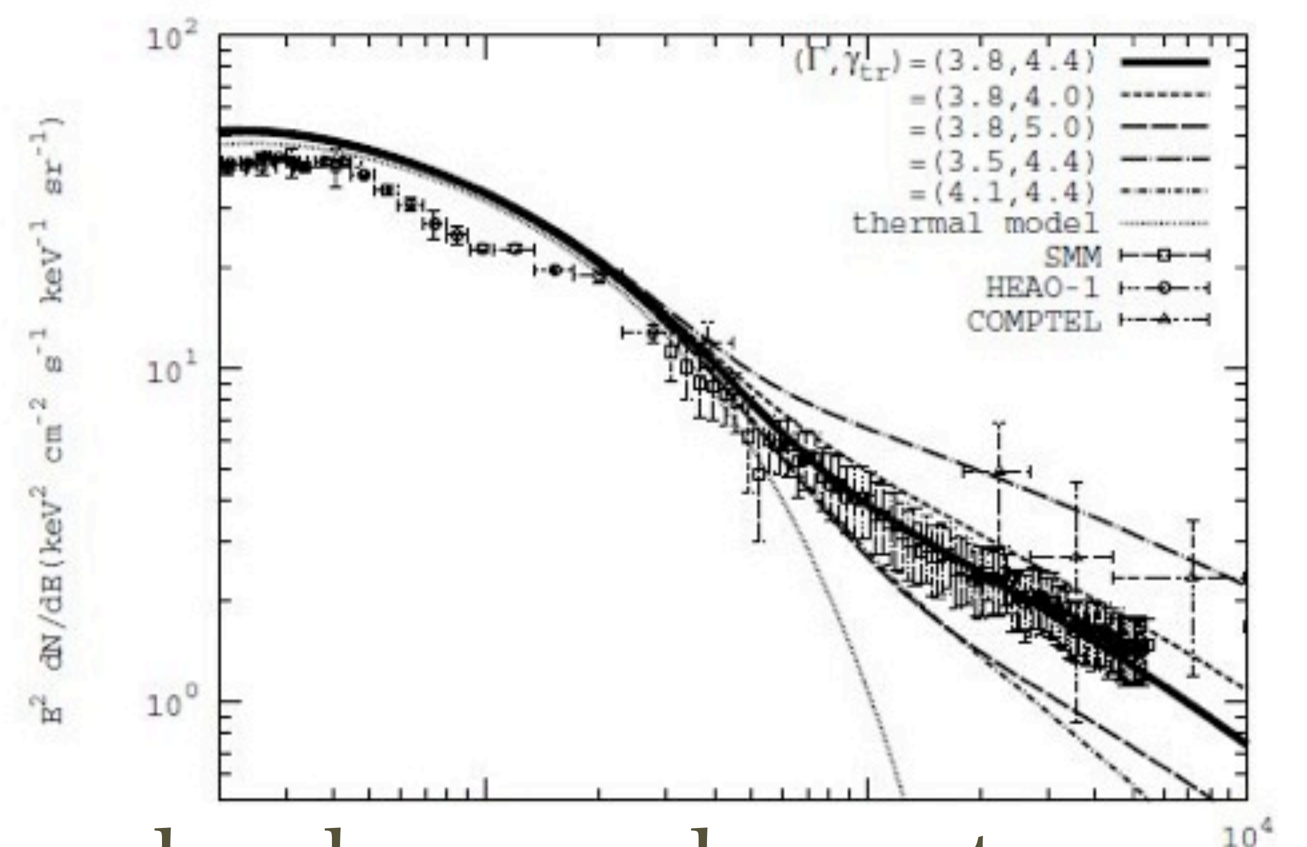

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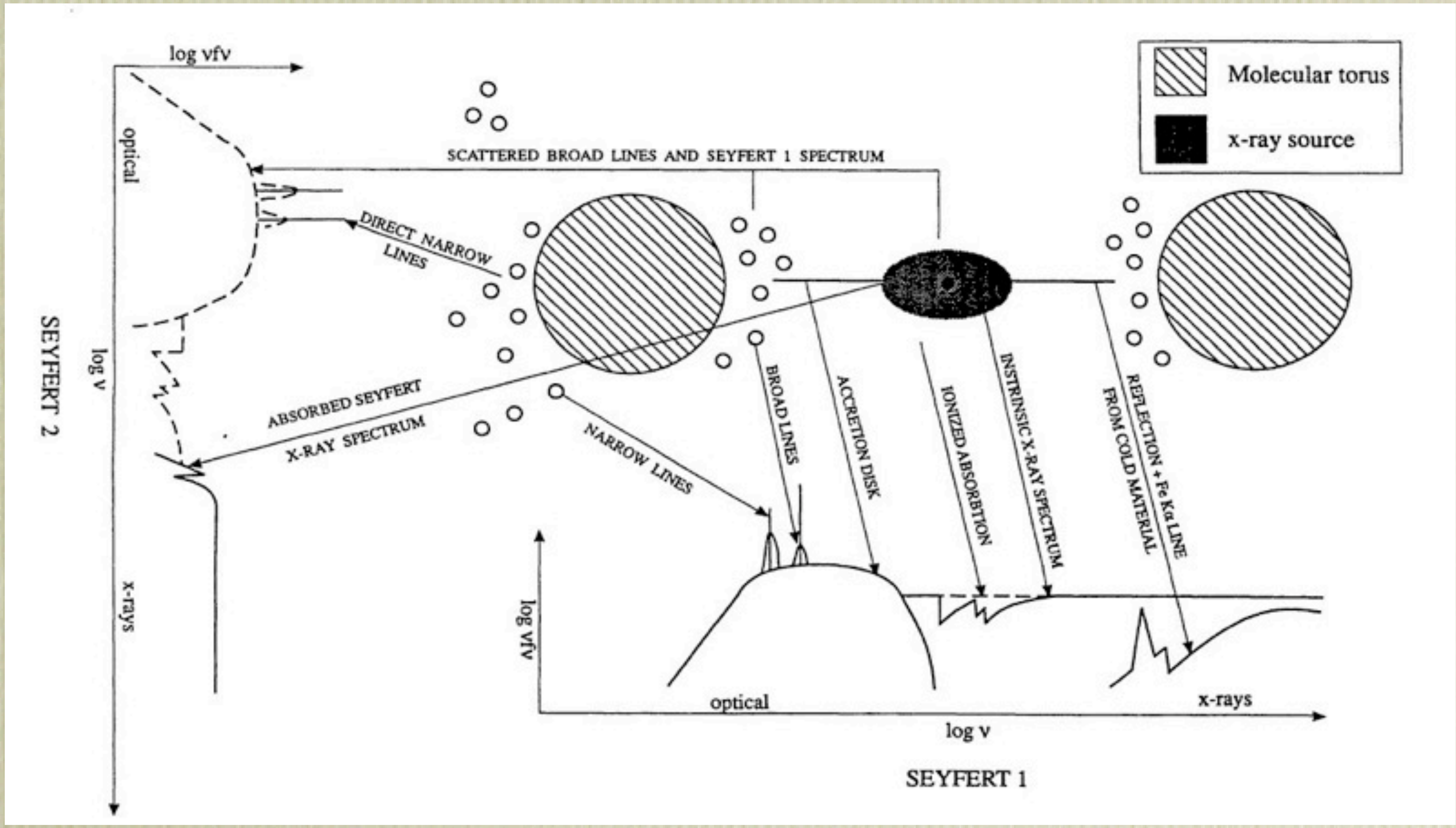
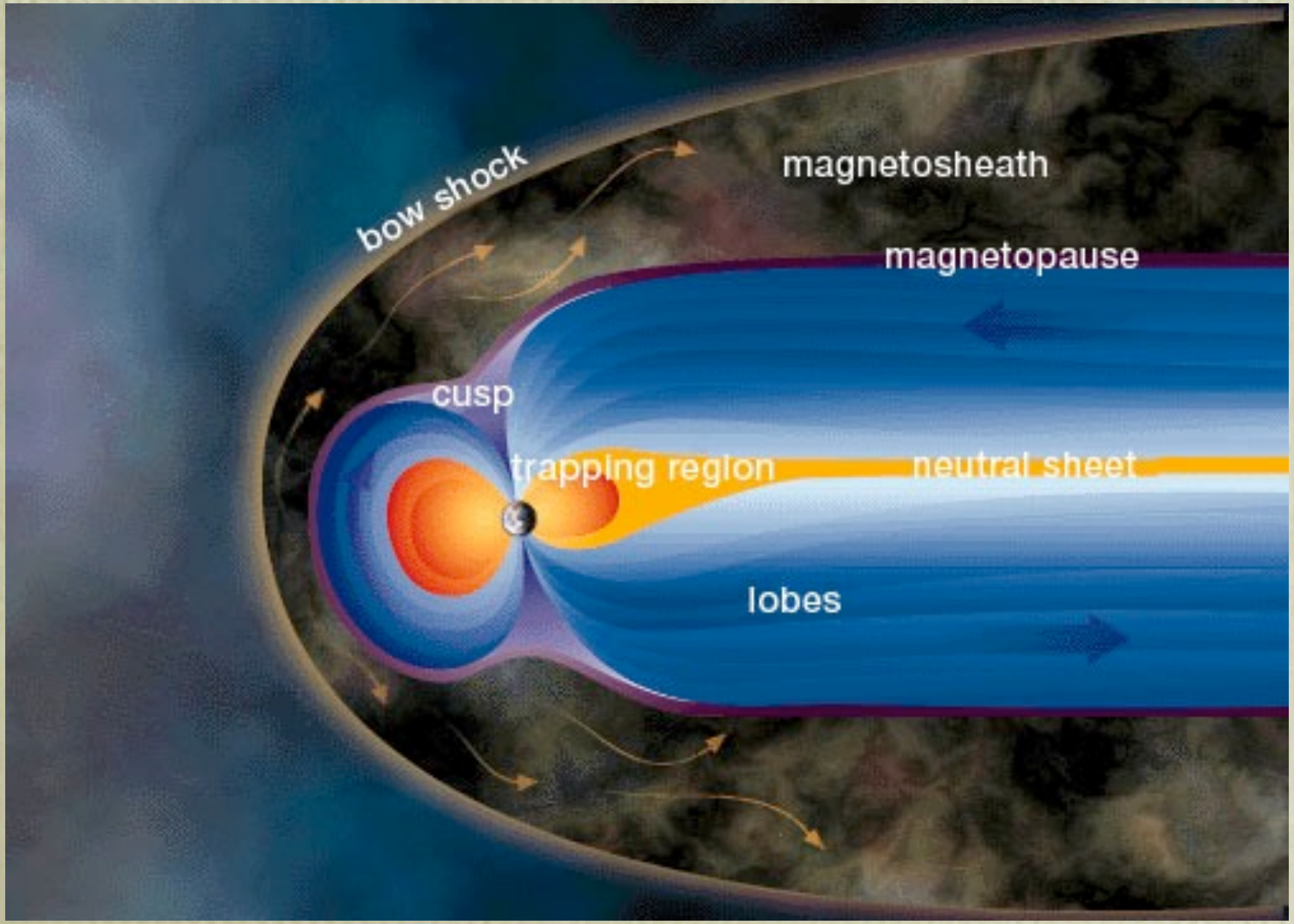
the Origin of Non-thermal Electrons in Hot Coronae in AGNs?

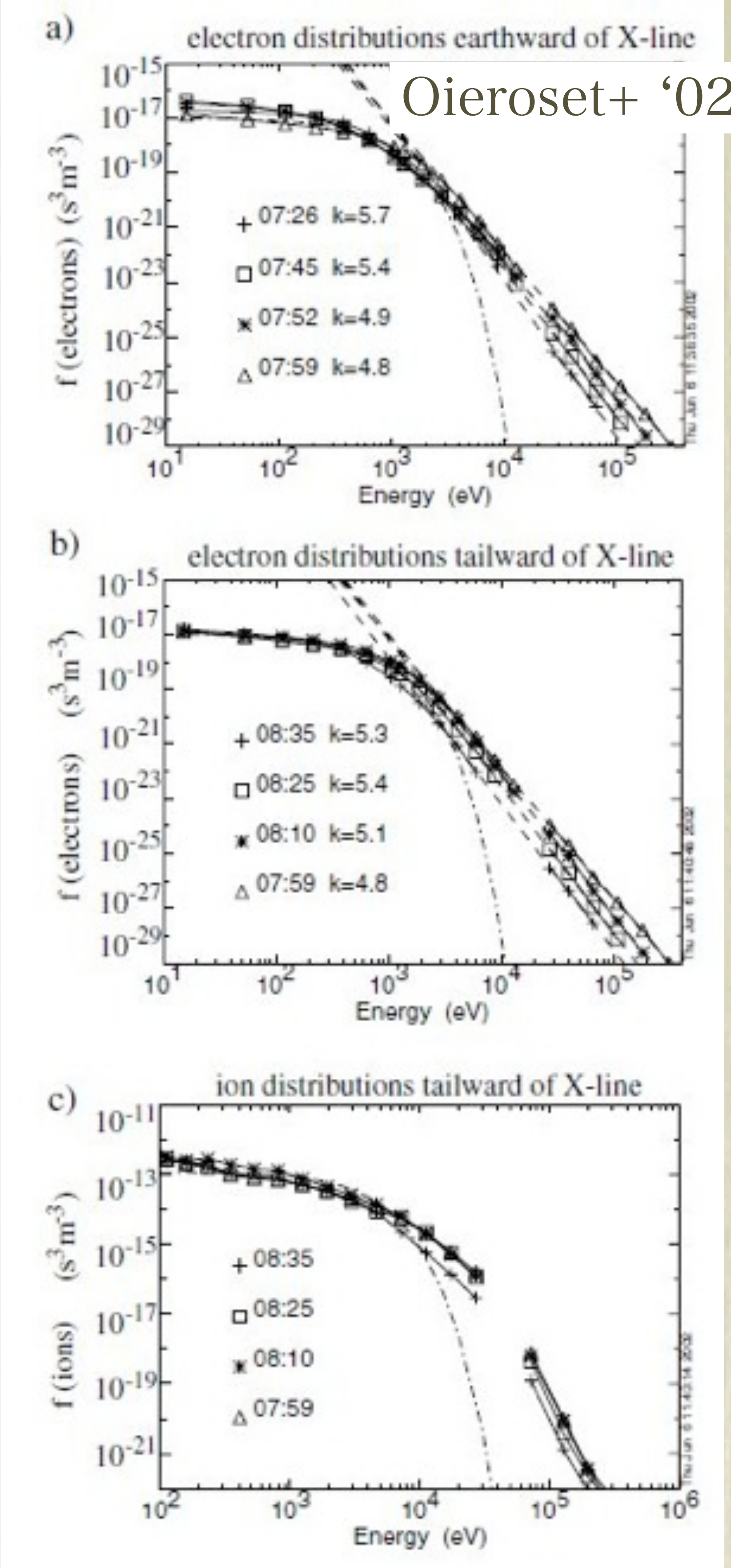
- The heat source of corona is still an open question
  - A populuar scenario: magnetic reconnections (e.g. Liu+'02)
  - non-thermal particles are accelerated in reconnections!



Particle accelerations in reconnections

- soft power-law spectrum ($dN/dE \sim E^{-4}$) is typically found in solar flares or Earth magnetosphere
- Interestingly very similar to X-ray-MeV background spectrum
  - A reasonable explanation, supporting the reconnection hypothesis for AGN coronae





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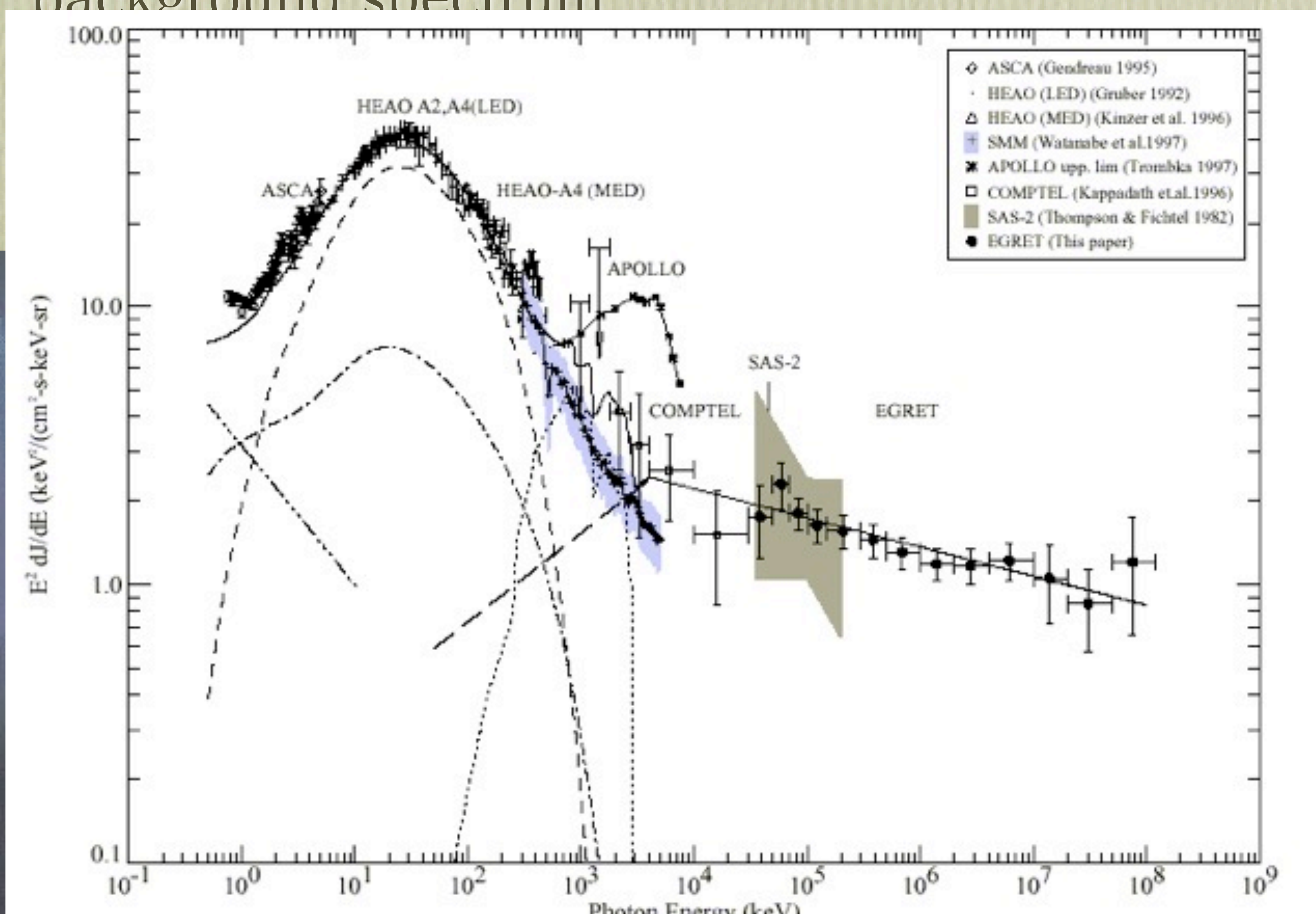

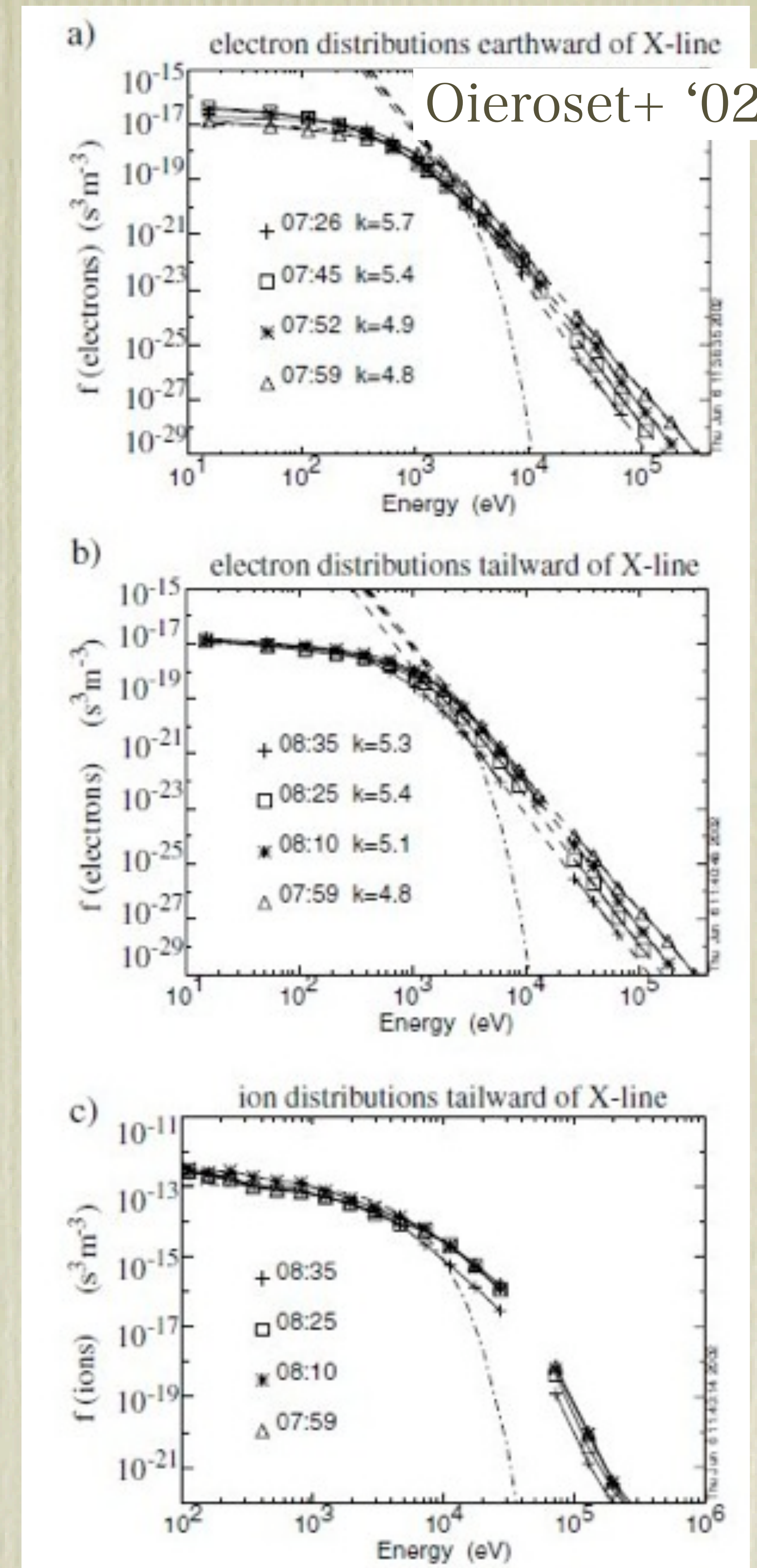

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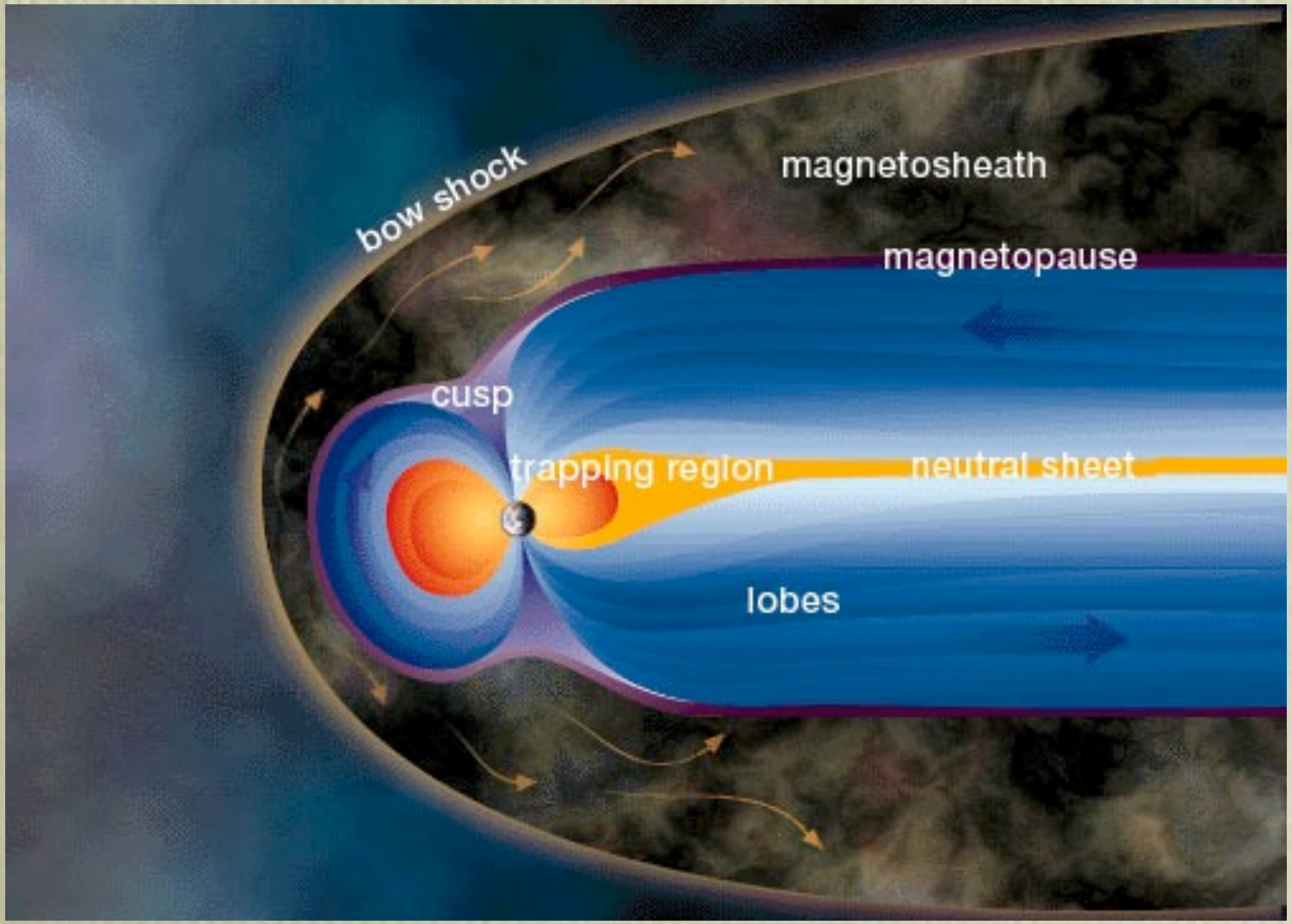
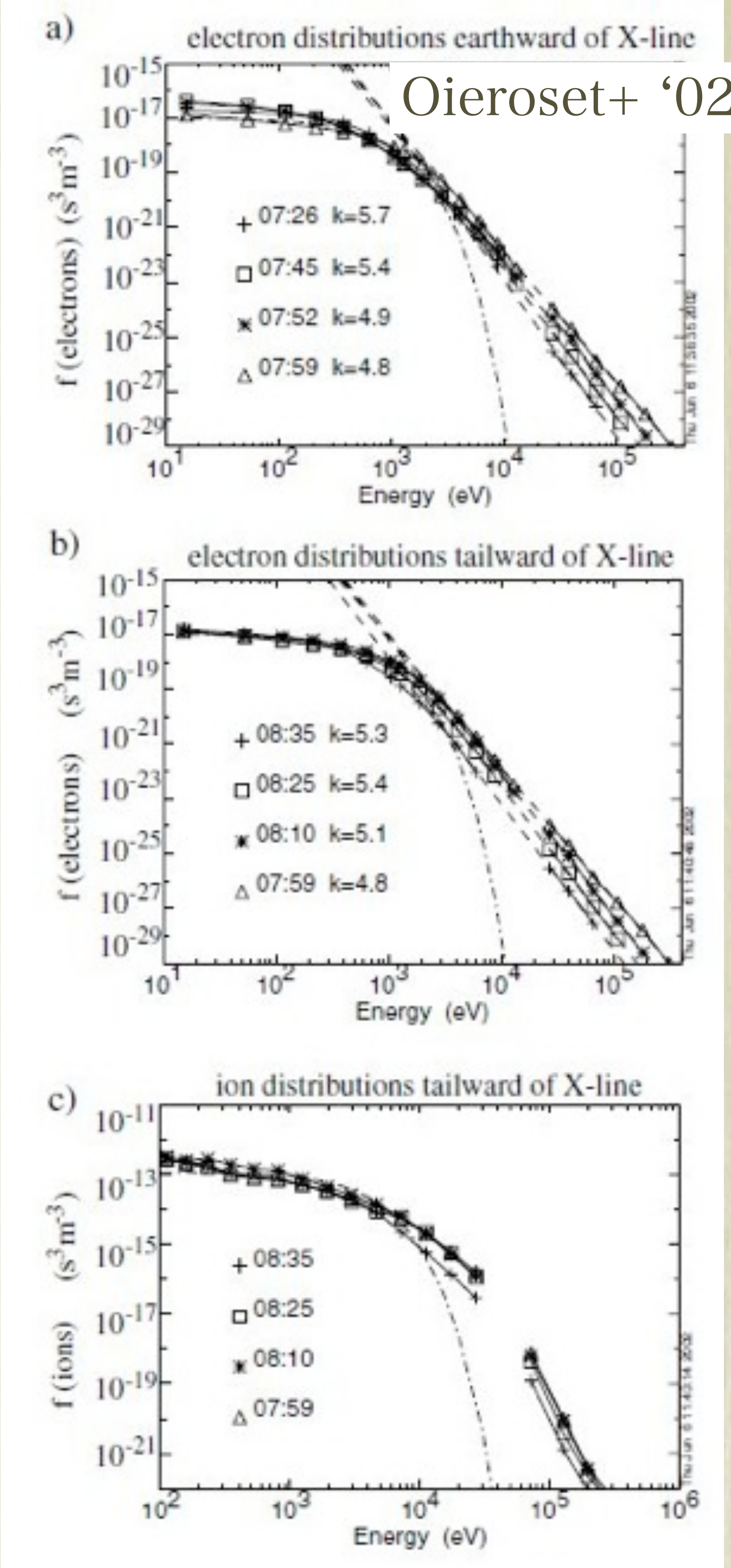


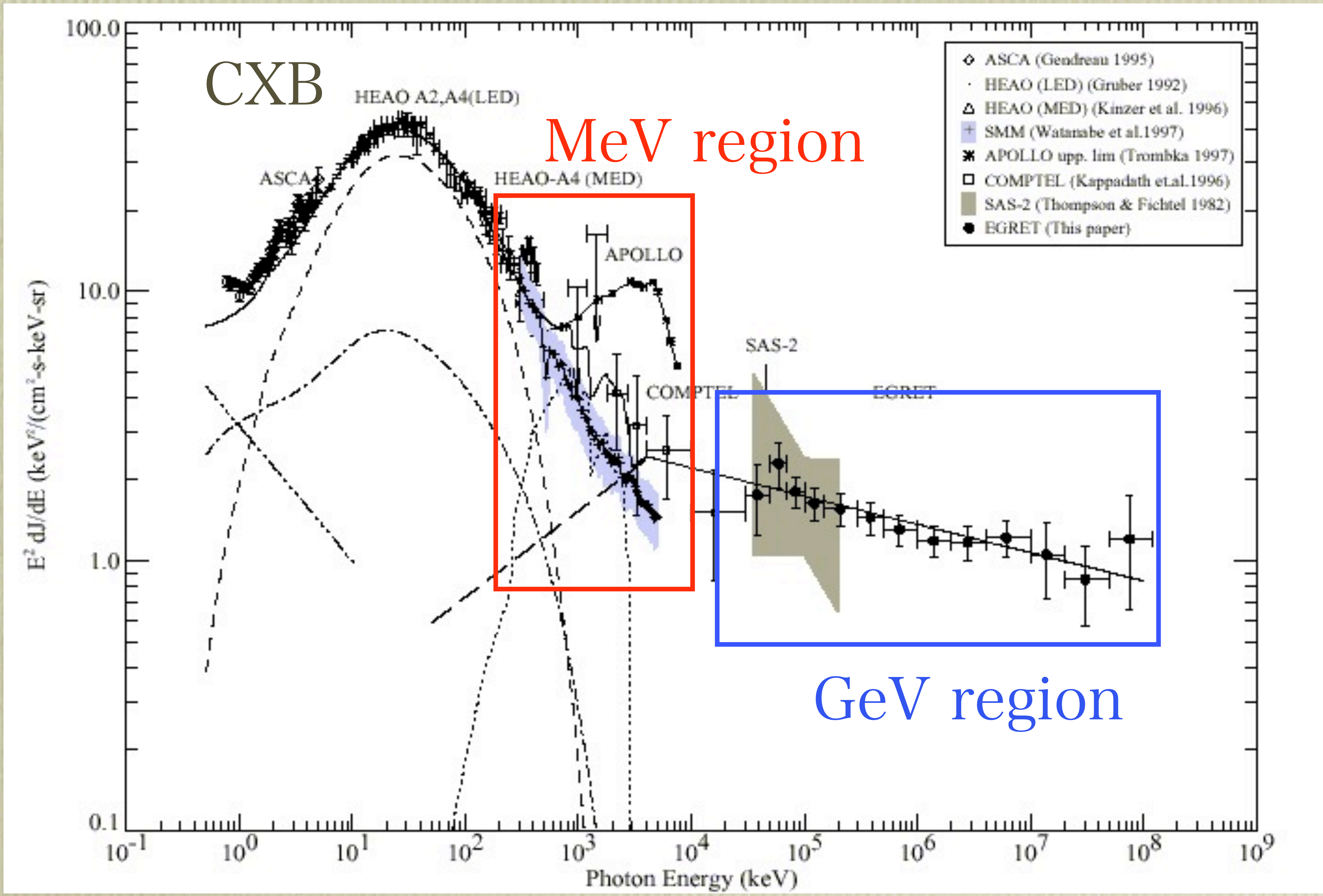
Oieroset+ '02



MeV background: Summary

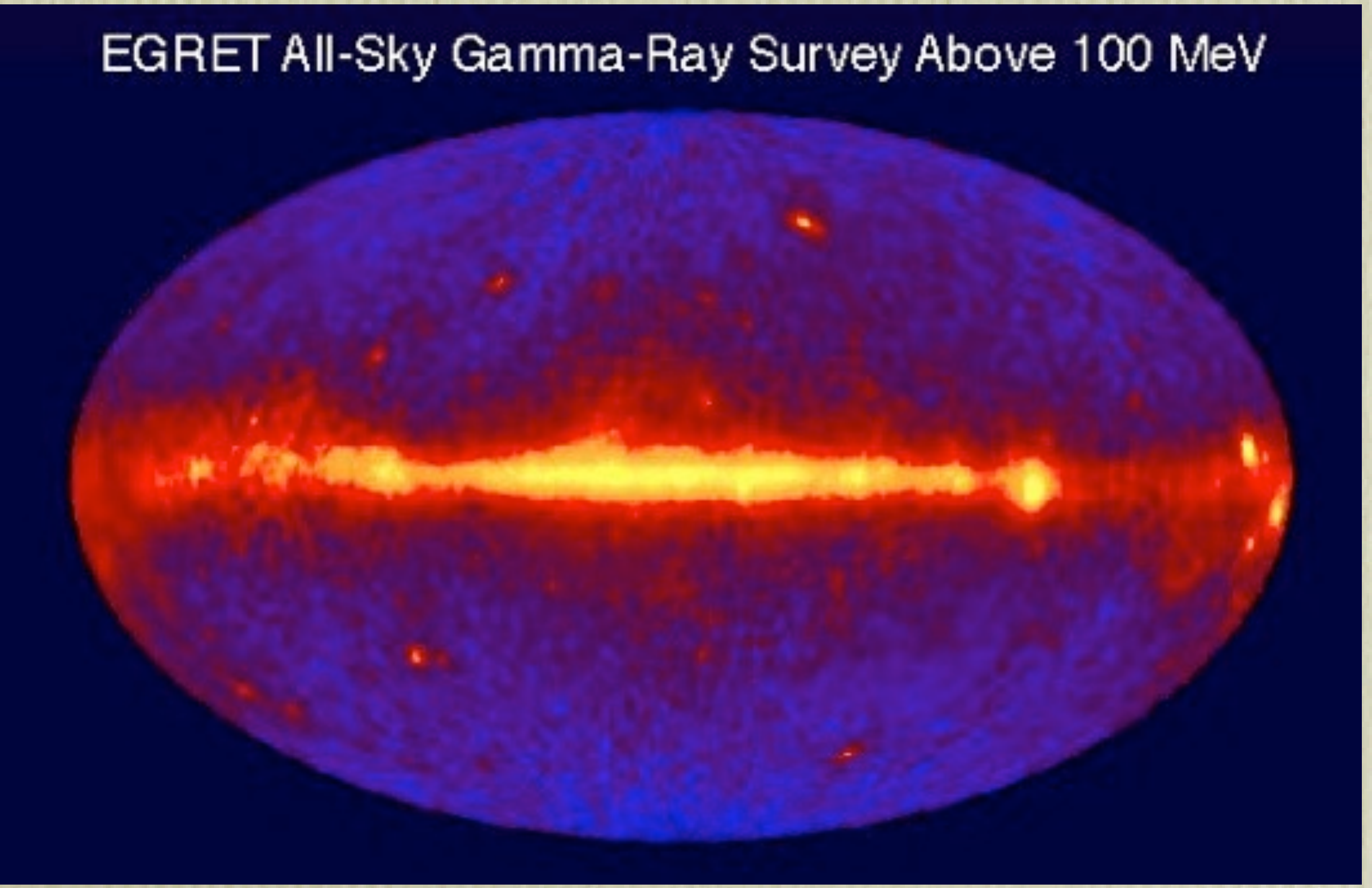
- The best explanation is “non-thermal tail” from normal AGNs
  - smooth power-law connection to CXB
  - non-thermal electrons naturally expected in AGN coronae
- no strong motivation to consider about other sources
  - too small SN Ia rate
  - no good theoretical motivation for MeV DM

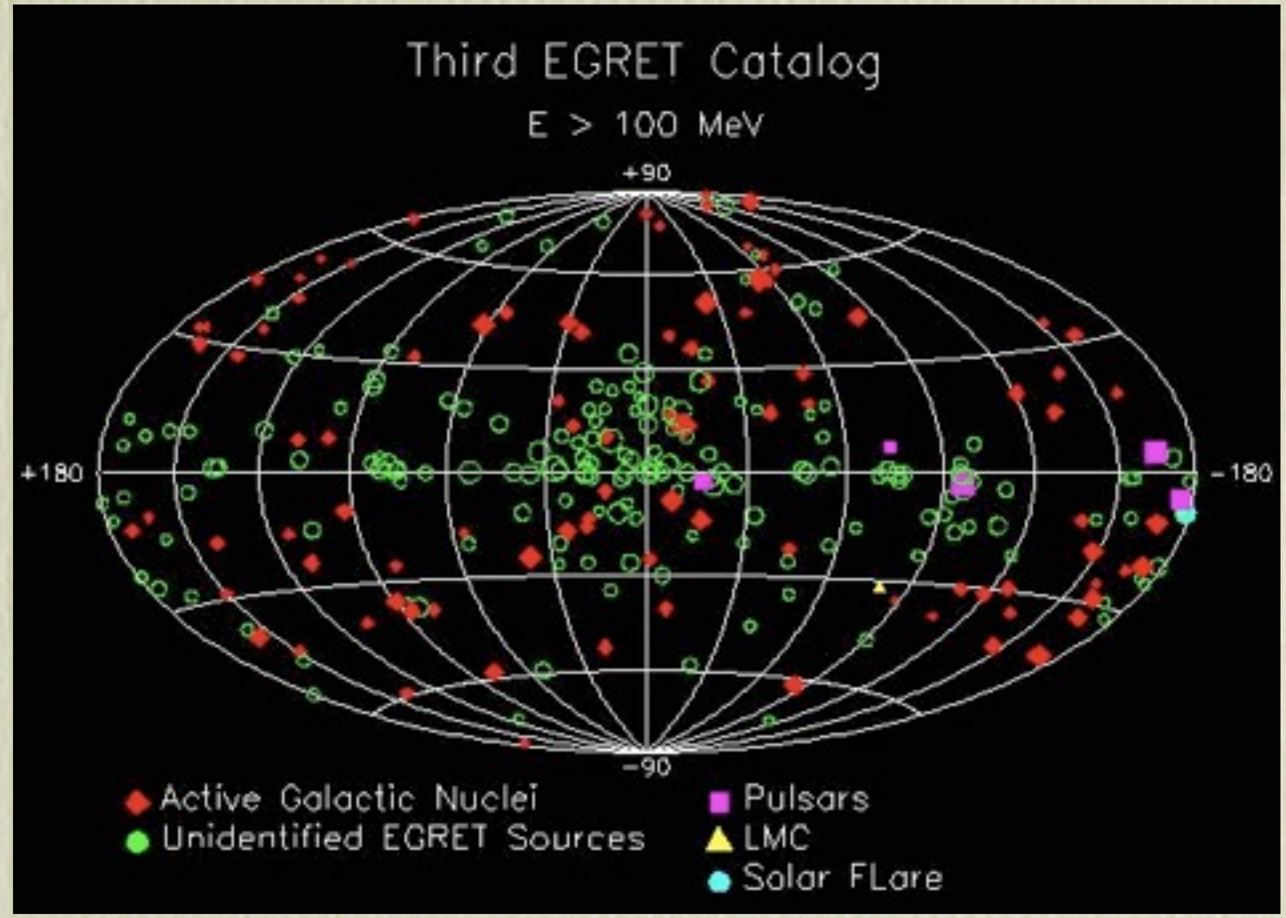
Origin of the GeV background



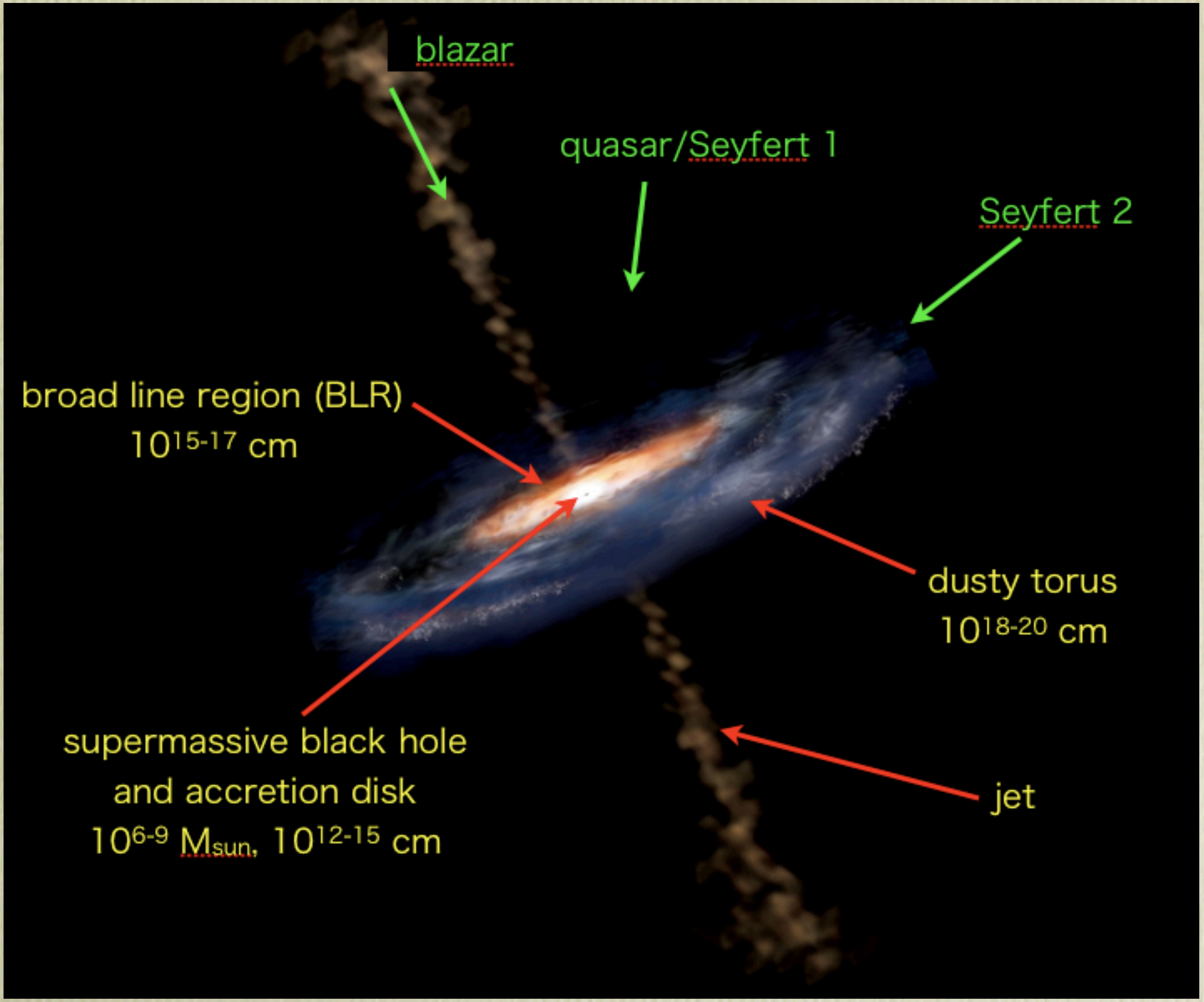
the primary candidate: blazars

- almost all extragalactic EGRET sources (~50) are blazars
- blazars can account for at least >~30 % of GeV background, but probably not 100% of the EGRET data
  - new sources? DM? systematics in theory and/or data?





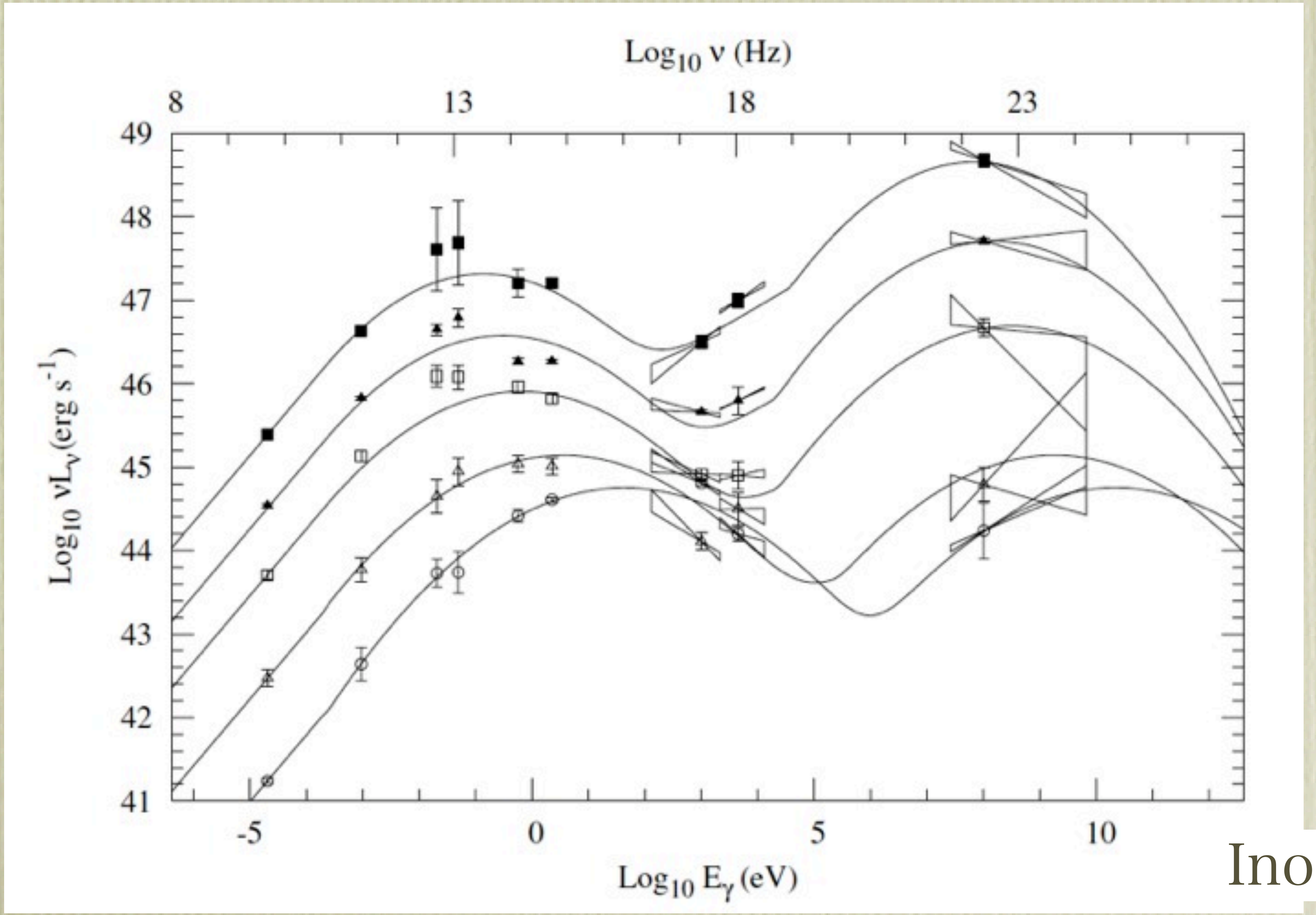
blazars



blazar
quasar/Seyfert 1
Seyfert 2
broad line region (BLR)
10^{15-17} cm
dusty torus
10^{18-20} cm
supermassive black hole
and accretion disk
10^{6-9} M_{sun}, 10^{12-15} cm
jet

blazar spectral energy distribution (SED)

- two broad peak by synchrotron and inverse-Compton by non-thermal electrons
- the SED sequence (high peak frequency for lower luminosity)
  - Fossati+’97, Donato+’01



Inoue+TT ’09

GeV background from Blazars

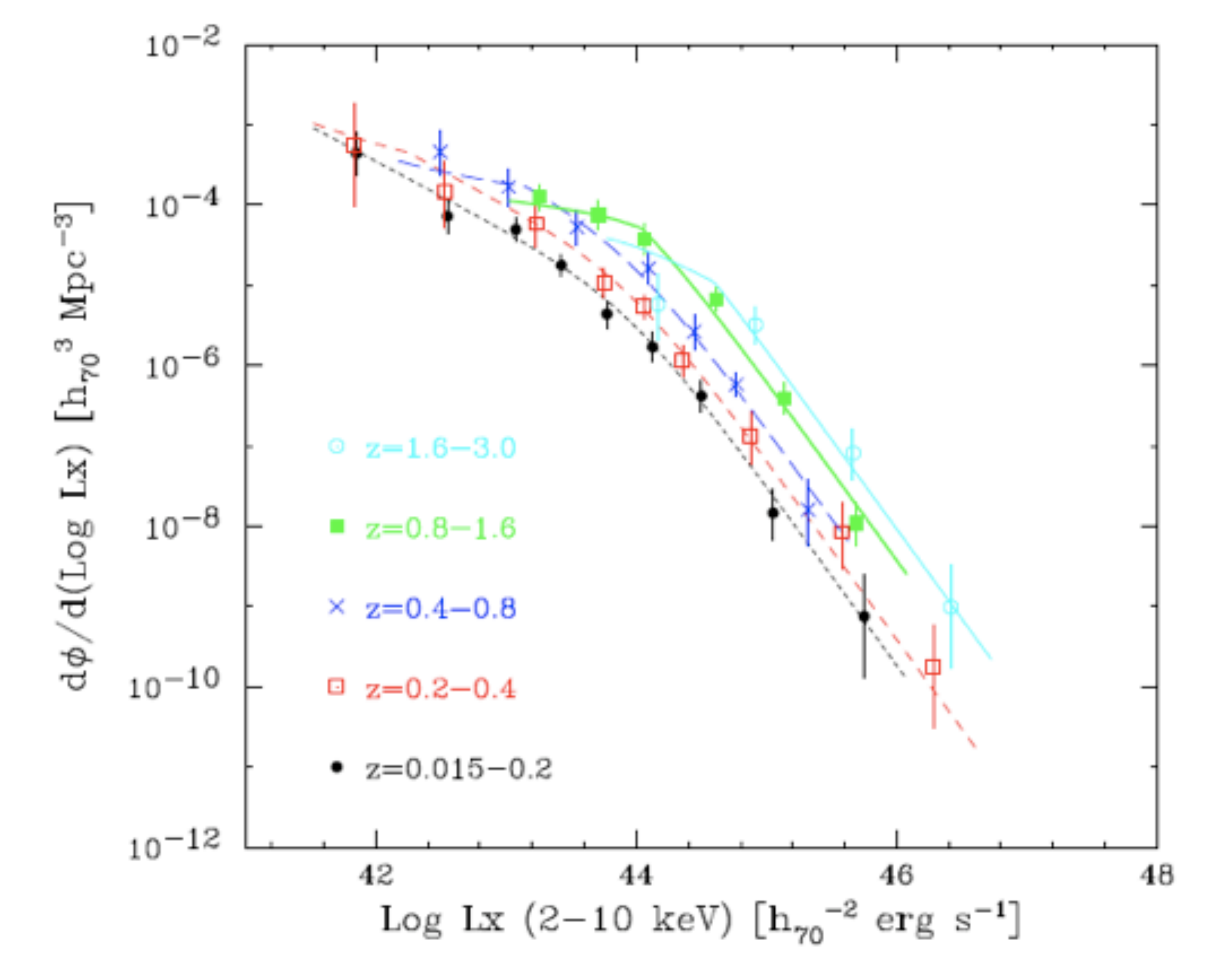
Padovani+'93; Stecker & Salamon '96; Chiang & Mukherjee '98; Mücke & Pohl '00; Narumoto & Totani '06; Giommi et al. '06; Dermer '07; Pavlidou & Venters '08; Kneiske & Mannheim '08; Inoue & Totani '09

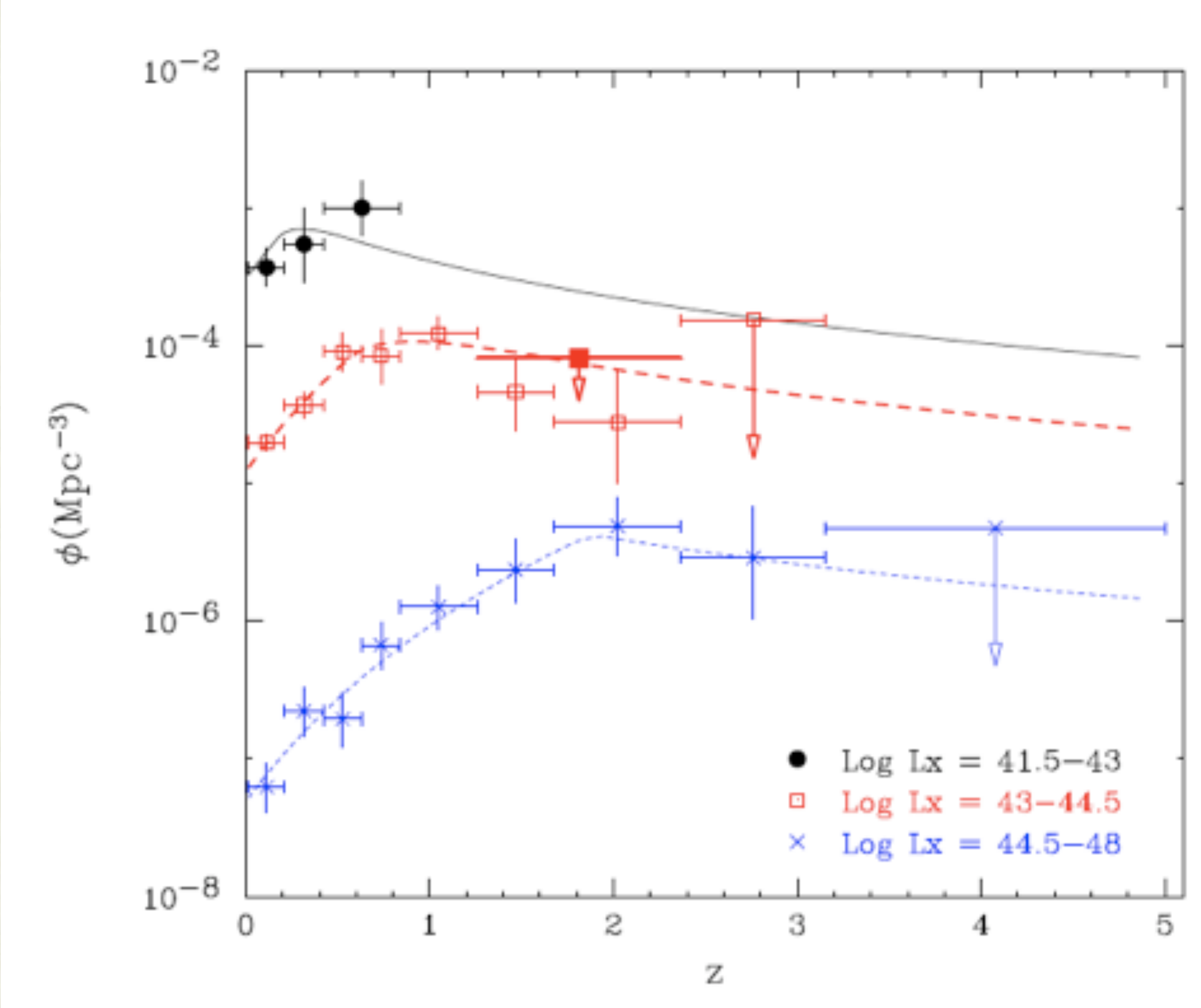
- The basic scheme:
  - luminosity function (LF) evolution model (X, radio, etc.)
  - fitting to EGRET blazar distribution (flux & redshift)
  - spectral modeling of blazars
    - (power-law, SED sequence, theoretical model, ...)

- The latest model by Inoue+TT '09 (arXiv:0810.3580)
  - "LDDE" LF evolution based on X-ray surveys of AGNs
  - the SED sequence for blazar spectra
  - careful fitting to the EGRET data by likelihood analysis
    - likelihood analysis including radio counterpart detection probability

AGN Luminosity Function Evolution

- LDDE (Luminosity Dependent Density Evolution)
- good fit to X-ray AGNs to z~3
- assume $L_X \propto L_\gamma$ for blazar-AGN connection

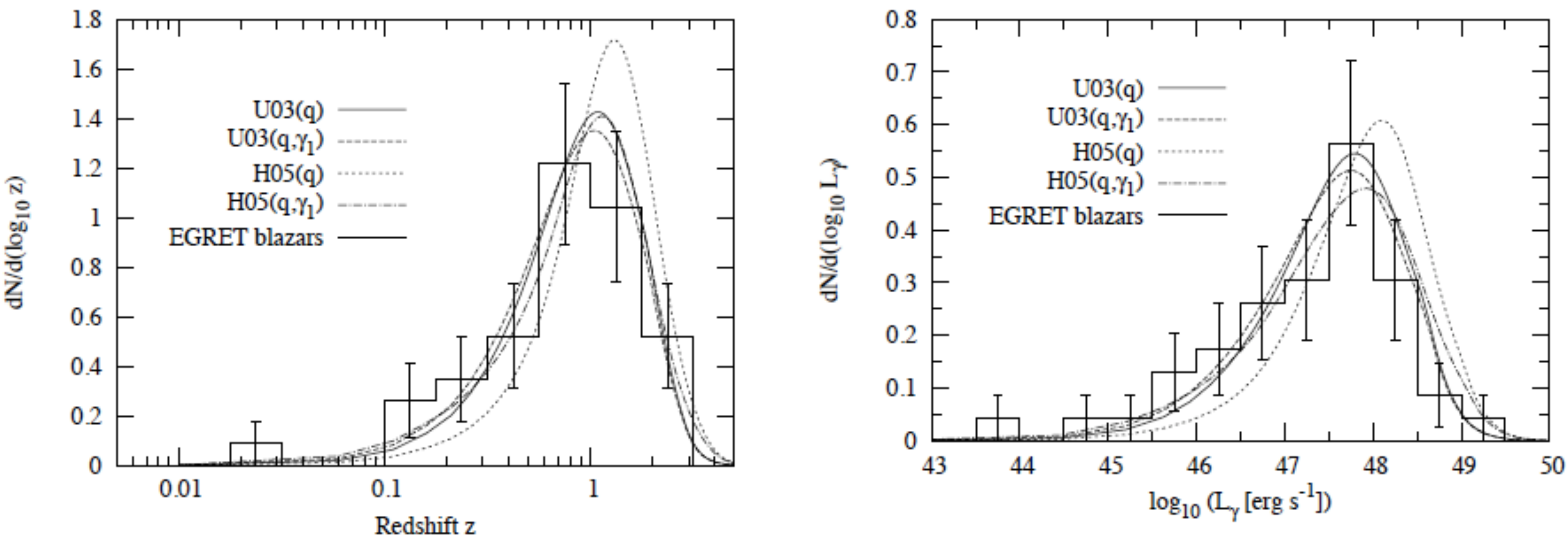




Ueda+'03

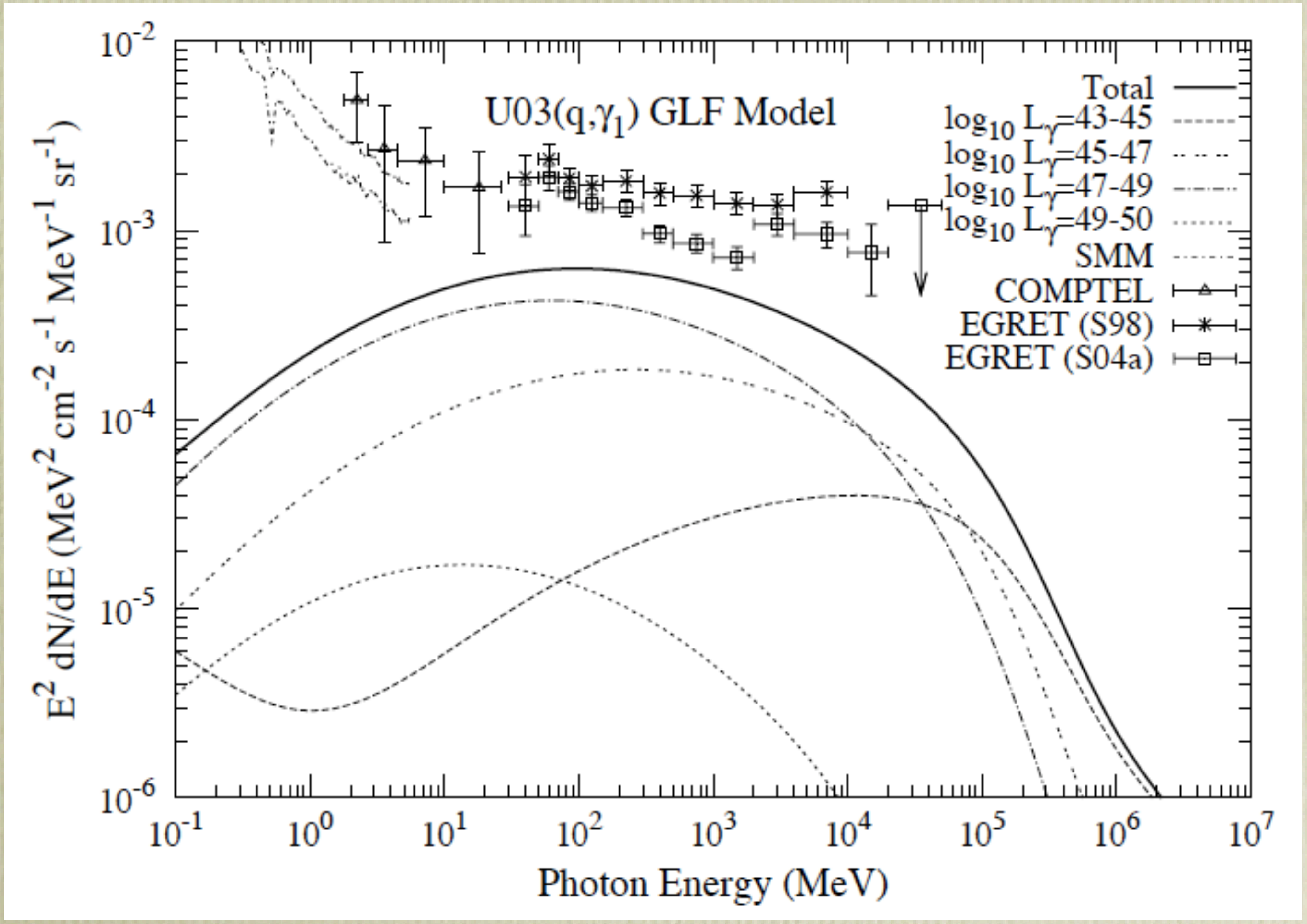
L and z distribution of EGRET blazars

- good fit to 46 EGRET blazars up to z~3 (cosmologically significant!)
- LDDE better fits than “pure luminosity evolution” model
- not large uncertainty about evolution



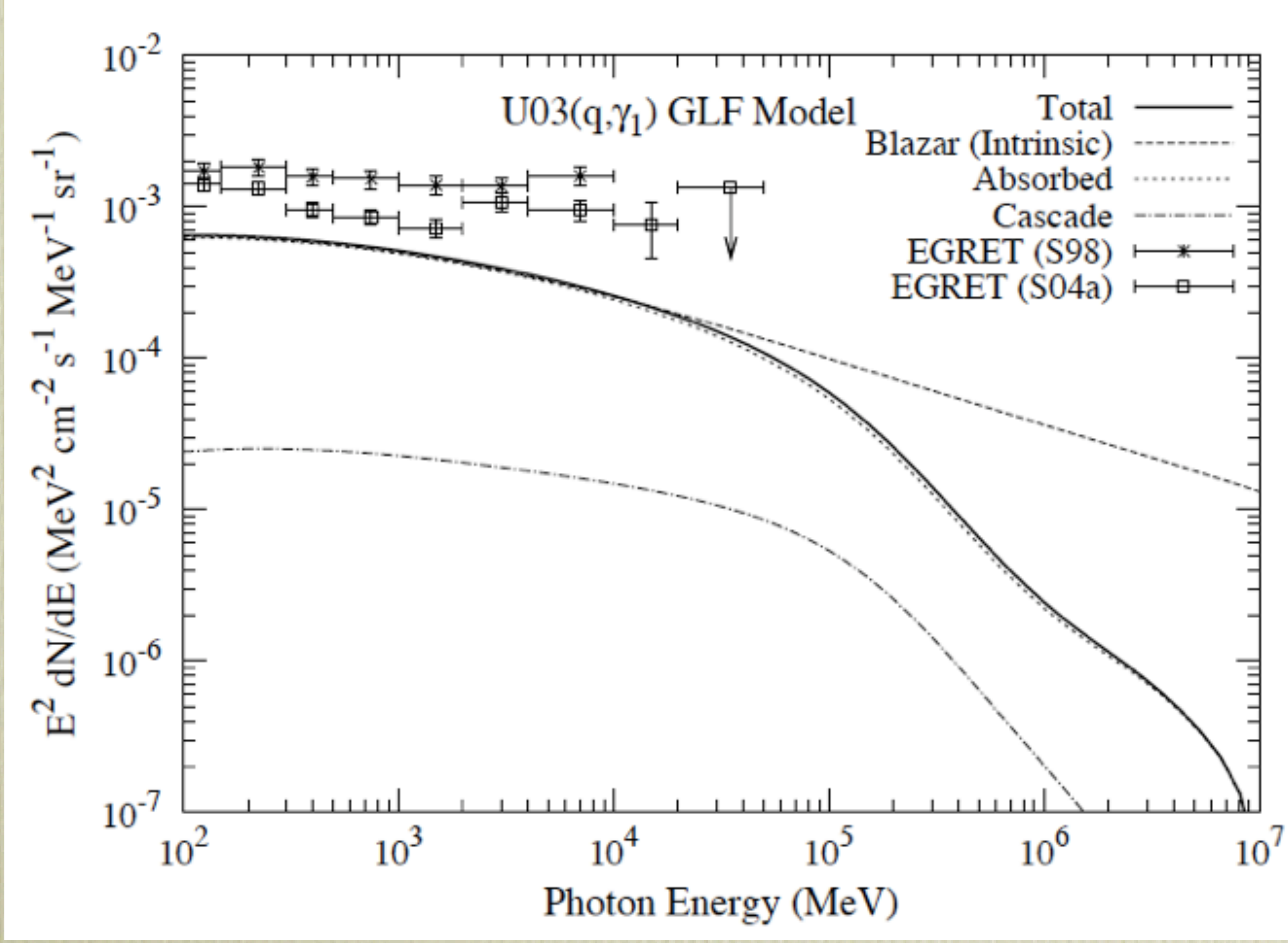
GeV background from blazars

- can account for >~ 50% by blazars
- but difficult to explain ~100%



Absorption of very high energy gamma-rays in IGM

- VHE gamma-ray (>~100 GeV) is absorbed by interaction with cosmic infrared background to create $e^{\pm}$
- absorbed energy goes to secondary cascade emission at <~100 GeV
- effect of cascade component not large, if the SED sequence is valid



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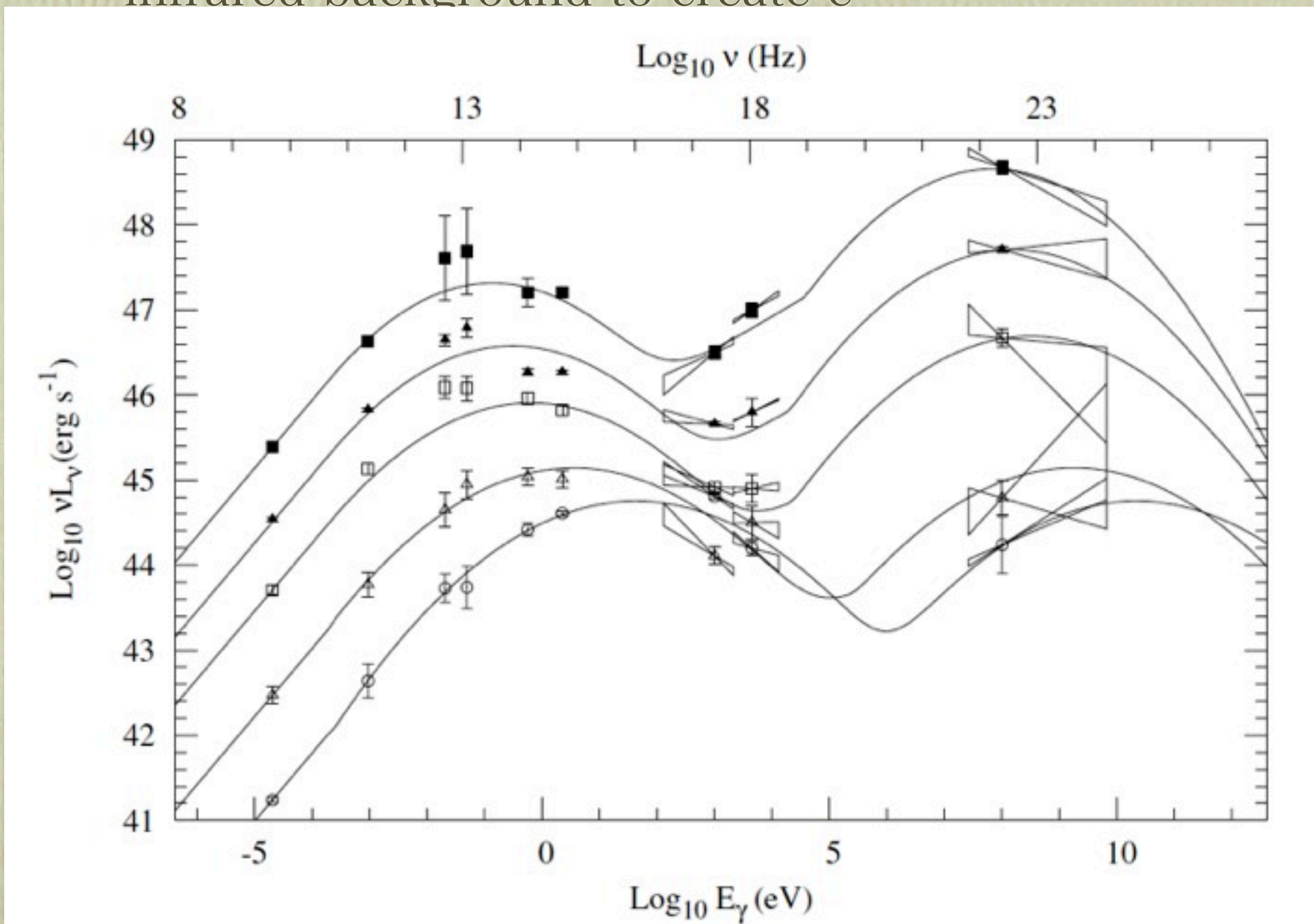

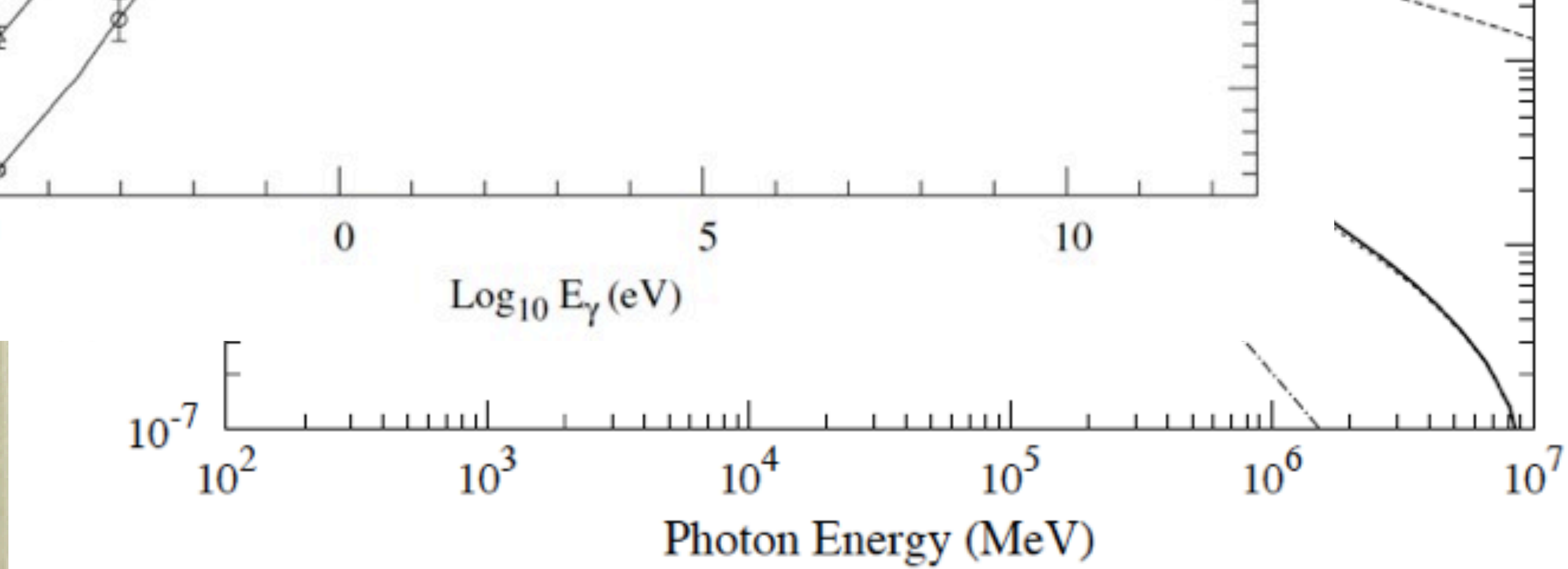

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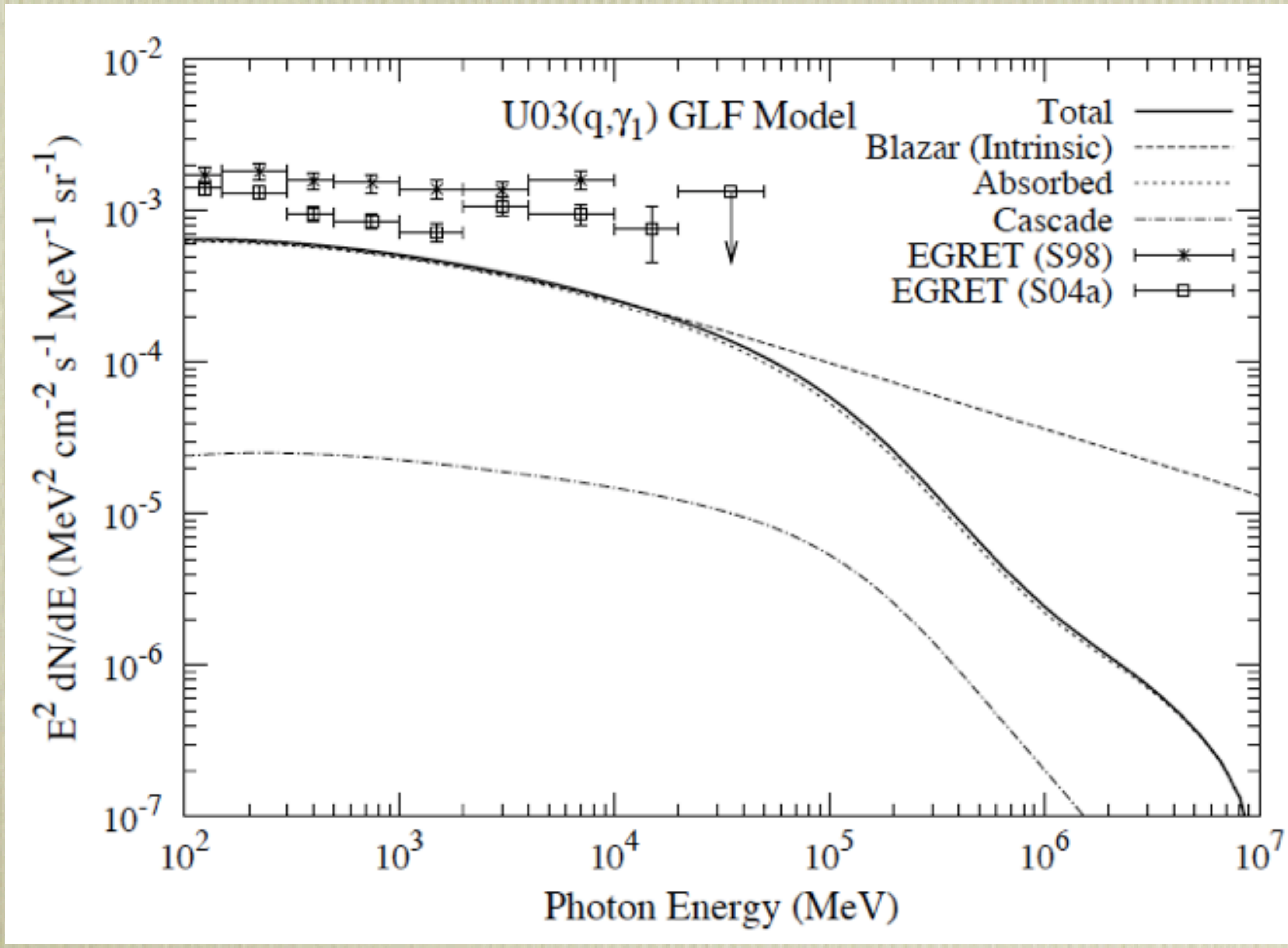
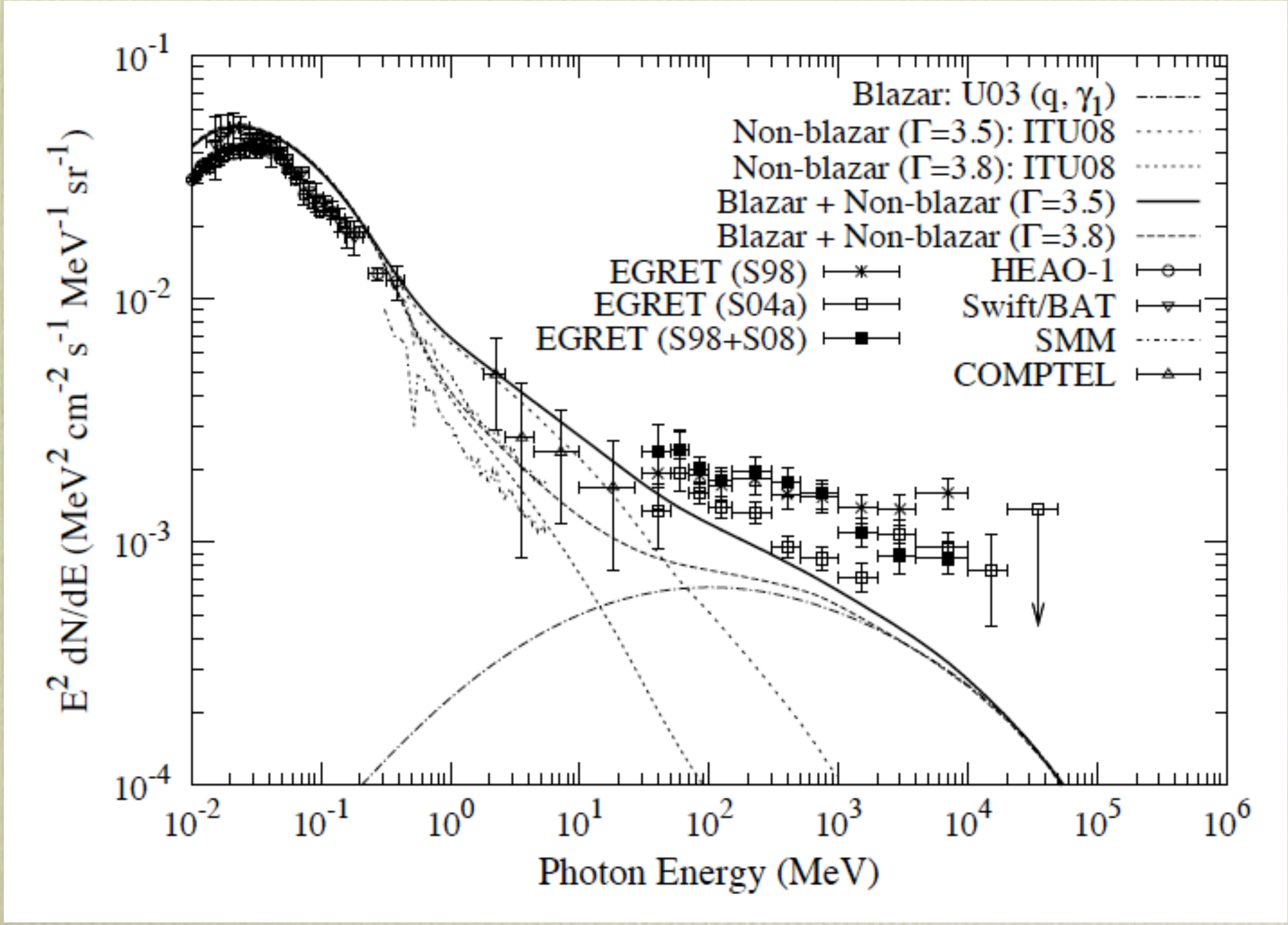


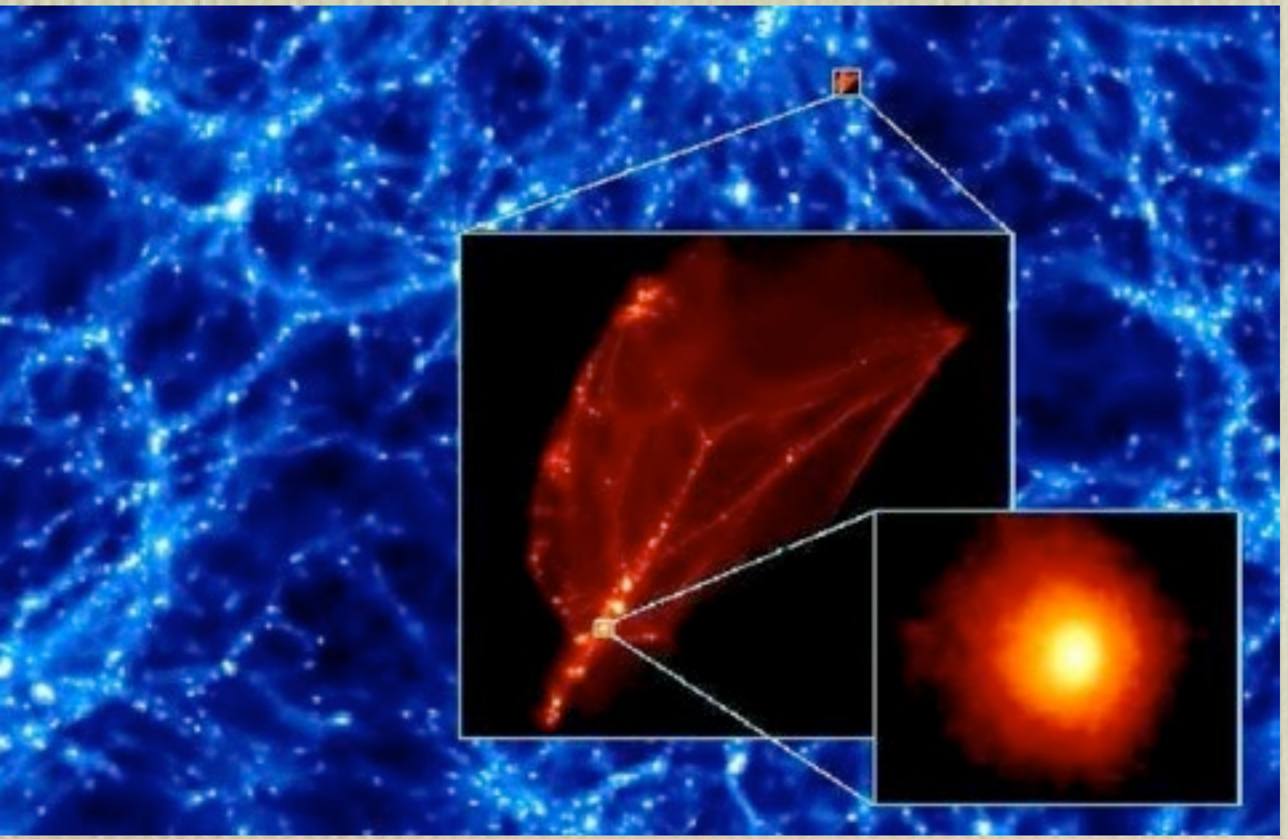
Total gamma-ray background from normal+blazar AGNs

- the "minimum" contribution from the two populations
  - normal AGNs in MeV and blazars in GeV



DM annihilation contribution to gamma-ray background?

- DM may contribute to gamma-ray background by
  - astrophysical/particle-physical boost factor
  - e.g., substructure down to ~10^{-6} M_{sun}



Diemand+ ’05

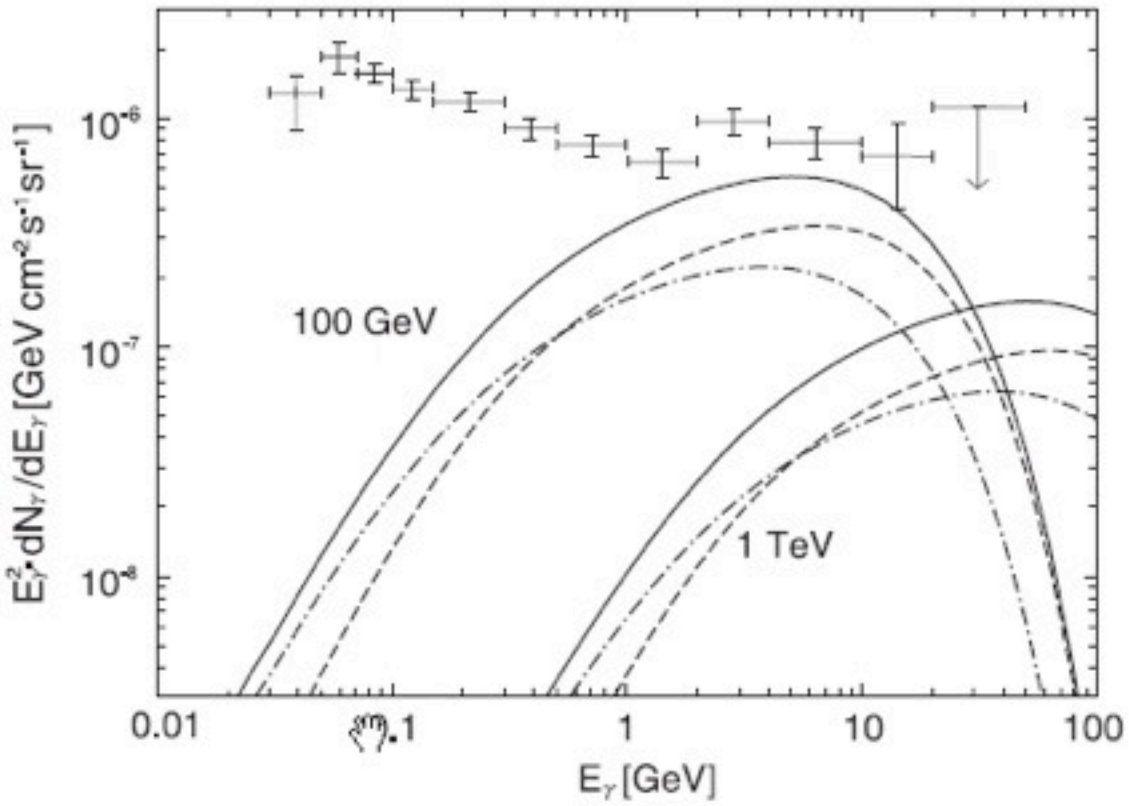


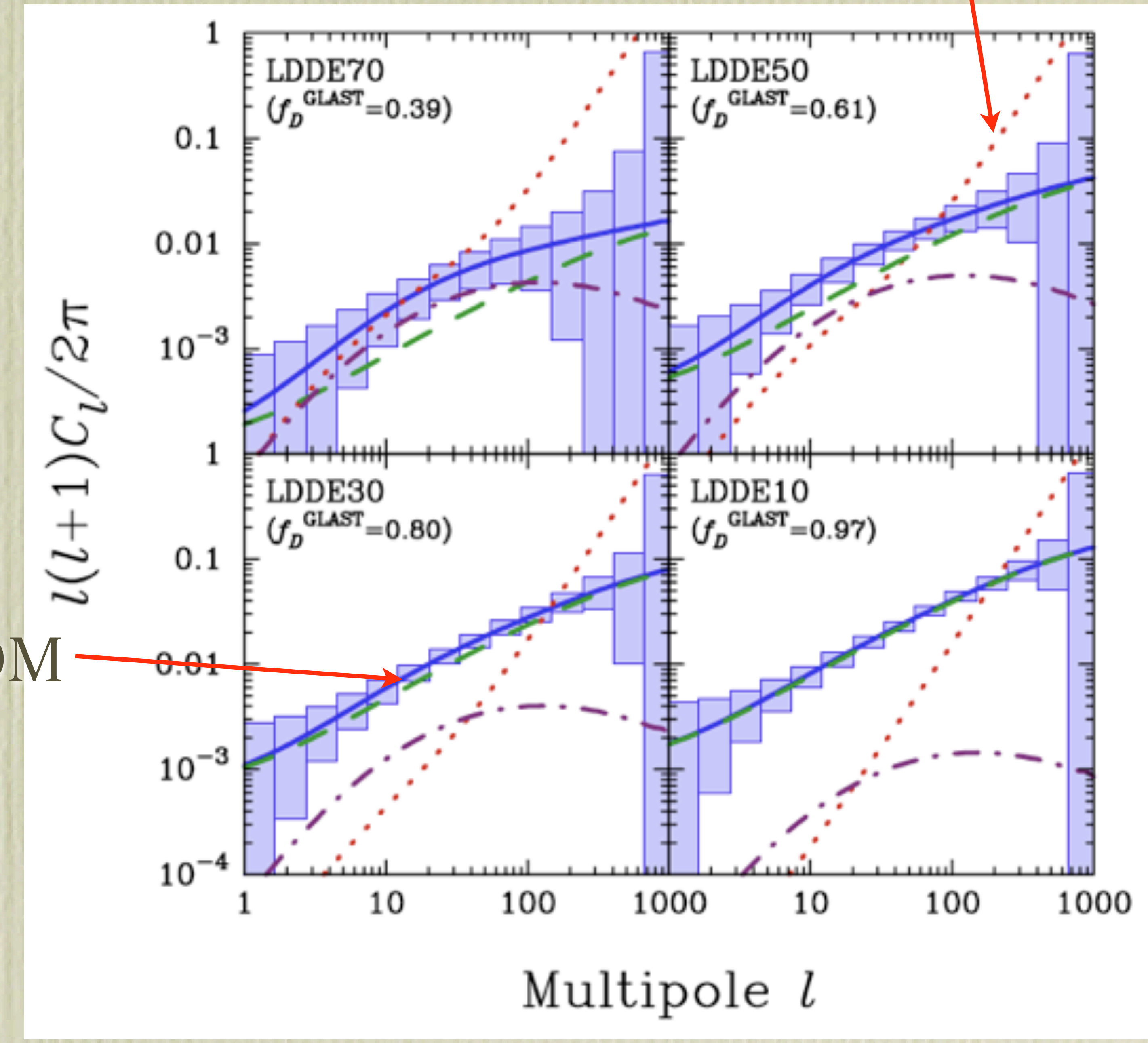
FIG. 1: The background gamma-ray flux from neutralino annihilation in the microhaloes. The GGRB (dashed), EGRB (dot-dashed), and the total (solid) components are shown. The two cases of m_χ = 100 GeV and 1 TeV are presented, with f_{surv} = 0.35 and 1, respectively. The EGRET EGRB data points are from ref. [14]. The GGRB component assumes R_d = 5 kpc and the baryon-compressed NFW profile for the Galactic halo. It is the mean of all sky except for the Galactic disk region, where the EGRB data are obtained.

Oda, TT, Nagashima ’05

Anisotropy background signal from DM annihilation?

- (relatively) easy prediction:
  - blazars & other astro sources
  - DM annihilation from extragalactic halos
- Complicated:
  - DM substructures in our Galaxy halo
- Challenge:
  - anisotropy in foreground Galactic diffse (CR origin)
- see also Cuocco+'08, Miniati+'07, Hooper+'07, Fornasa+'09, Siegal-Gaskins+'08, Taoso+'09, Lee+'08

blazars

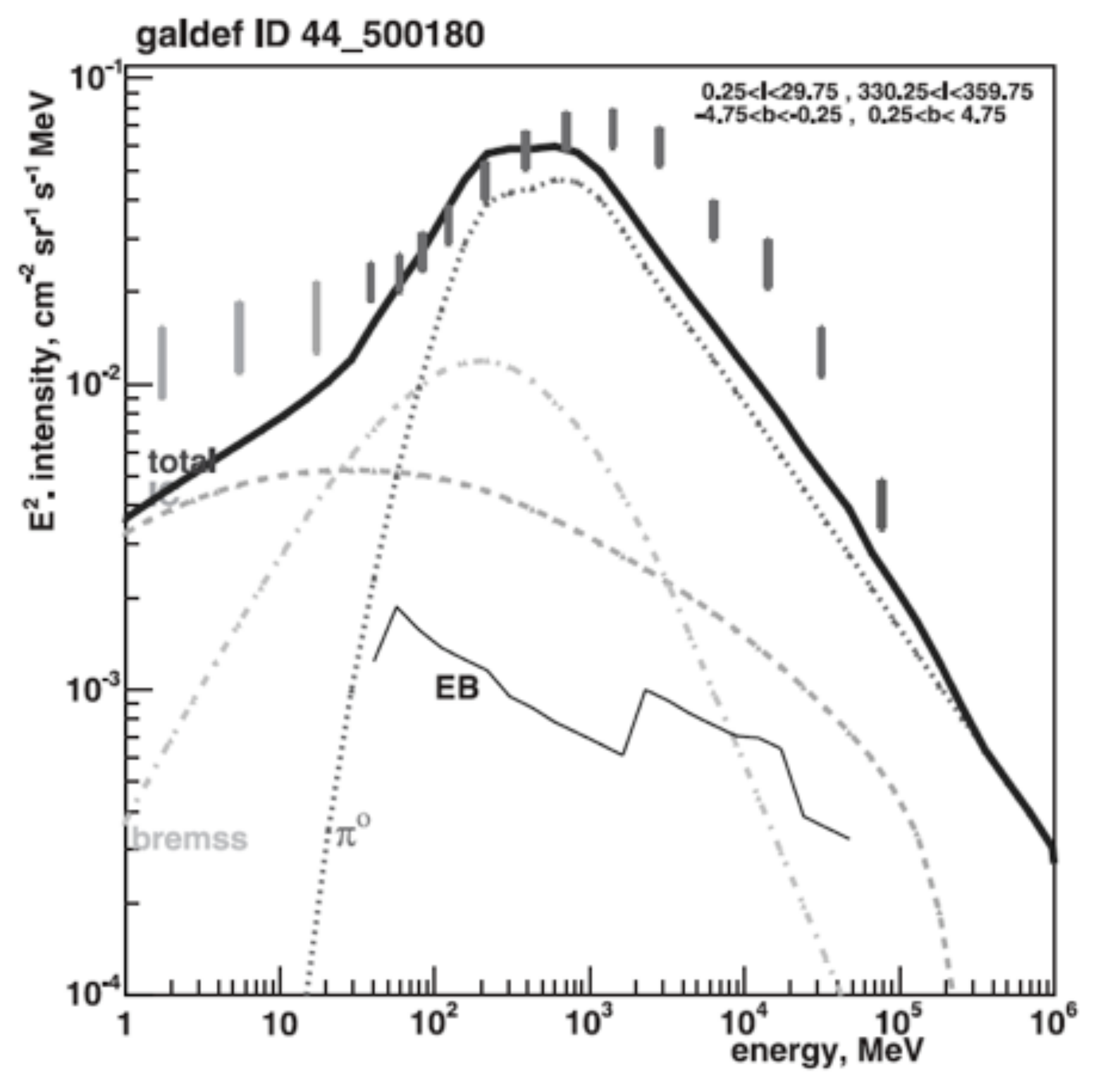


DM

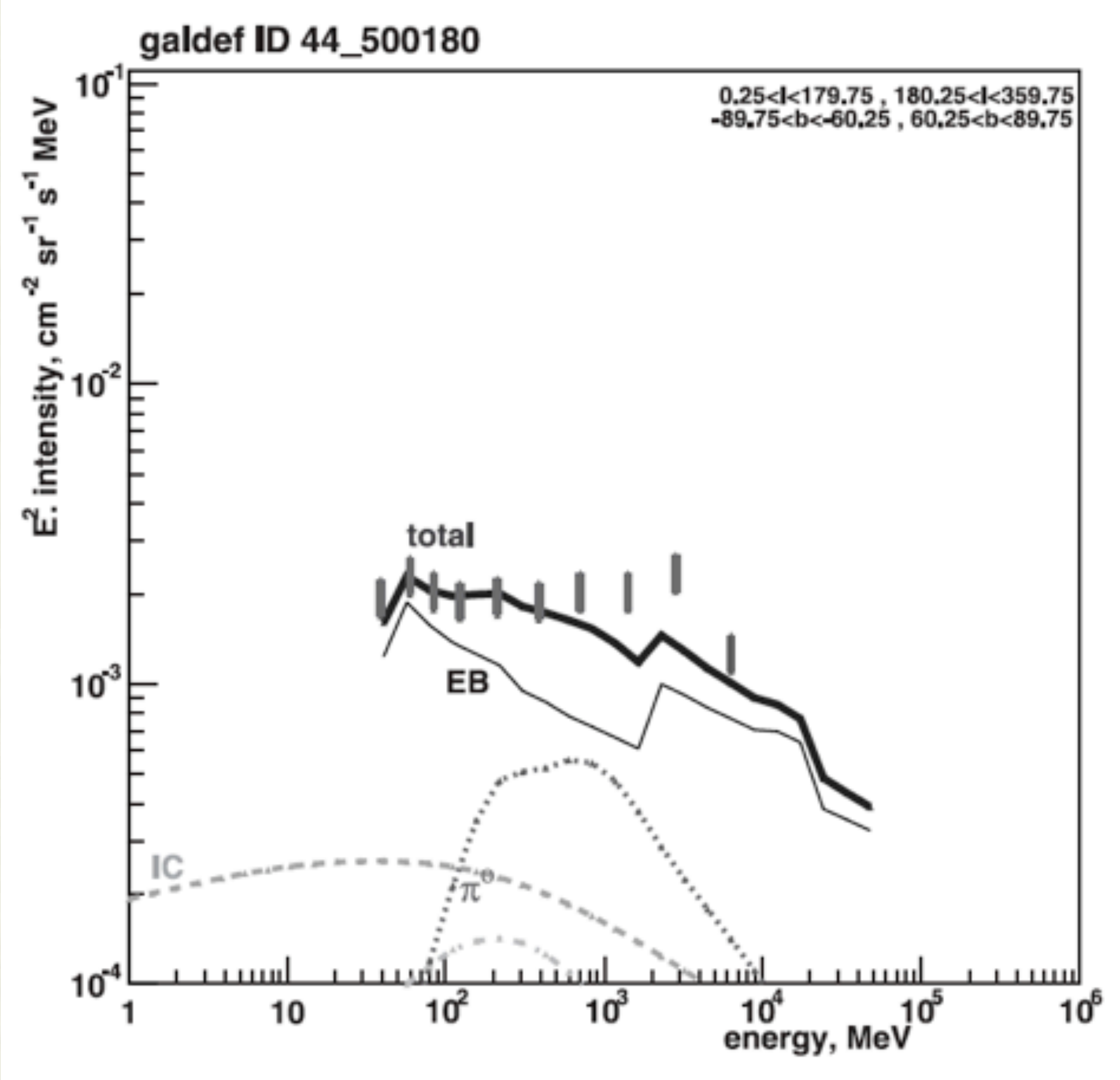
Ando, Komatsu, Narumoto & TT '07

Galactic vs. Extragalactic Diffuse

Galactic center region



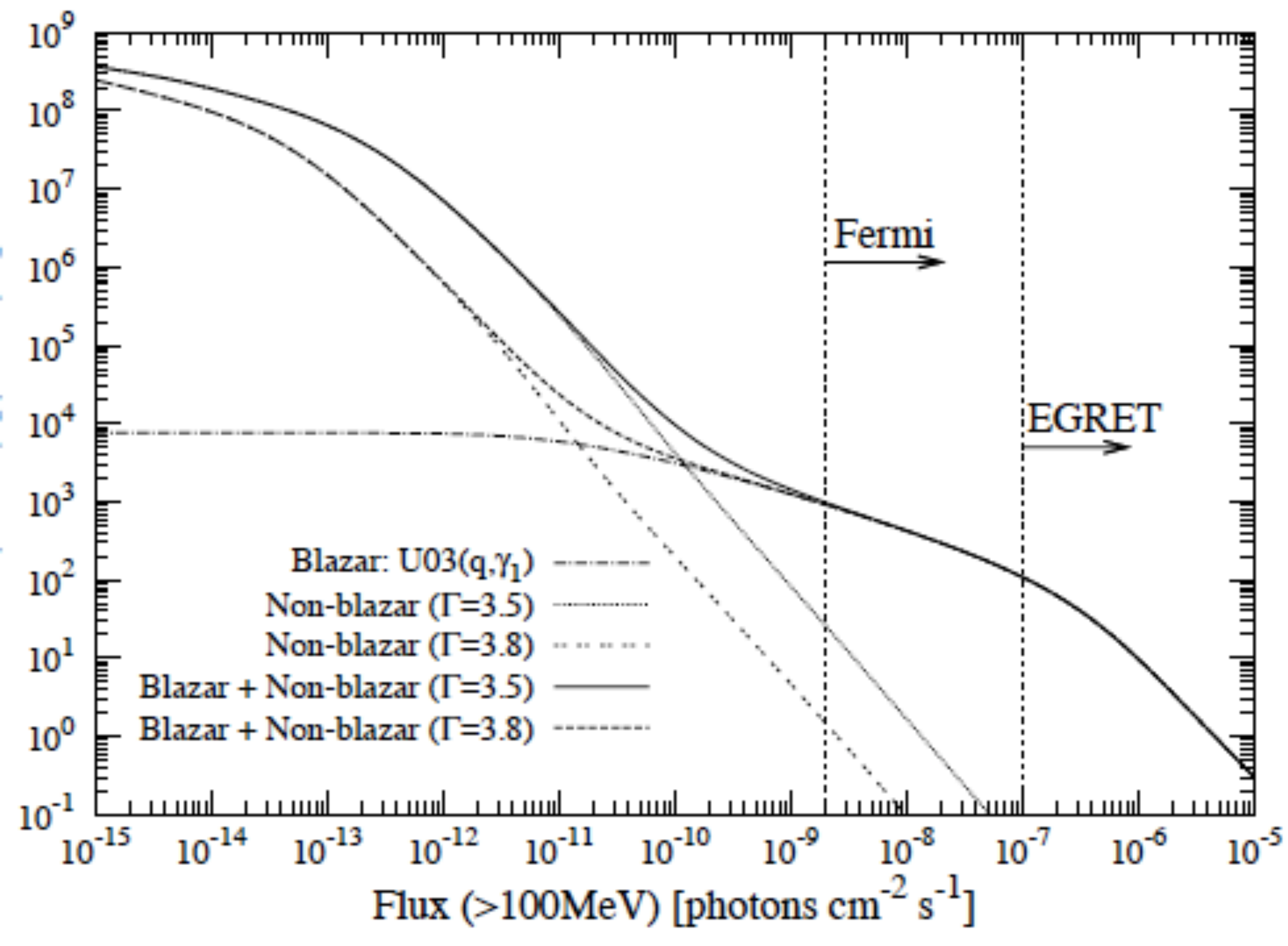
Galactic pole region

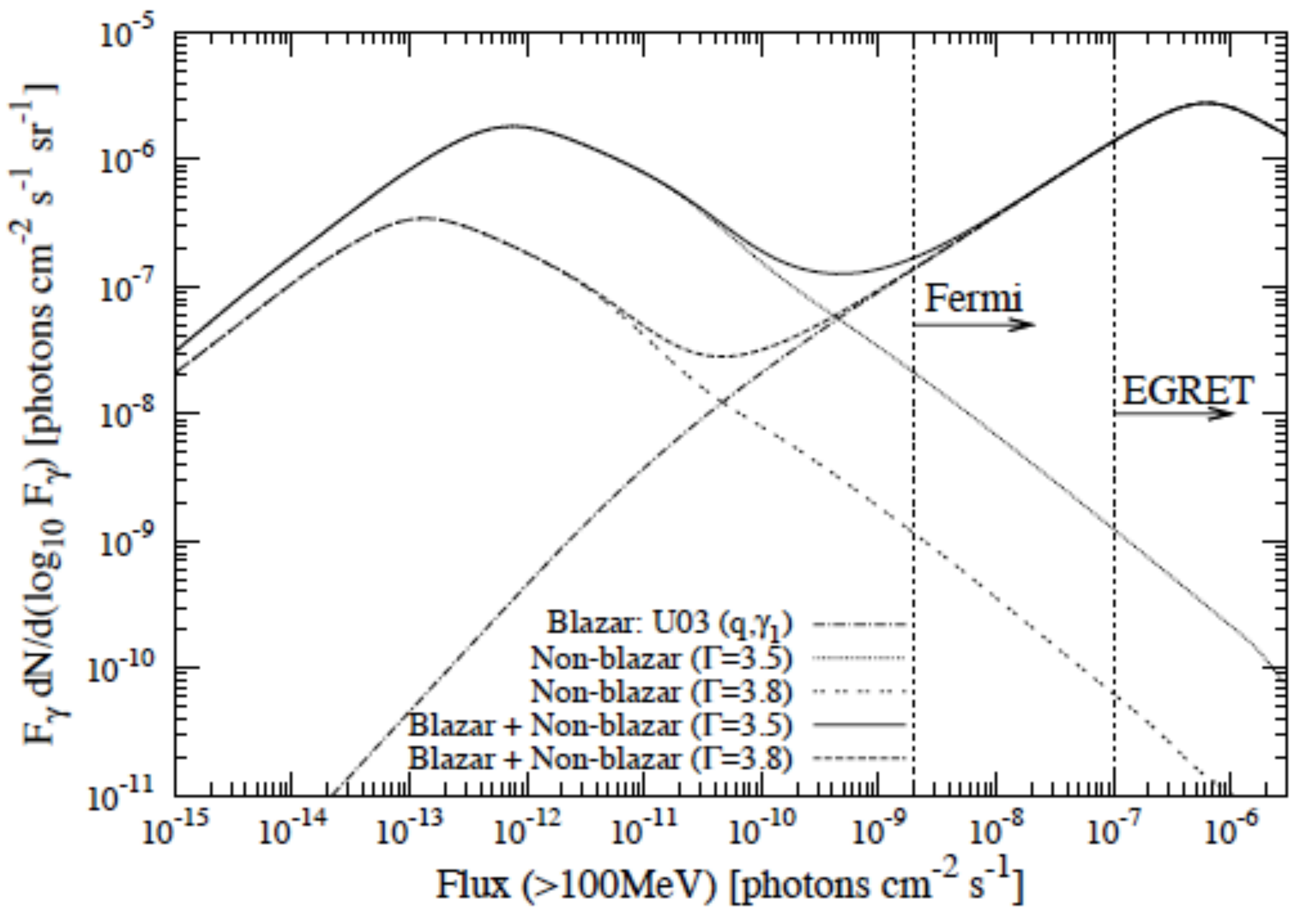


- Strong+'04

Blazar Prediction for Fermi (1)

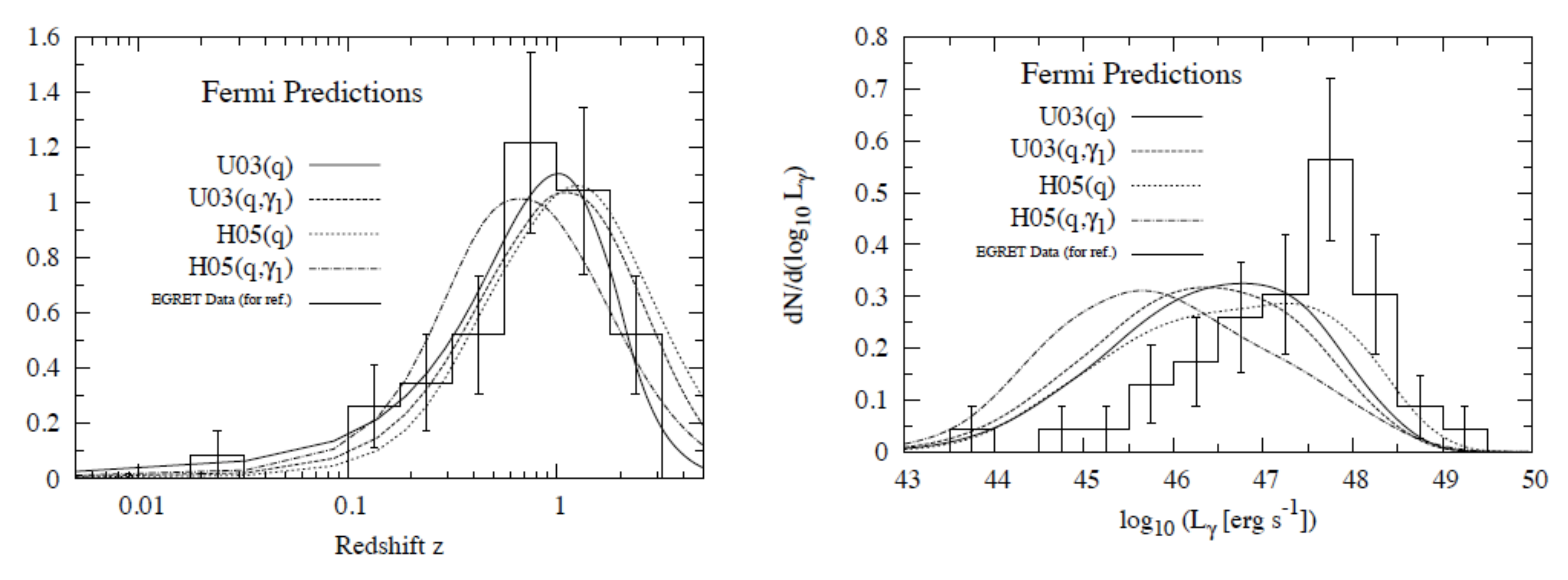
- ~1,000 blazars down to the expected final Fermi sensitivity
  - (considerably lower than many previous studies)
  - ~100 blazars in the current bright source catalog of Fermi
- Background from blazars will be resolved completely (>~99%)
  - background from normal AGNs remain largely unresolved





Blazar Prediction for Fermi (2)

- redshift distribution not much different from EGRET
  - (but many more high-z blazars in absolute number than EGRET
- probes lower luminosity range than EGRET



GeV Background: Summary

- blazars can account for ~50% of EGRET background data, but likely not all
- AGN's non-thermal tail + blazar can account for ~50-100% at < 1 GeV
- A bump at > GeV?
  - DM annihilation?
  - systematic error in the EGRET detector (e.g. Stecker+'08)?

- Prospects for Fermi:
  - GeV background from blazars will be completely resolved
  - precise determination of LF evolution of blazars (AGN jets)
    - BH mass growth history vs. jet activity history of AGNs?

Conclusions

- MeV:
  - MeV background can naturally be explained by non-thermal electrons in AGN coronae
  - The Galactic 511 keV emission can be explained by the past higher activity of Sgr A*
  - no strong motivation to consider about MeV DM particle
- GeV:
  - a latest model succeeds to explain all MeV-GeV cosmic background only by AGNs including blazars
  - no evidence for DM contribution to GeV background, although WIMPs (neutralinos) are theoretically well-motivated DM

Origin of GeV Background

- GeV background
  - blazars? (only <~30% of CGB can be explained: Chiang & Mukherjee '98; Mucke & Pohl '00; Narumoto & Totani '06)
  - galaxy clusters? (probably negligible under standard assumptions)
  - WIMP annihilation!?

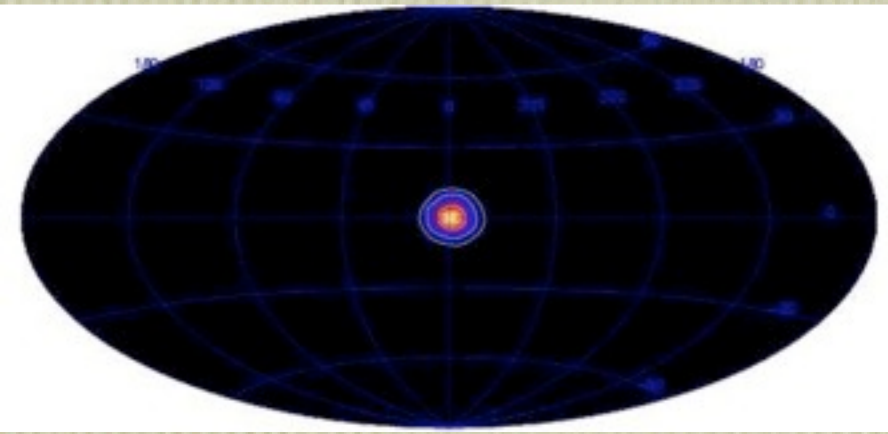
On the MeV DM Possibility

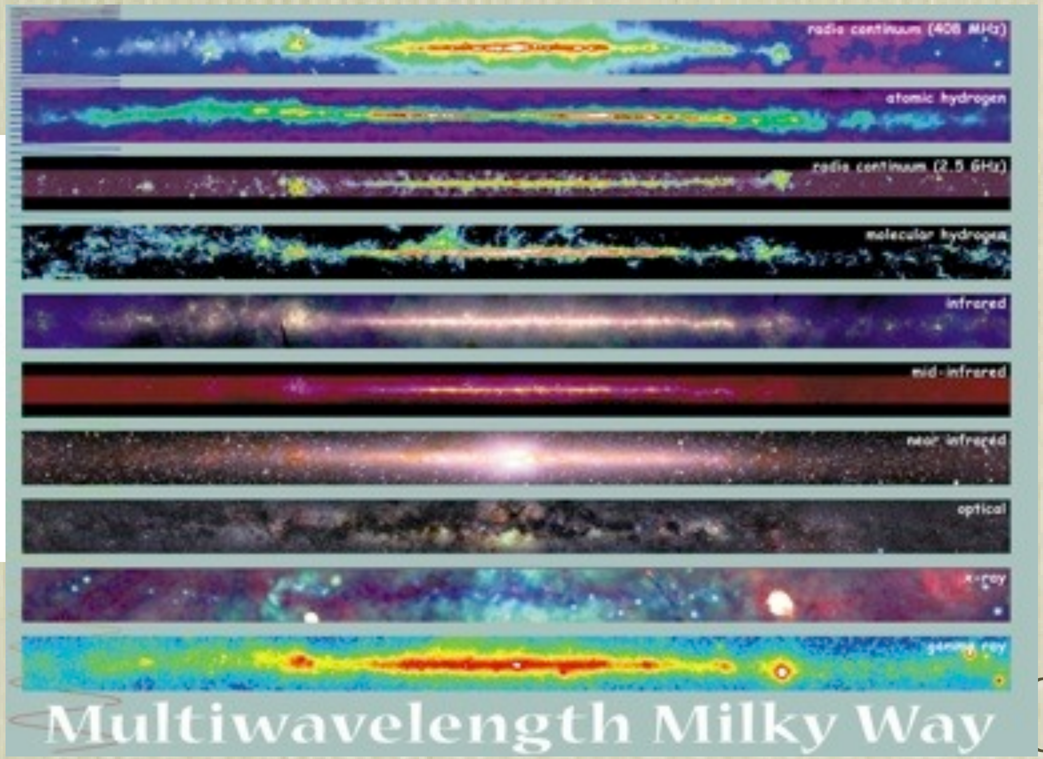
- cosmic MeV background can be explained by a physically reasonable extension of AGN spectrum for CXB

- Another motivation for MeV DM: 511 keV emission from the Galactic Center or bulge region?

The 511 keV Annihilation Line Emission from GC

- extended spherical bulge with ~8 deg FWHM (~1.1 kpc)
- bulge / disk flux ratio = 3-9 (c.f. mass ratio 0.3-1.0)
- positron production rate ~1.5×10^{43} s^{-1}





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The Origin of the 511 keV Emission!?

- narrow line width (~5.4 keV FWHM)
  - injection positron energy <~ 3 MeV (Beacom+'05)
  - cooled in interstellar matter
  - travelling time scale before annihilation ~ 10^7 yr
- large bulge-to-disk ratio
  - excluding massive stars, supernovae, pulsars, GRBs, etc.
  - low-mass X-ray binary: still low B/D

511 keV emission from supermassive black hole Sgr A* ?

- positron production rate from accretion flow onto Sgr A* can be calculated from the currently standard RIAF (radiatively inefficient accretion flow) model (Totani 2006)
    - too low e^+ production rate for the current accretion rate
    - ~10^3 times higher accretion rate in the past 10^7 yrs can explain the 511 keV emission

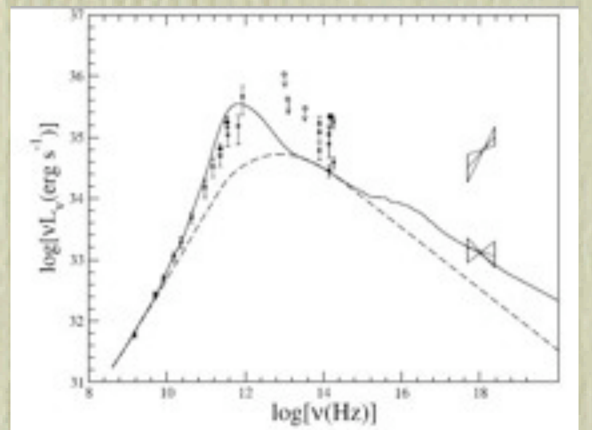


FIG. 1.—RIAF model for the quiescent state of Sgr A*. The IR data with error bars are from Ghez et al. (2004) and Genzel et al. (2003), the radio data with error bars from Falcke et al. (1998, *open circles*) and Zhao et al. (2003, *filled circles*), the IR data with upper limits from Serabyn et al. (1997, *open circles*) and Hornstein et al. (2002, *filled circles*), and the two "bow ties" in the X-ray for the quiescent (*lower*) and flaring (*higher*) states from Baganoff et al. (2003, 2001). The dashed line shows the synchrotron emission by power-law electrons with $p = 3$. The solid line shows the total quiescent emission, including that from thermal electrons. The slight difference in the value of p compared with that in YQN03 ($p = 3.5$) is to fit the quiescent IR data better.

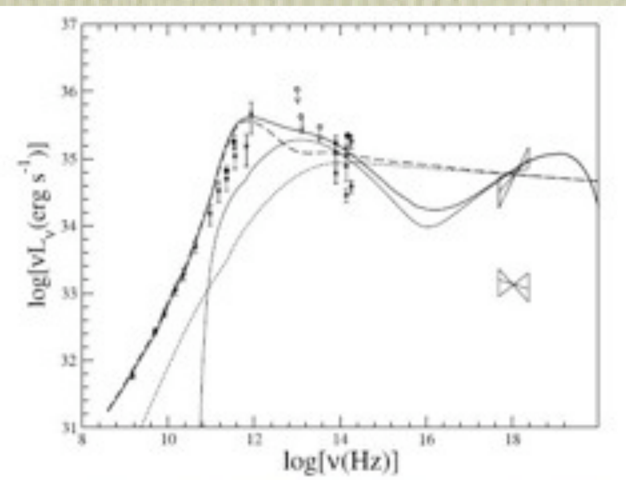
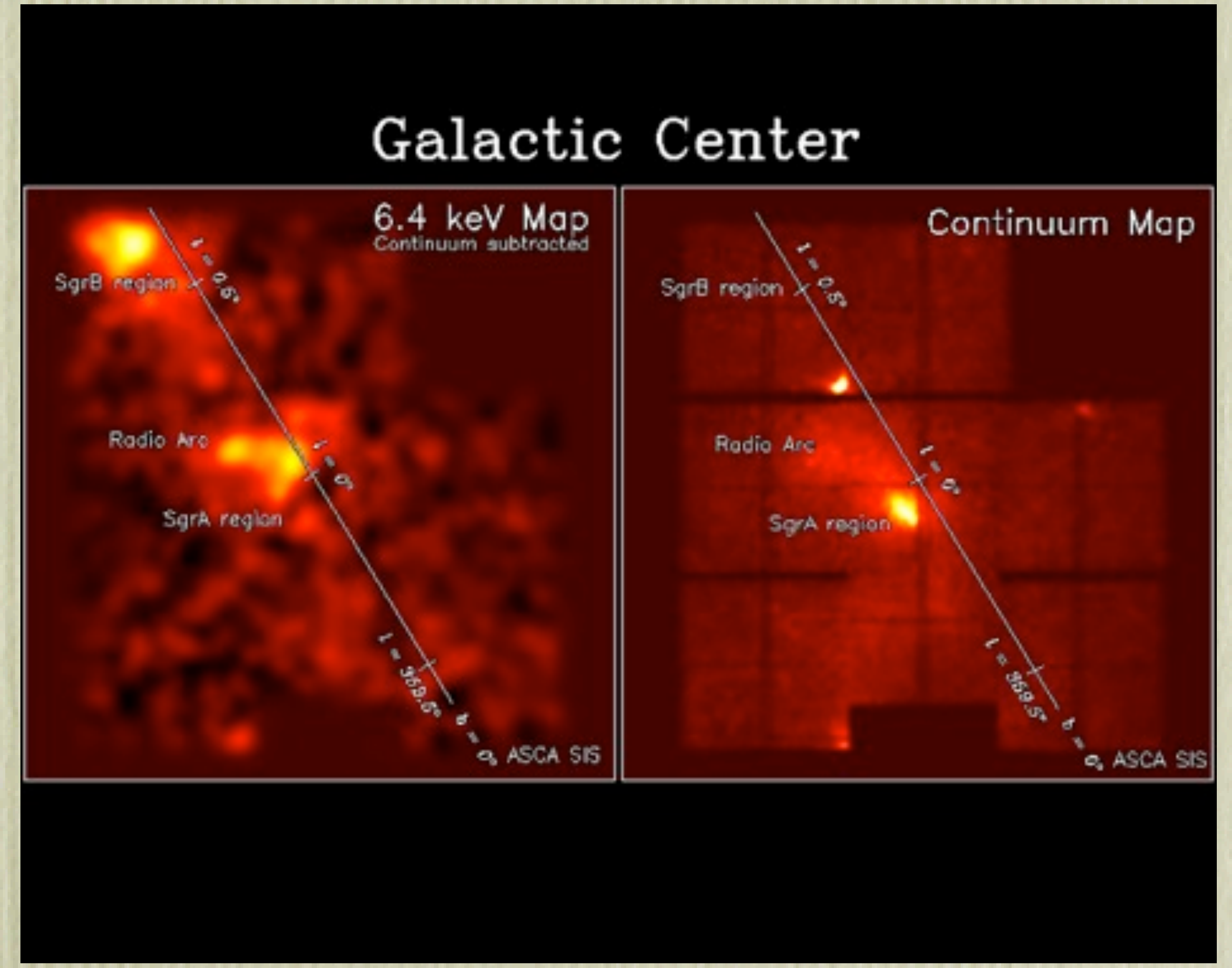


FIG. 3.—Pure synchrotron models for the IR and X-ray flares in Sgr A*. The two dashed lines are models in which the electrons are assumed to have $p = 2.1$. The solid lines are for the broken power-law model (eq. [1]), with $p_1 = 3$, $p_2 = 1$, $\eta = 7\%$, $\gamma_{max} \sim 10^6$, and $\eta_{acc} = 1$. In each case, the thin lines correspond to the emission from only the power-law electrons, and the thick lines to the total emission, including the thermal electrons.

Yuan+ '04

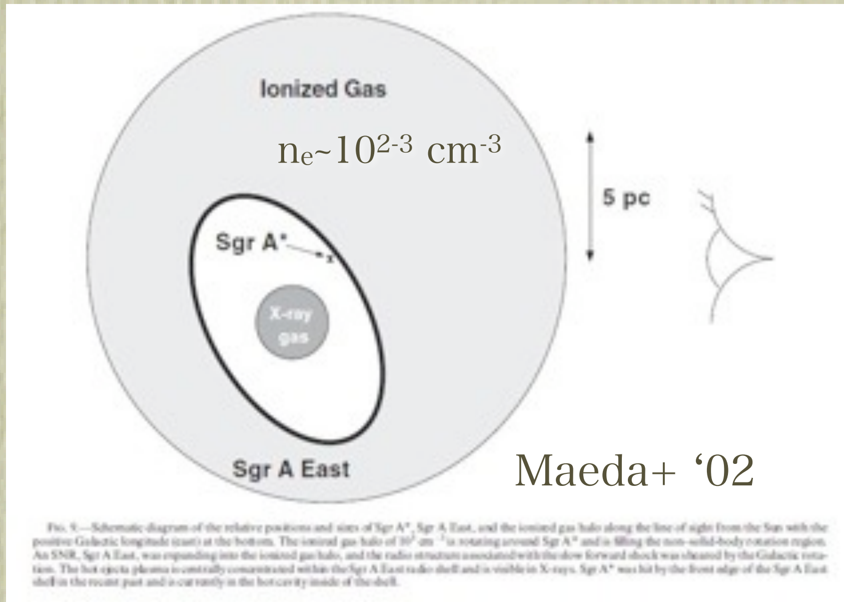
Evidence for the past higher activity of Sgr A*

- X-ray reflection nebulae around GC indicate that Sgr A* was much more luminous ($\times 10^{5\text{-}6}$) than now until 300 yrs ago (Koyama+'96; Murakami+'00, Koyama+'08)
- this factor consistent with $\times 10^3$ higher accretion rate in RIAF



Why Sgr A* currently so dim?

- The Key: supernova remnant Sgr A East
  - Sgr A* appears to be inside the Sgr A East bubble
  - current accretion rate must be quite different from ordinary rate
  - $\times 10^3$ higher accretion rate is typical for nuclei of nearby Milky-Way-like galaxies



- Sgr A* gives a reasonable explanation for the large B/D ratio of the 511 keV emission
  - astrophysical explanation well possible
  - no strong pressure to consider MeV dark matter