

# *“High Energy Neutrinos from Astrophysical Accelerators of Cosmic Ray Nuclei”*

Based on work by:



Luis Anchordoqui



Dan Hooper



Subir Sarkar

and Andrew Taylor

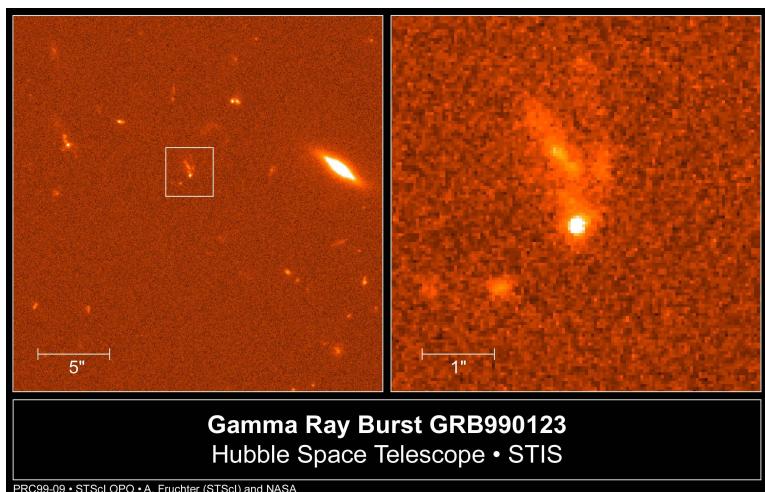
(astro-ph/0703001)

“*Quicquid Nitet Notandum*”  
“whatever ~~shines~~ arrives is to be observed”

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# Candidate Sources: AGN- $10^{44}$ erg s $^{-1}$ (luminosity break energy)

GRB-  $10^{52}$  erg s $^{-1}$   
(luminosity break energy)



## Starburst- $10^{42}$ erg s $^{-1}$ (luminosity break energy)



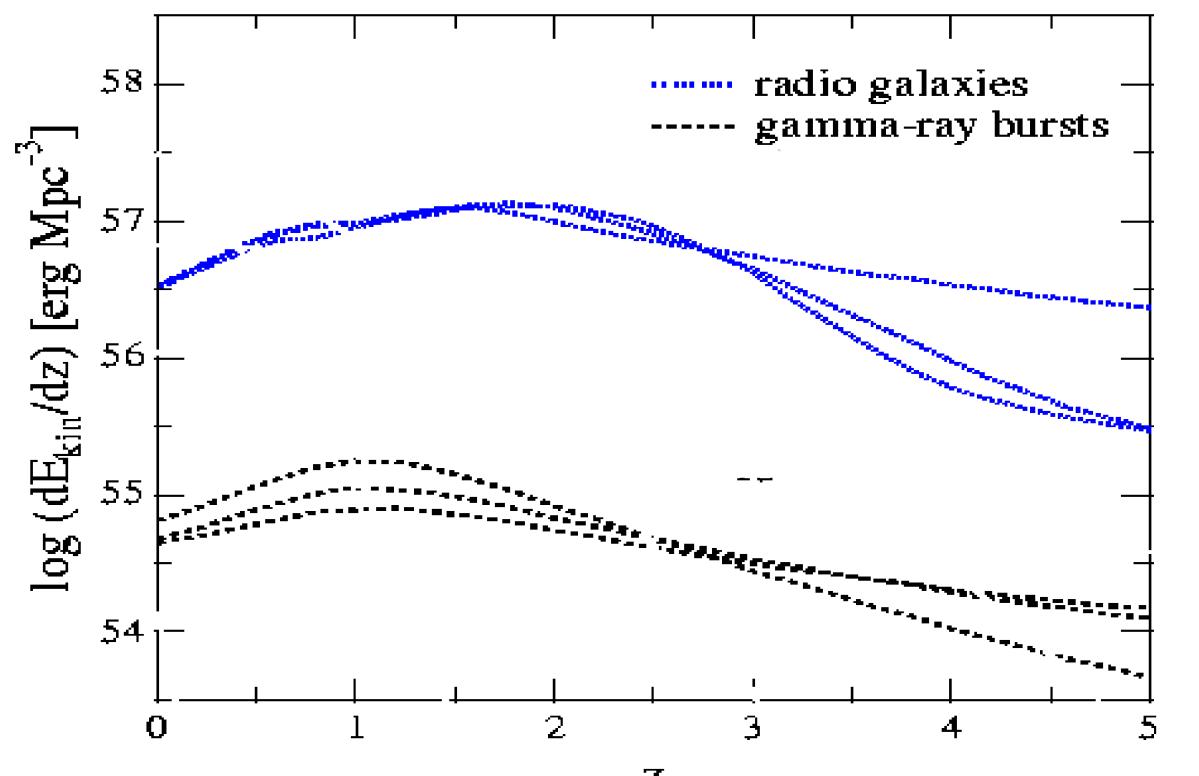
# Power density of Sources-

Extragalactic Cosmic Rays,  $E > 10^{18}$  eV, have an energy density  $\sim 10^{-8}$  eV cm $^{-3}$   $\rightarrow 10^{-20}$  erg cm $^{-3}$   
 $\rightarrow 10^{54}$  erg Mpc $^{-3}$

$$\rho_L = \int L \frac{dn(z)}{dL} dL$$

$$\frac{dE}{dz} = \frac{dt}{dz} \rho_L$$

From S. Inoue  
[astro-ph/0701835](https://arxiv.org/abs/astro-ph/0701835)



(3 different redshift evolution of sources used)

# Power Density of Sources-

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→  $10^{-20}$  erg cm $^{-3}$

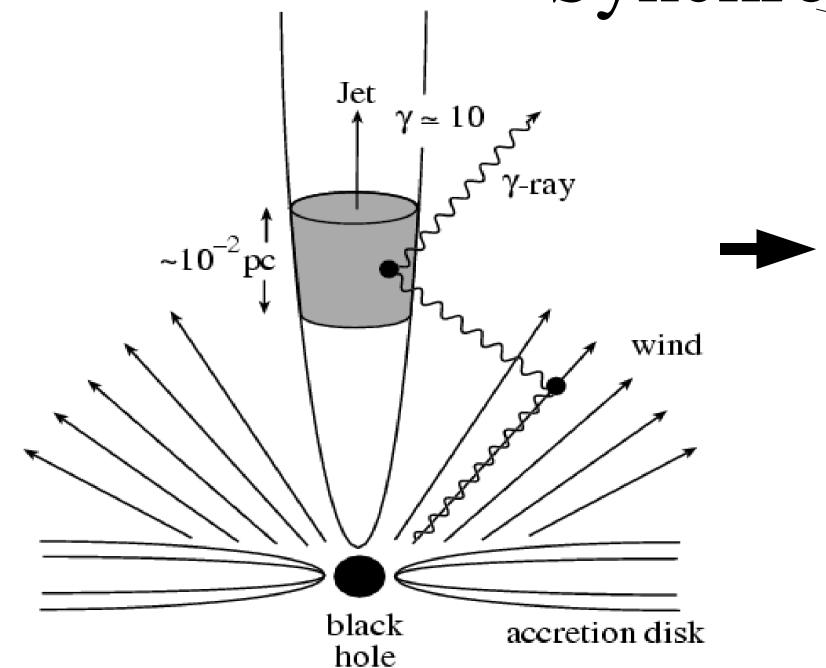
→  $10^{54}$  erg Mpc $^{-3}$

**Problems for GRBs** being sources if transition to Extragalactic Cosmic Rays occurs at  $10^{17}$  eV

# AGN Model and Radiation Field

Black Body

Synchrotron

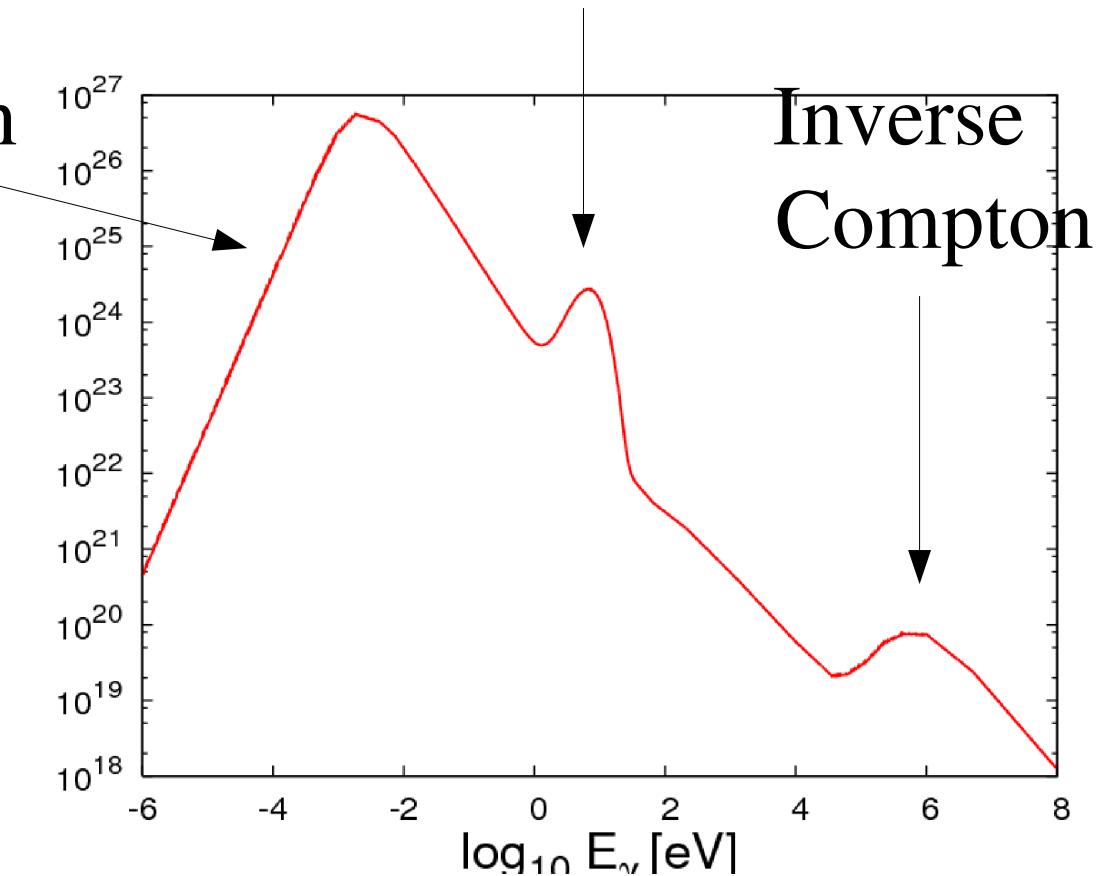


$$\Gamma \sim 30$$

$$l_{source} = \Gamma c \Delta t = 10^{-2} \text{ pc}$$

$$n_\gamma = 10^{13} \text{ cm}^{-3}$$

Inverse  
Compton

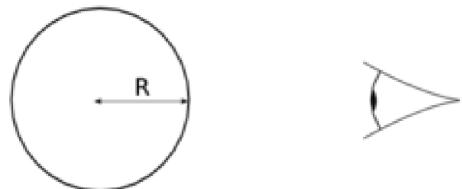


NB. relativistic sources have smaller  $n_\gamma$  values

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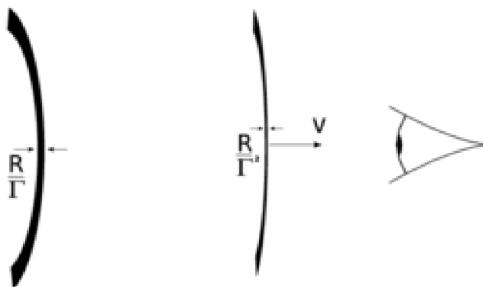
# GRB Model and Radiation Field

Observer's Frame (pre-Fireball)



(post-Fireball)

Shell Rest Frame      Observer's Frame

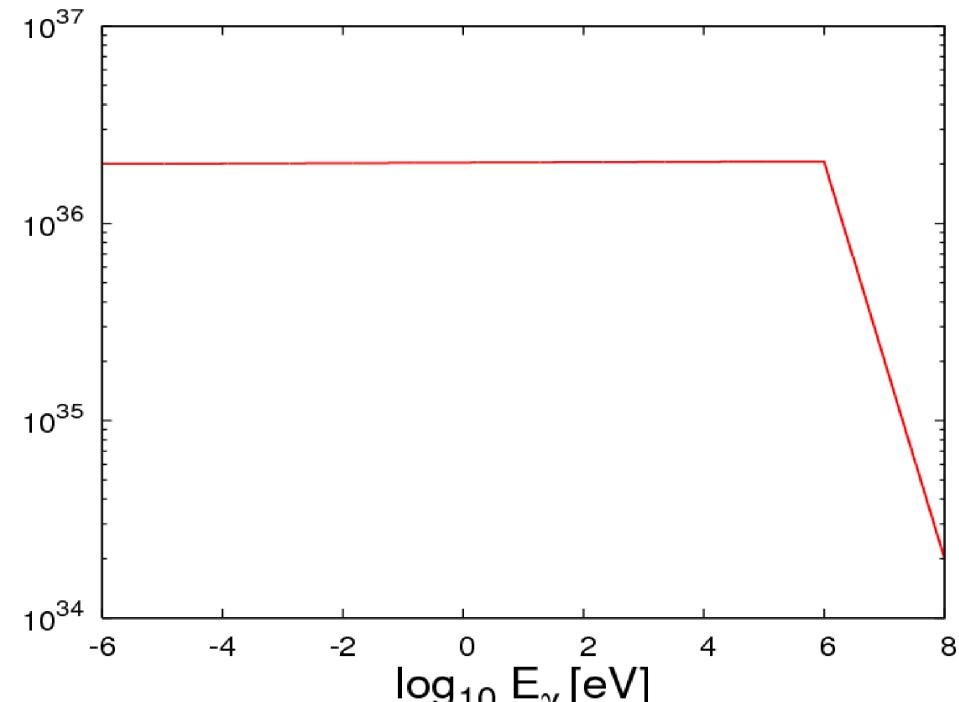


$$dN/dE \propto E^{-\beta}, \quad \begin{aligned} \beta=1, & E < \text{MeV} \\ \beta=2, & E > \text{MeV} \end{aligned}$$

$$\Gamma \sim 300$$

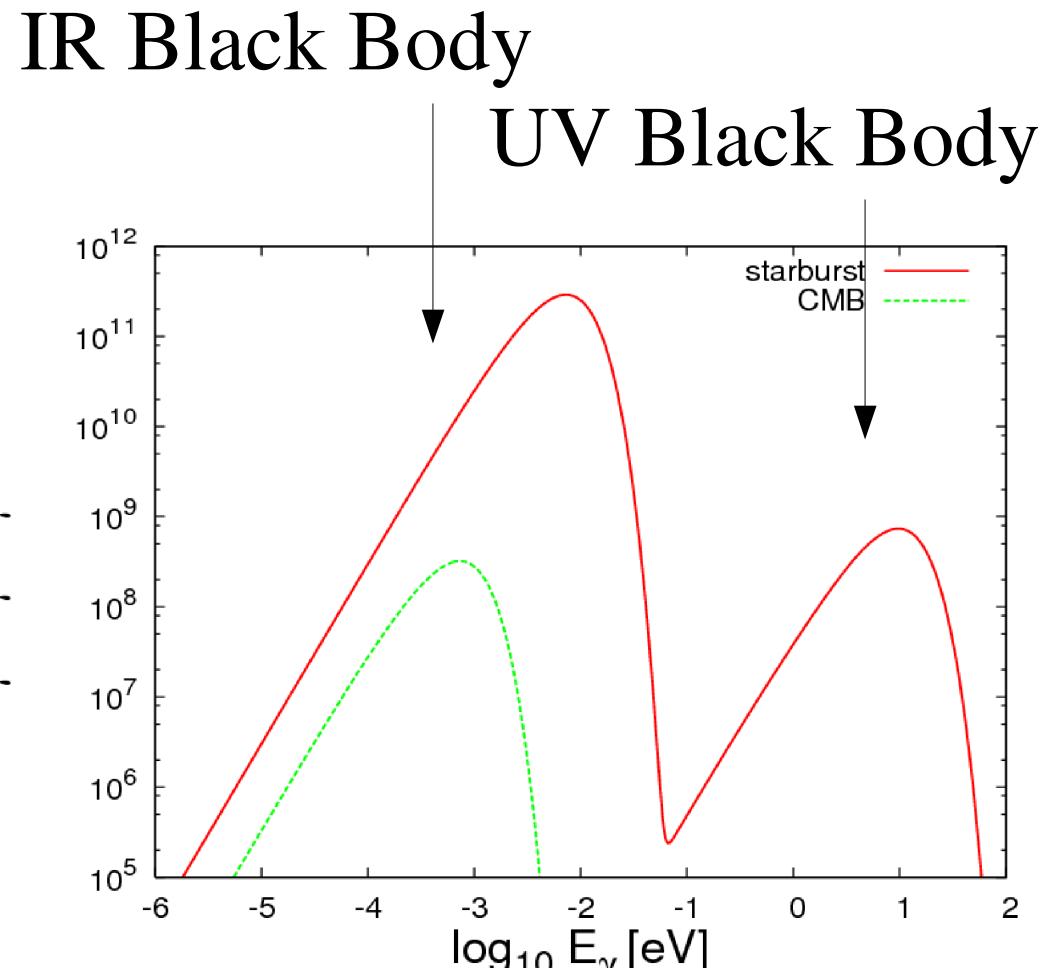
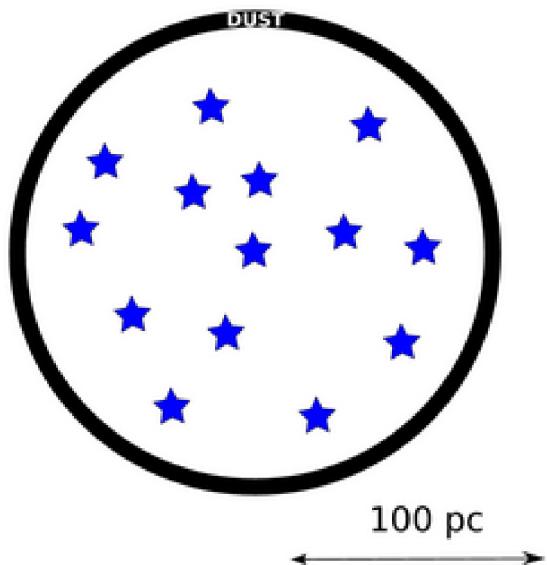
$$l_{\text{source}} = \Gamma^2 c \Delta t = 10^{-6} \text{ pc}$$

$$n_\gamma = 10^{17} \text{ cm}^{-3}$$

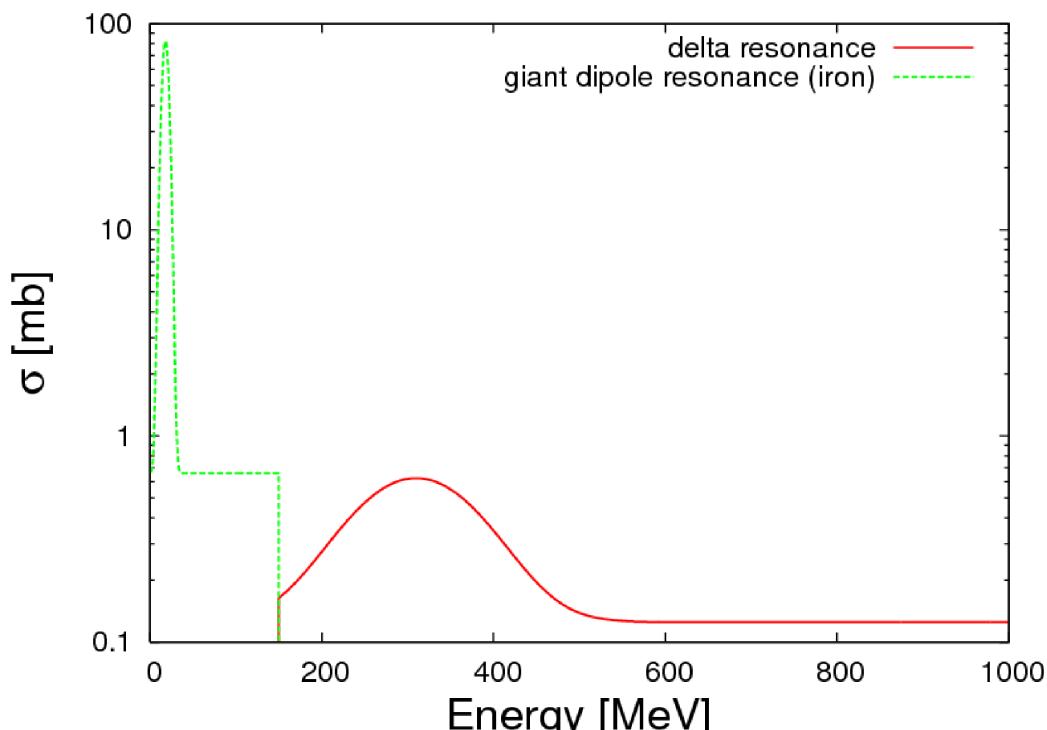


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# Starburst Galaxy Model and Radiation Field



# Cosmic Ray Interactions with Radiation



2 cross-sections: pion production  
photodisintegration

opacity factor-  $f_\pi$

$$f_\pi = l_{source} / l_{interaction}$$

$$l_{source} = c\Delta t$$

$$l_{interaction} = 1/(n_\gamma \sigma_\Delta)$$

GRB-  $f_\pi^{max} = 0.5$

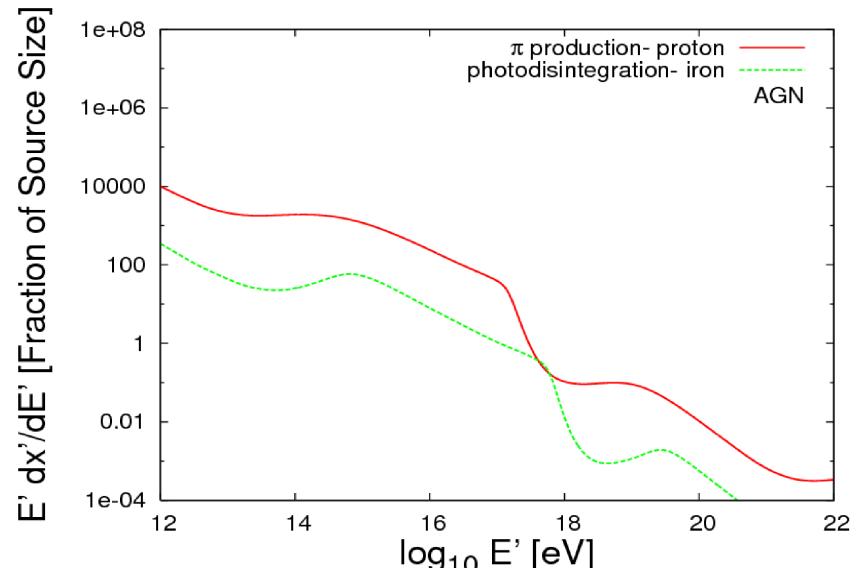
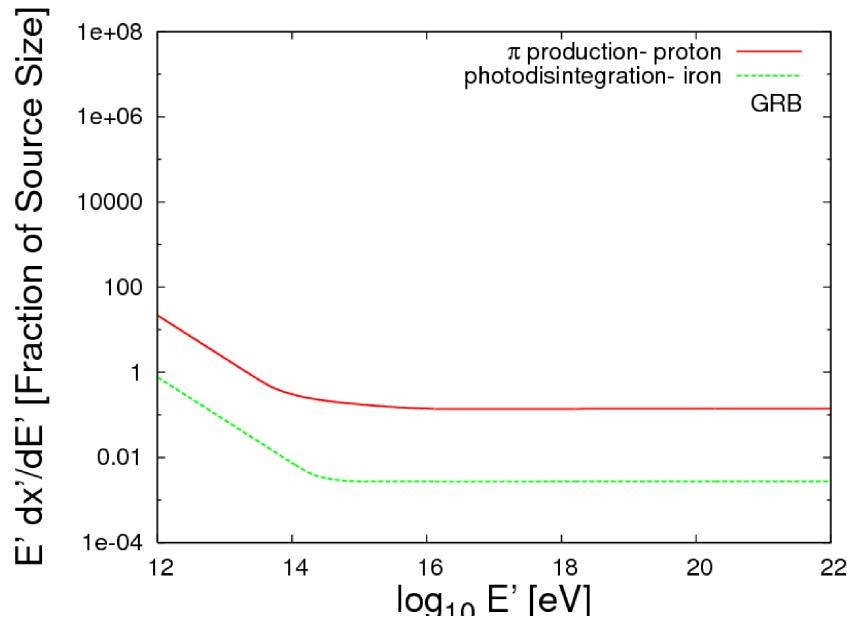
AGN-  $f_\pi^{max} = 500$

Starburst Galaxy-  $f_\pi^{max} = 4 \times 10^{-4}$

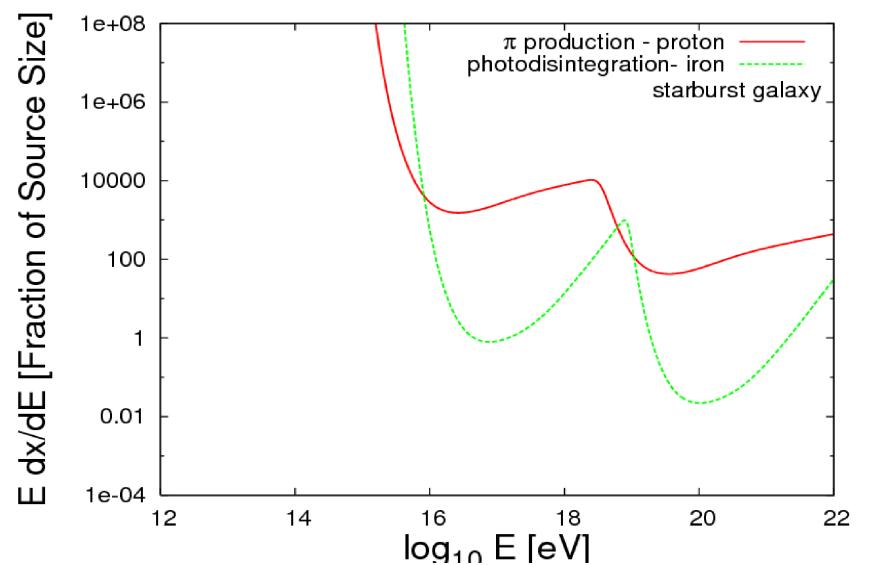
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# Interactions Rates in Sources- AGN

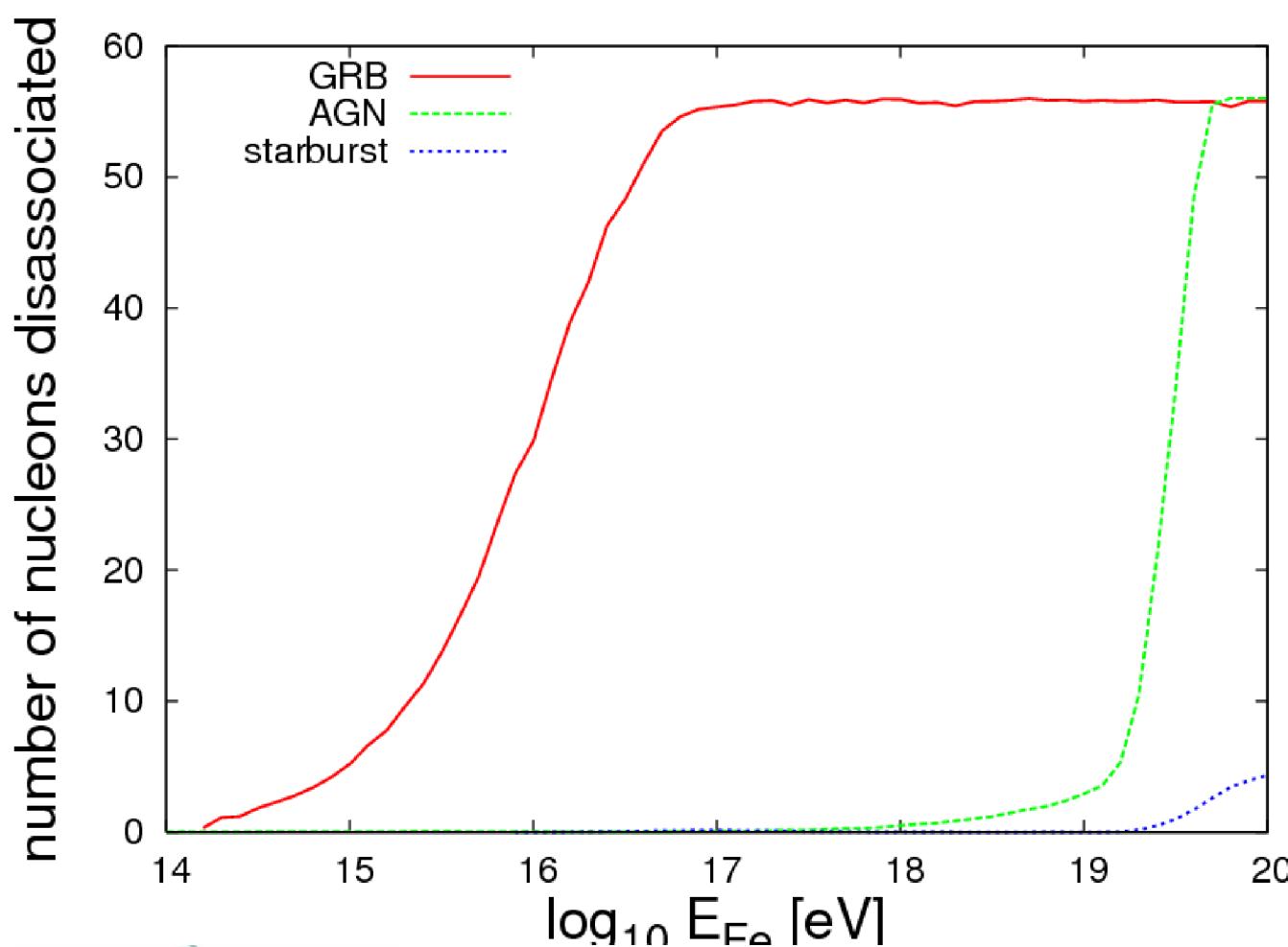
GRB



Starburst



# Degree of Photodisintegration in Source Regions



Complete  
Photodisintegration:

GRB-  $E_{\text{Fe}} > 10^{17} \text{ eV}$

AGN-  $E_{\text{Fe}} > 10^{20} \text{ eV}$

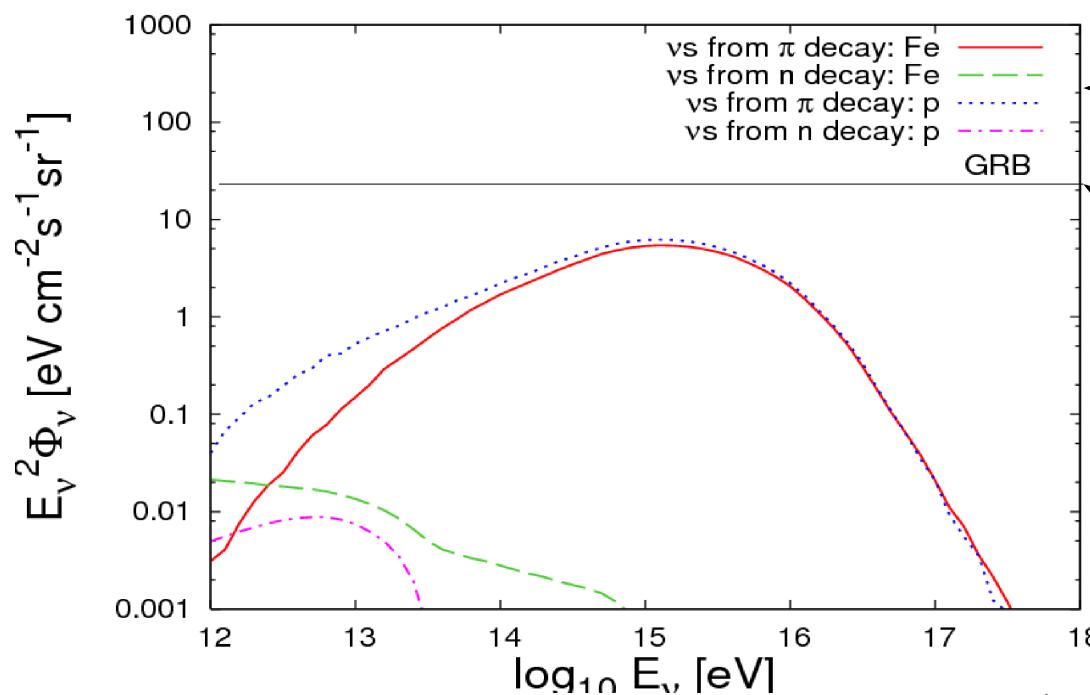
L. Anchordoqui et al.  
*astro-ph/0706.0517*

N.B. photo-disintegration of nuclei  
will be hadronic source of gamma-rays



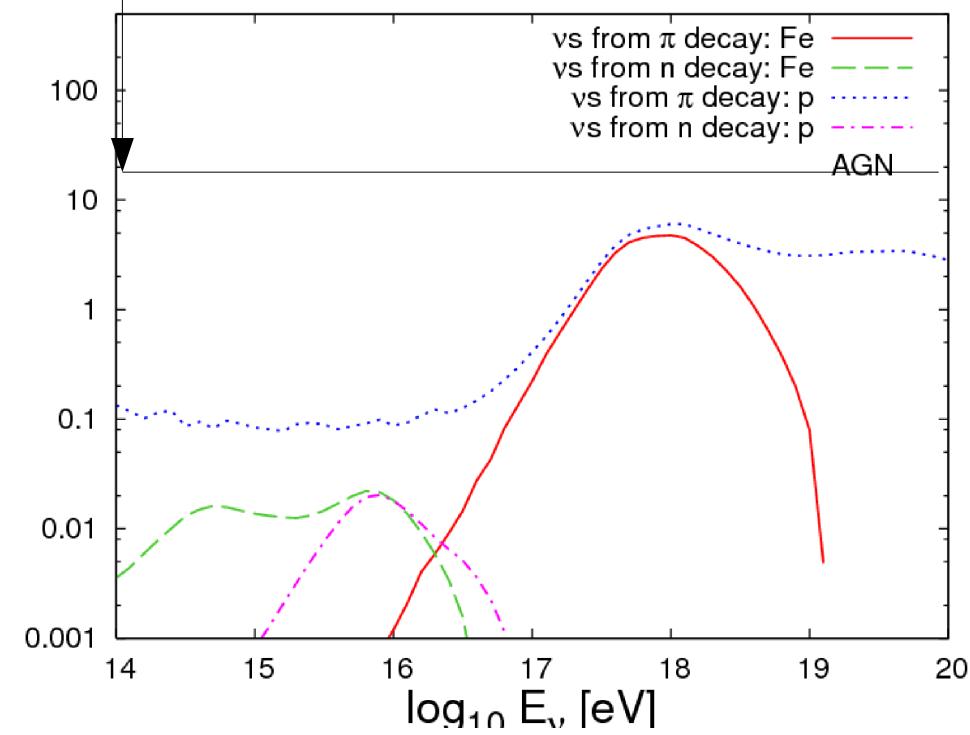
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# Diffuse Neutrino Fluxes Produced by Candidate Sources



GRB result

Waxman Bahcall bound



AGN result

$$\Phi_\nu = \int \Phi_\nu \frac{dN}{dV} d\chi$$

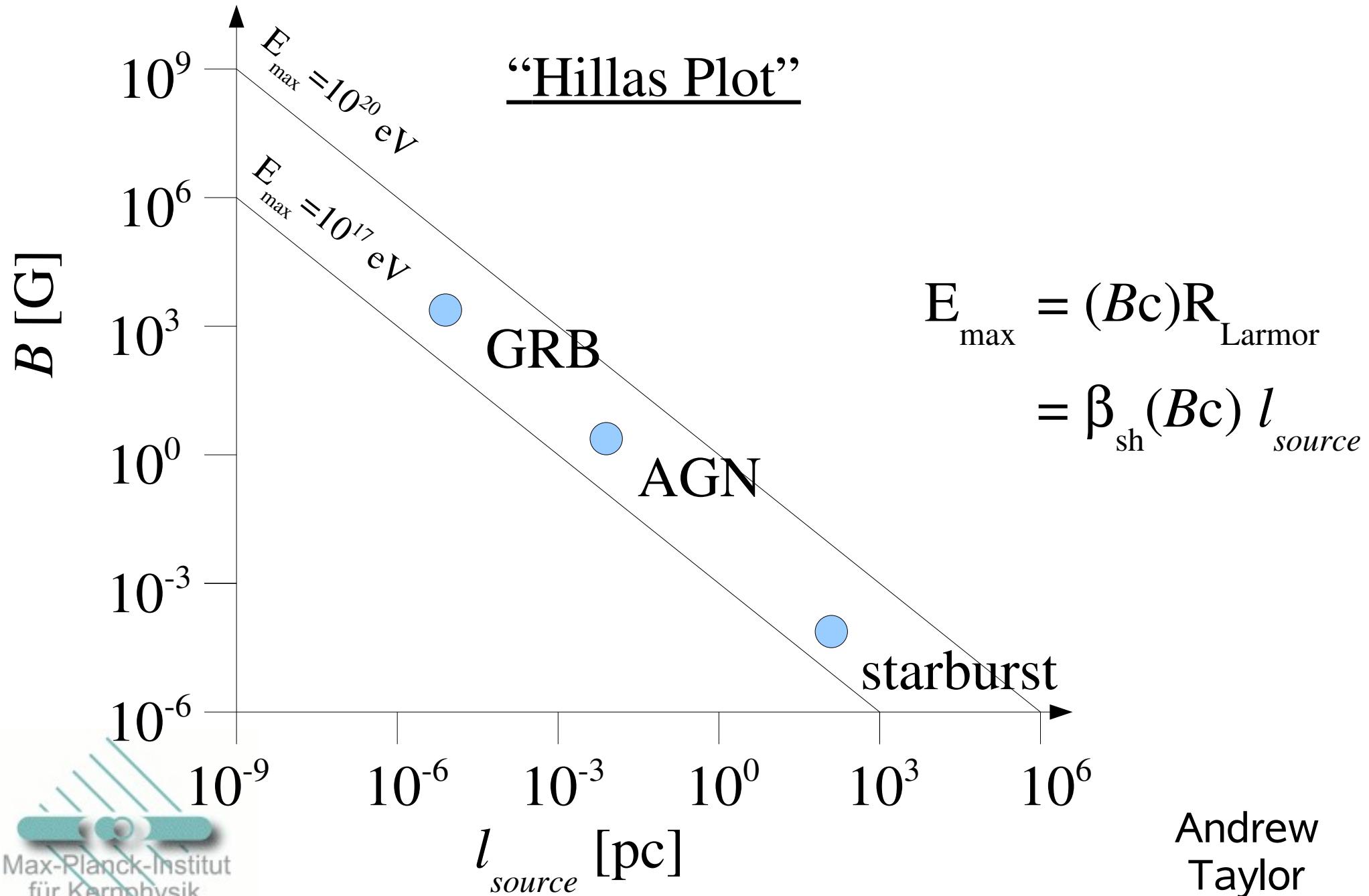
NB. Starburst flux  $\sim 10^{-4}$  WB bound

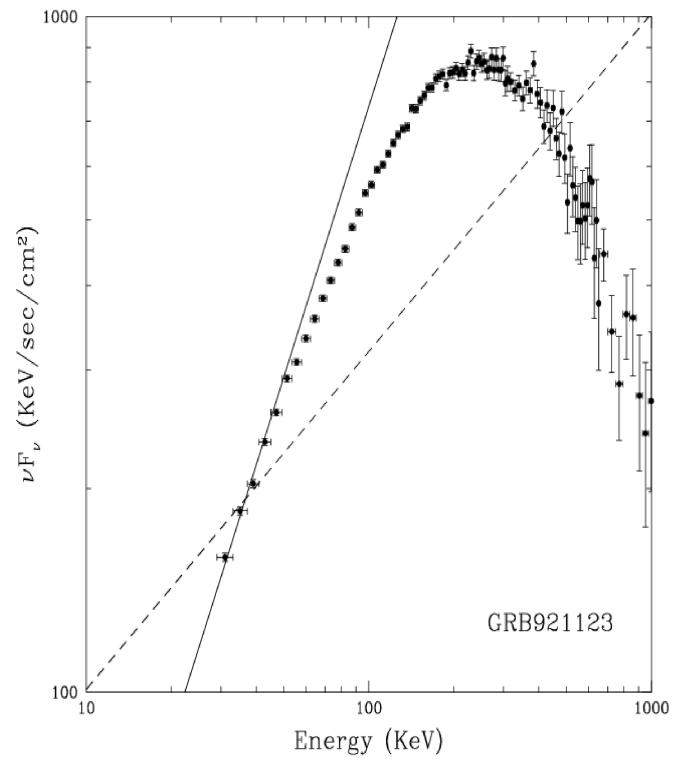
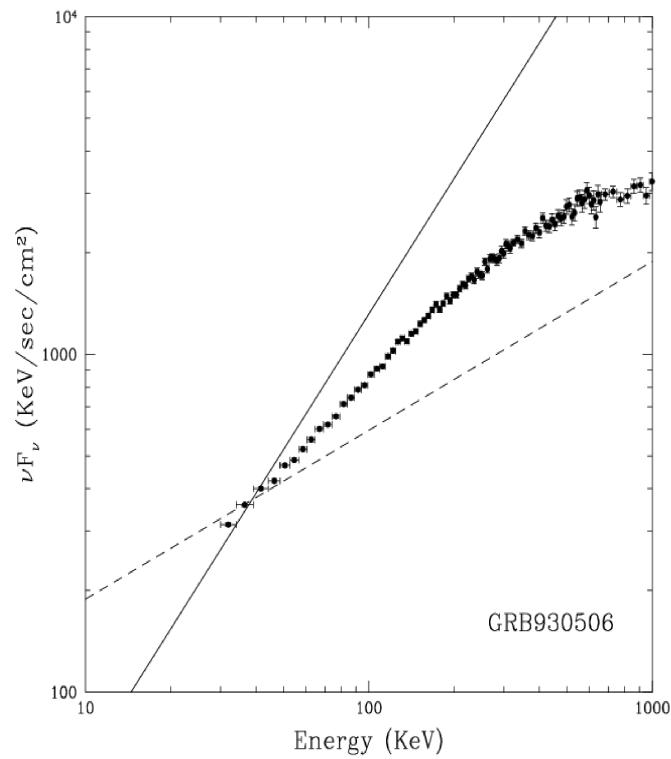
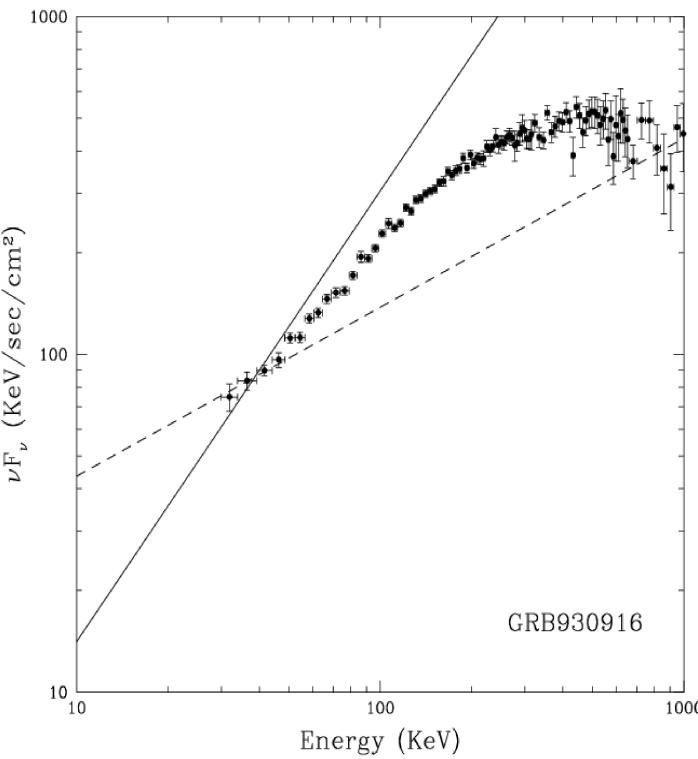
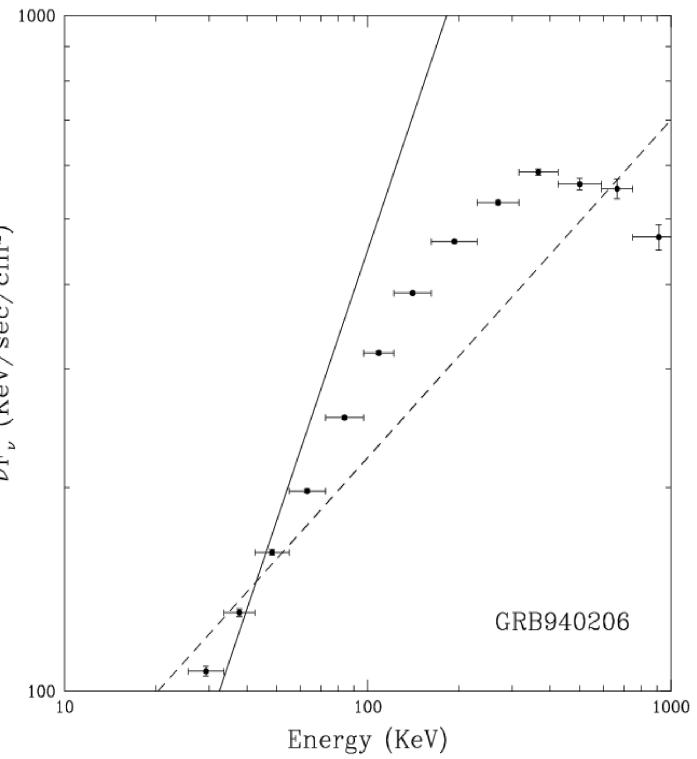
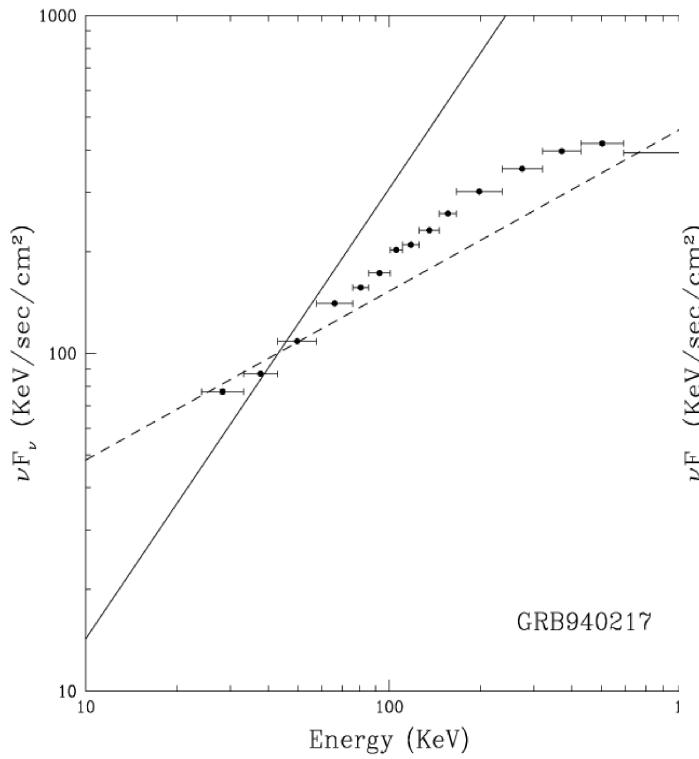
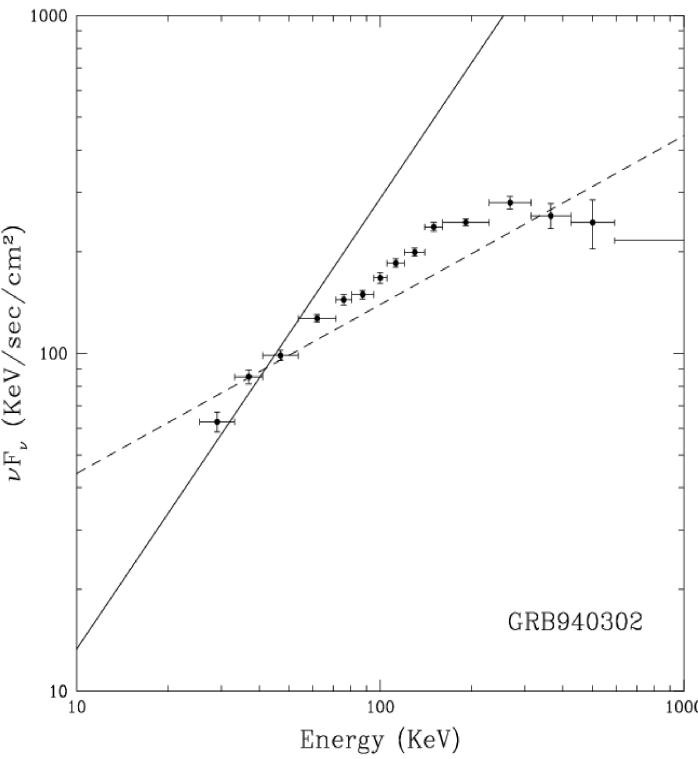
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# Conclusion

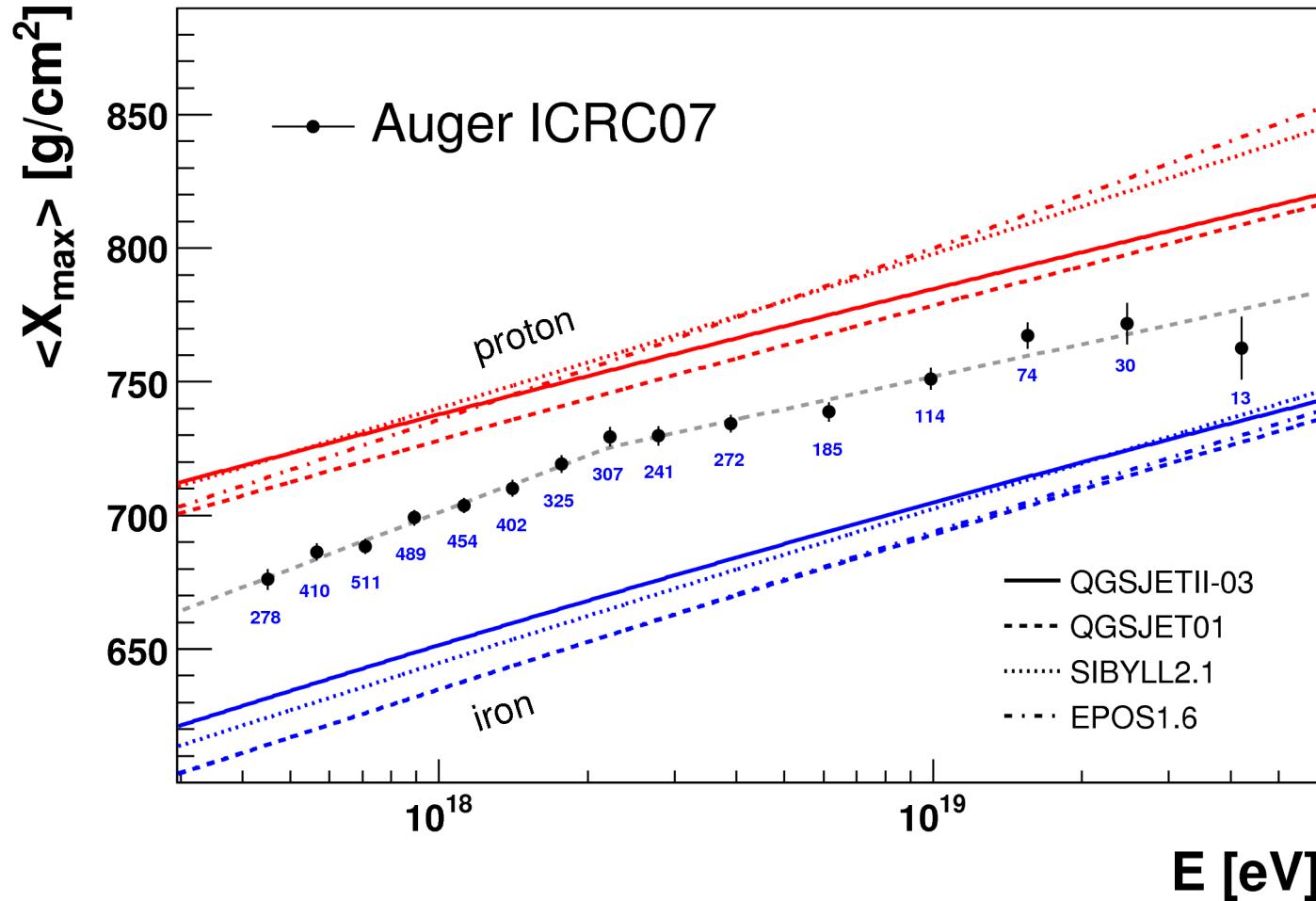
- Extragalactic accelerators cosmic rays will leads to the photo-disintegration of any nuclei present
- The degree of photo-disintegration is a good indicator of the neutrino flux produced by the source
- Conversely, the presence of nuclei in the high energy cosmic ray flux would be indicative of low neutrino fluxes being produced by the source

# Source Size and B-Field Strength

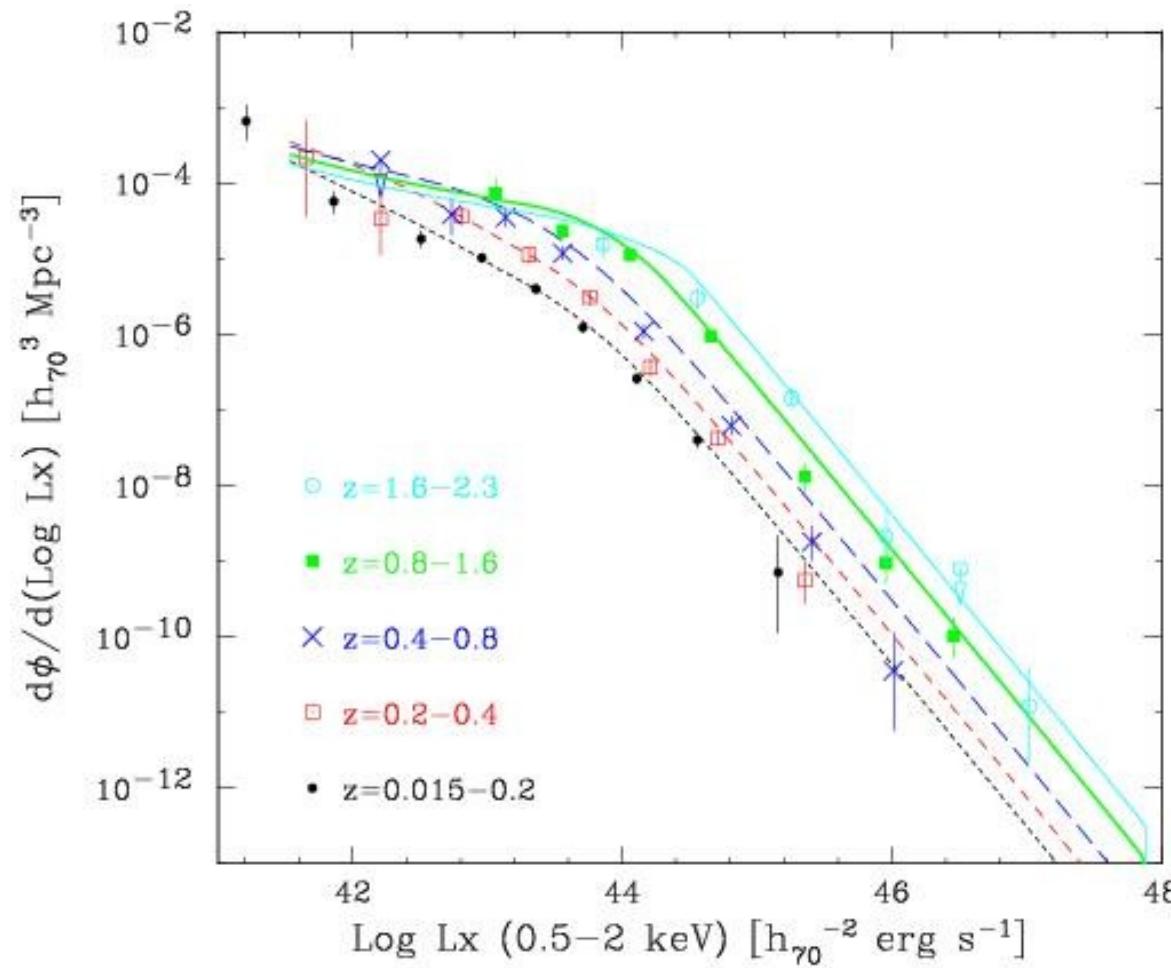




# The latest $X_{\max}$ Data from Auger



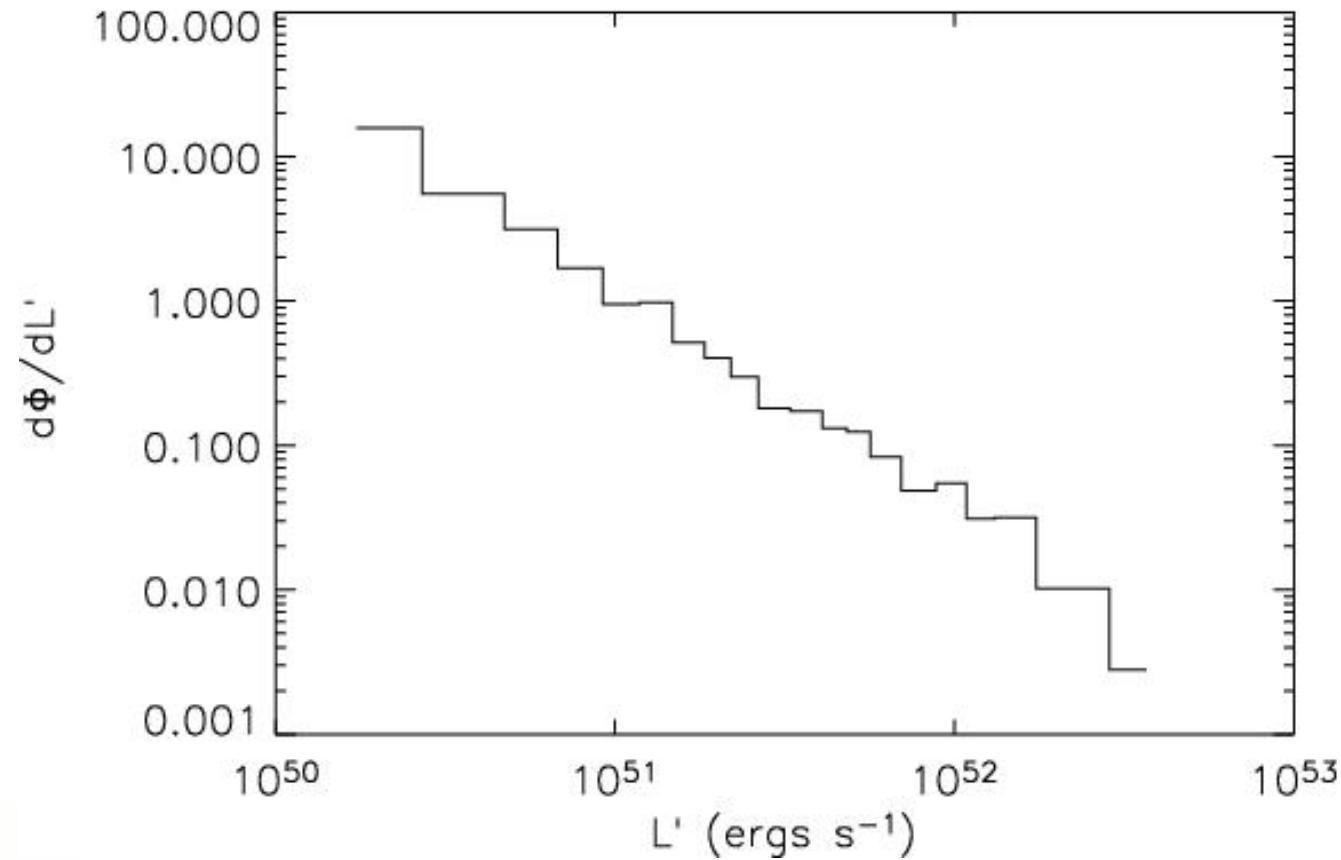
# Luminosity Function- AGN



From Y. Ueda et al.  
*astro-ph/0308140*

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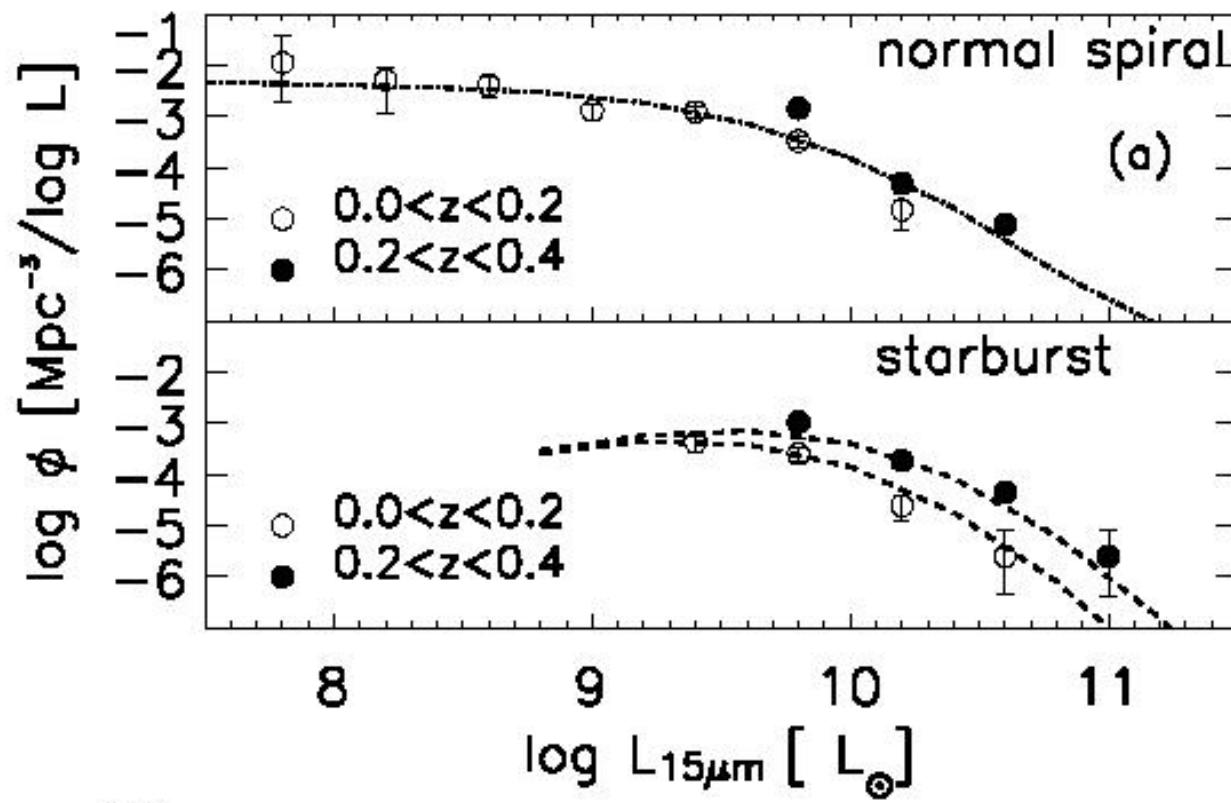
# Luminosity Function- GRBs



From D. Kocevski et al.  
*astro-ph/0601146*

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# Luminosity Function- Starburst



From F. Pozzi et al.  
*astro-ph/0403242*

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# Starburst Galaxy SEDs

