IDS Report

Chuck Dermer (Naval Research Laboratory)

GLAST/SWG

10 February 2003

Collaborators:

Armen Atoyan (University de Montreal) Blazars, GRBs

Robert Berrington (NRL) Clusters of Galaxies

Markus Böttcher (Rice University) GRBs, Blazars

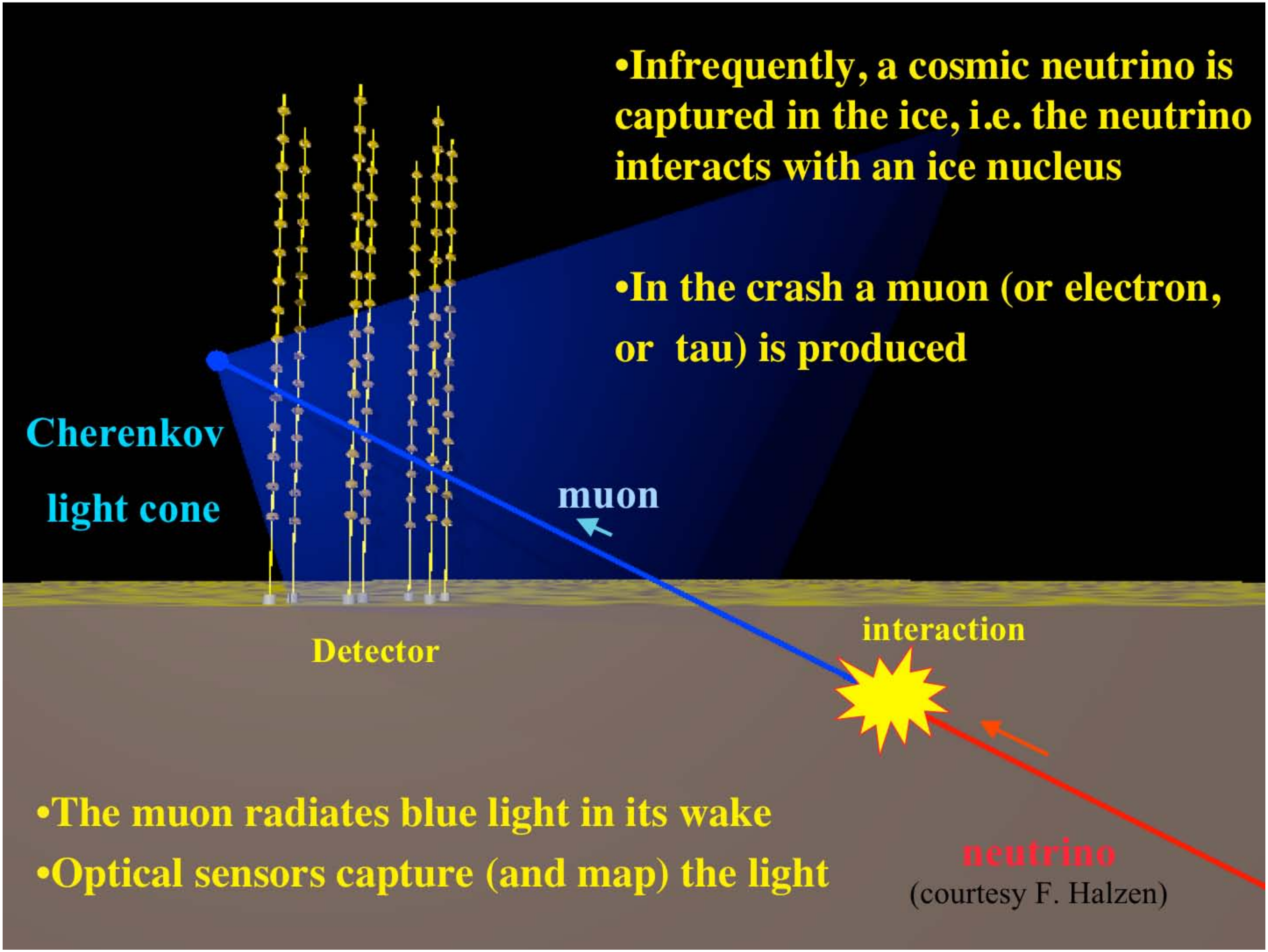
James Chiang (UMBC/SLAC) GRBs

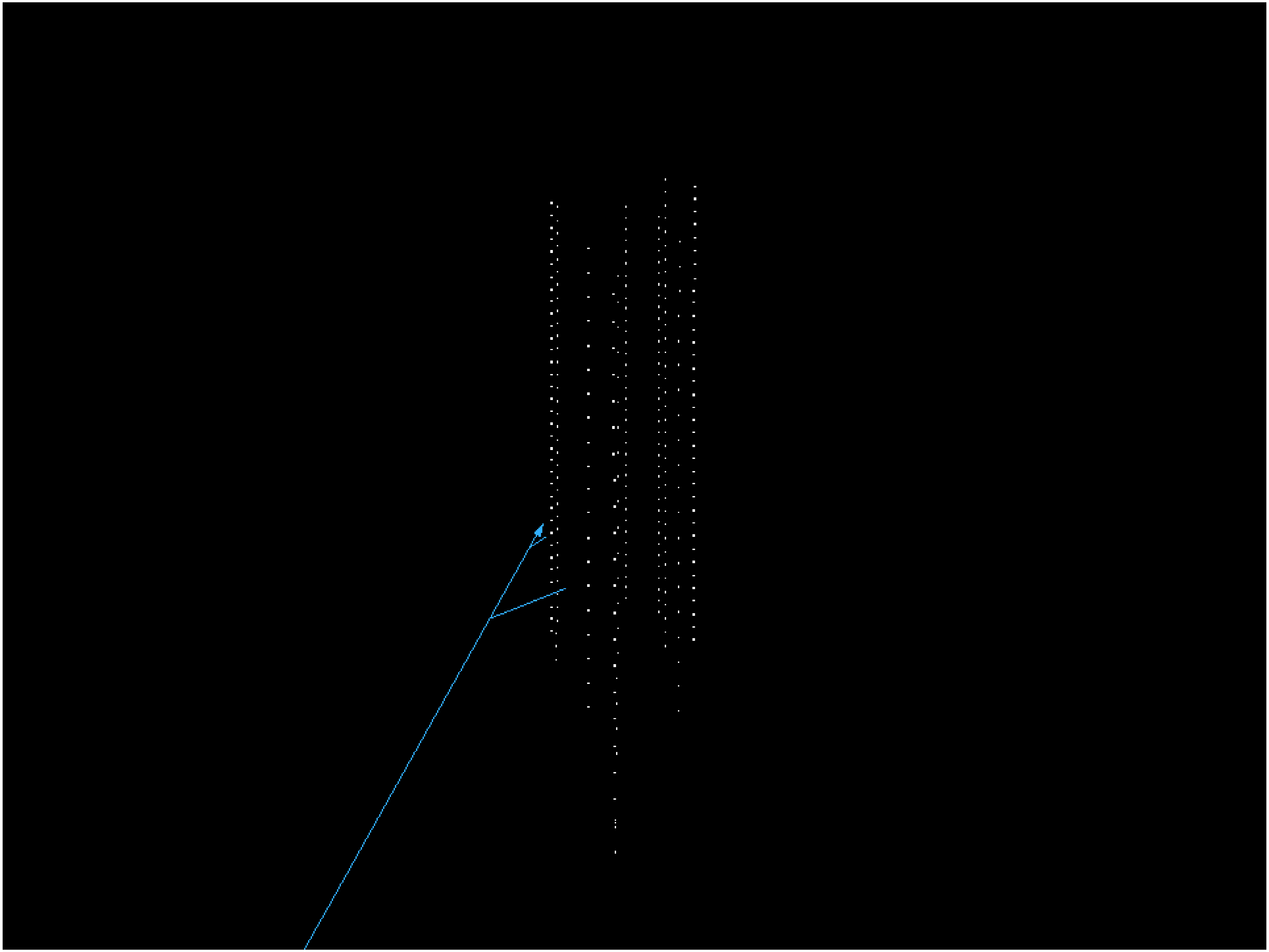
Stuart Wick (NRL) Cosmic Rays, Neutrinos

Gamma Ray/High Energy Neutrino Connection

$$p + \gamma' \rightarrow n + \pi^{+}\,,\; p + \pi^{0} \rightarrow \gamma$$

$$\pi^{+} \rightarrow e^{+} + \nu_{e} + \nu_{\mu} + \bar{\nu}_{\mu}$$

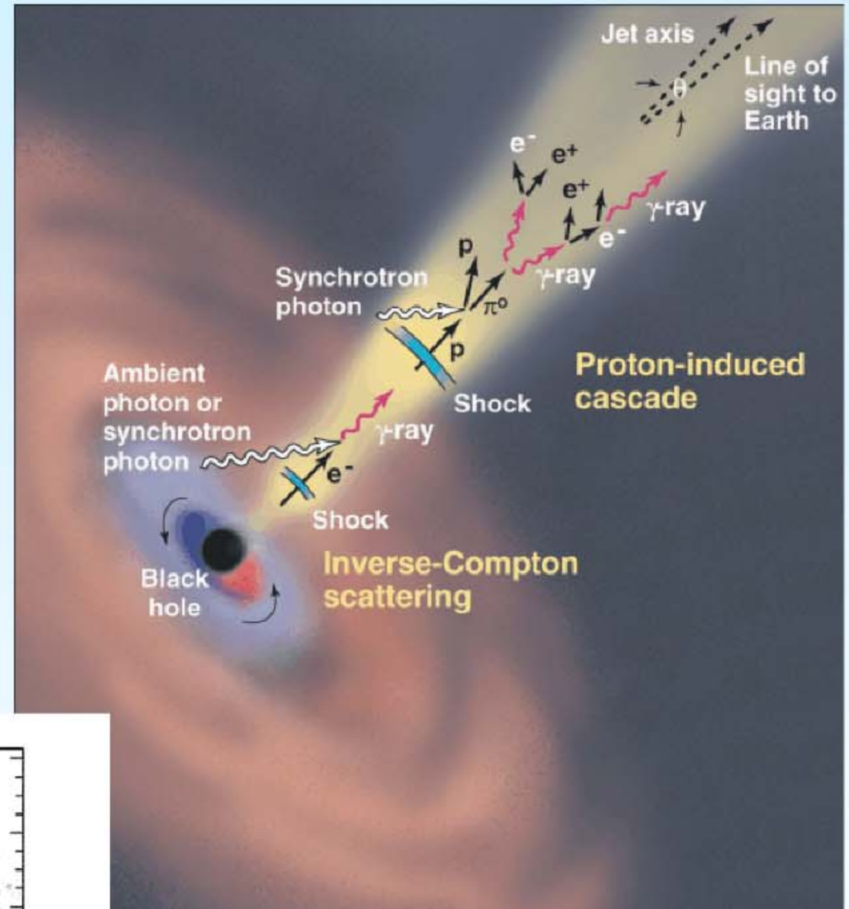

•Infrequently, a cosmic neutrino is captured in the ice, i.e. the neutrino interacts with an ice nucleus
•In the crash a muon (or electron, or tau) is produced
Cherenkov light cone
muon
Detector
interaction
neutrino
•The muon radiates blue light in its wake
•Optical sensors capture (and map) the light
(courtesy F. Halzen)

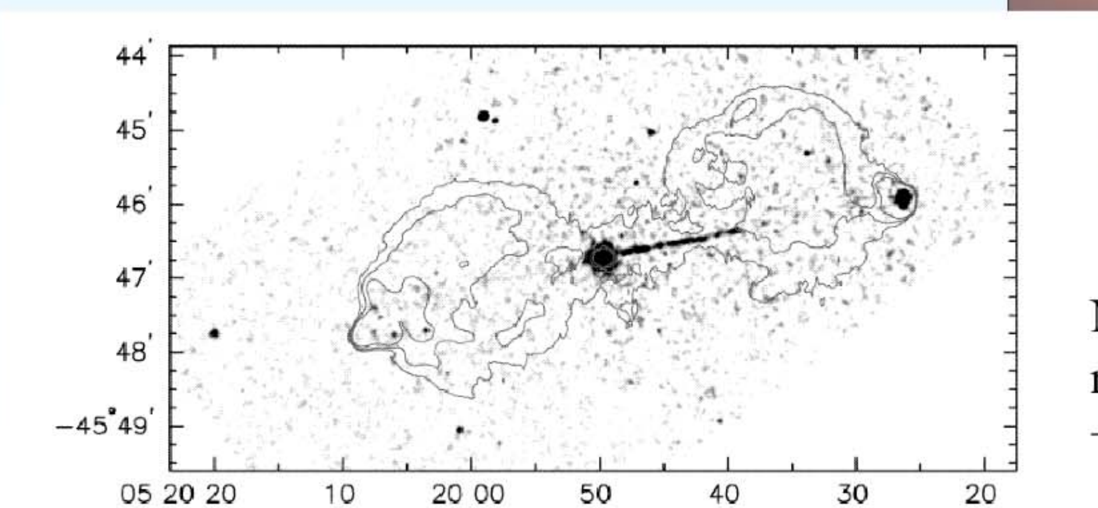


1. Neutral Beams from Blazar Jets

(March ApJ)

Combined lepton + hadron model
Importance of external radiation field
Neutron, neutrino, high-energy gamma-ray production
Evidence for UHECR acceleration



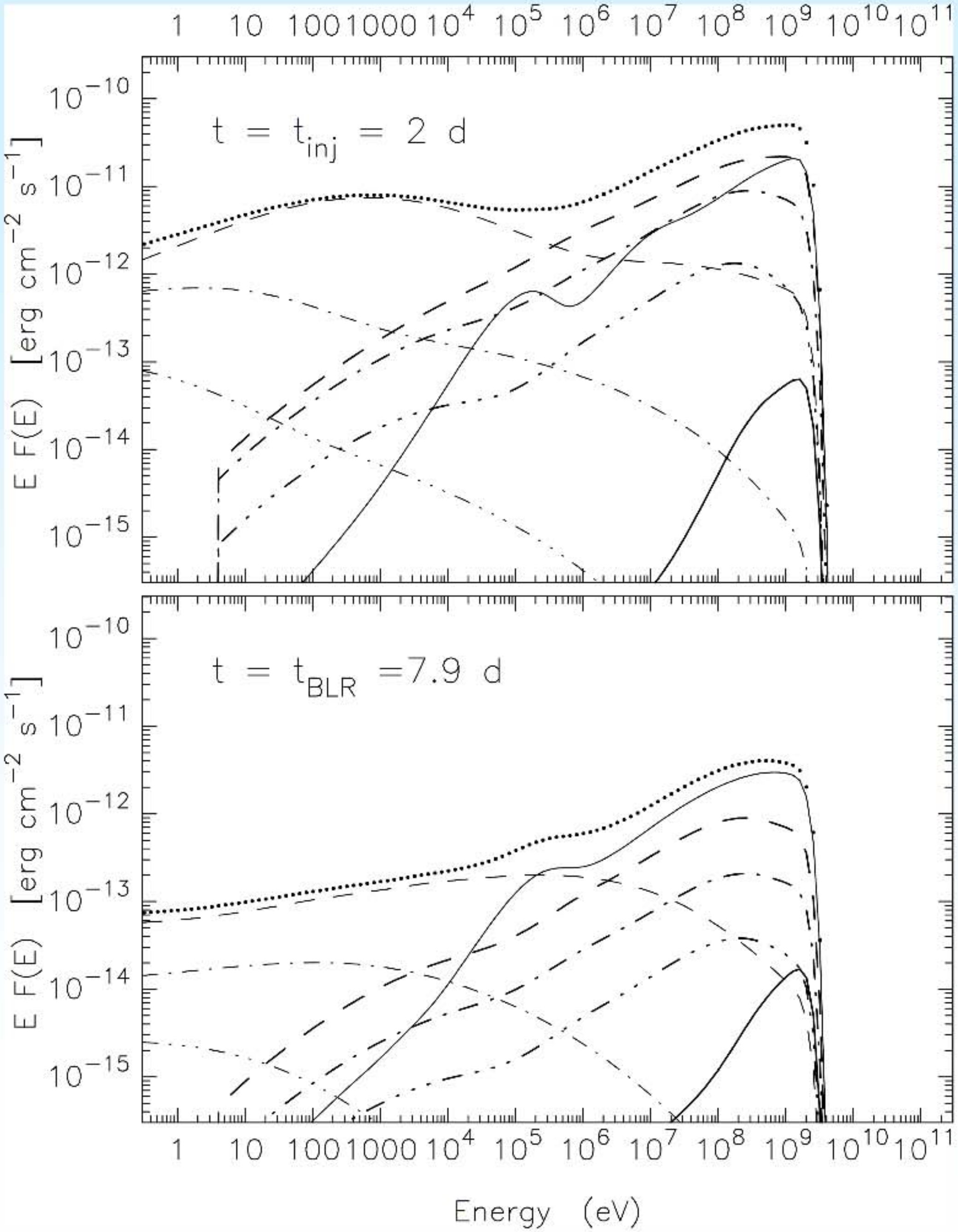


> 100 kps scale jet of Pictor A (Wilson et al. 2001, ApJ 547, 740)

Nonthermal gamma-rays ⇒
nonthermal particles
+ Intense photon fields

⇒ Strong photomeson production

Hadronic Cascade Radiation from 3C 279



(Limits proton/electron ratio)

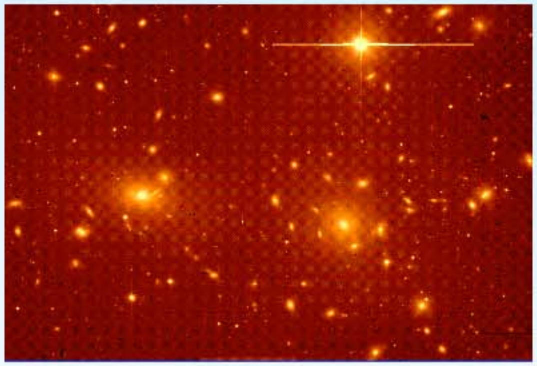
Predict detectable neutrino production from 3C 279 with a km-scale neutrino telescope; Hadronic gamma-ray emission detectable with GLAST

2. Nonthermal Particles and Radiation Produced by Cluster Merger Shocks

Thermal bremsstrahlung X-ray Emission of Galaxy Clusters traces gravitational well

Rich clusters (thousands of Galaxies; ~10^{15} M_{sun}; kT ~ 5-10 keV, L_X ~ 10^{43} - 10^{45} ergs s^{-1})

Velocity dispersions ~500-1000 km s^{-1}



Poor clusters (hundreds of Galaxies; ~10^{14} M_{sun}; kT ~ 1-5 keV, L_X ~ 10^{41} - 10^{43} ergs s^{-1})

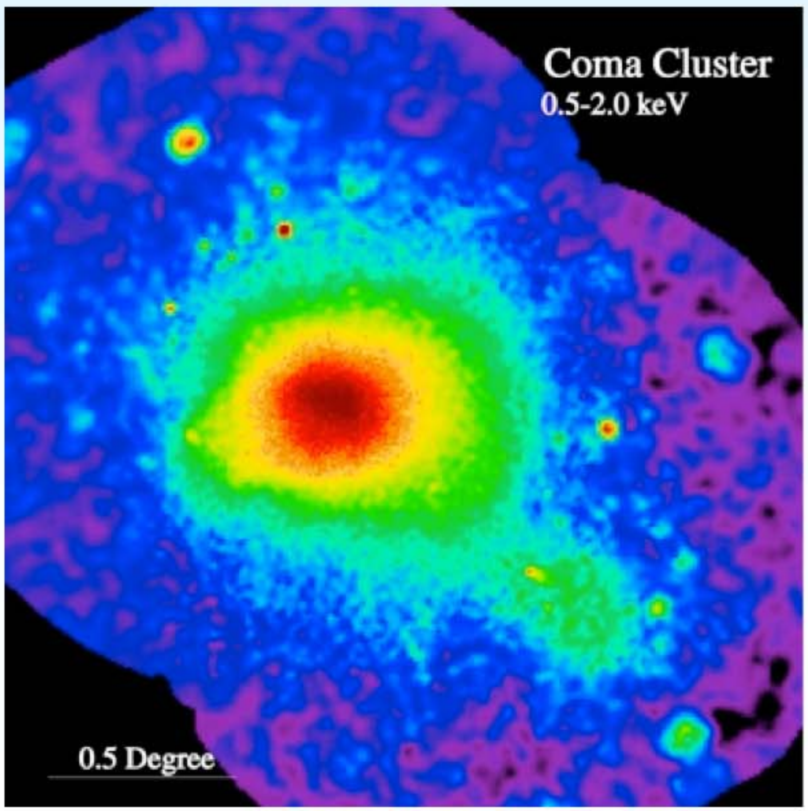
Velocity dispersions ~250-500 km s^{-1}

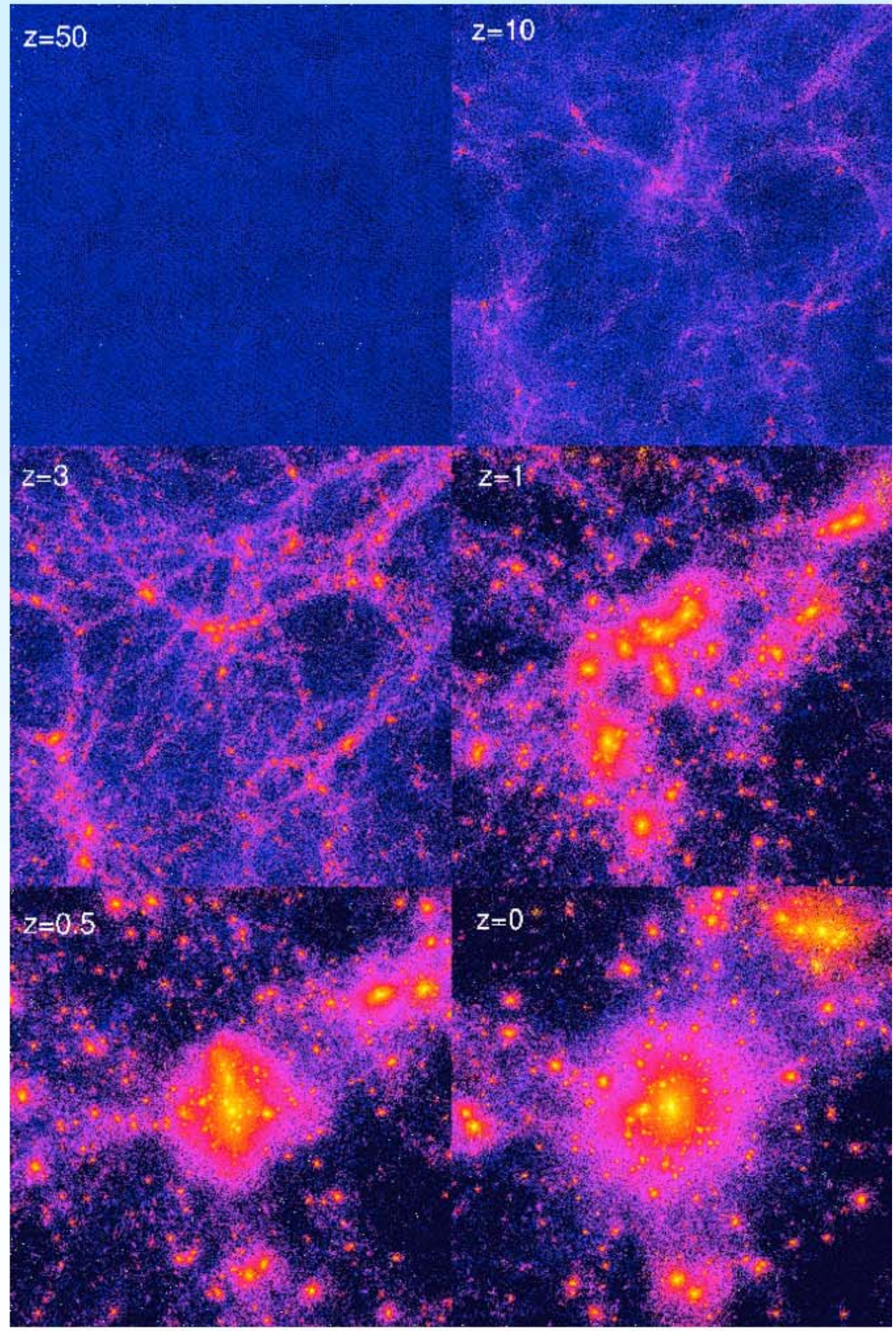
~5-10% of total mass of cluster; Orbital motion dominated by distribution of dark matter

Which clusters are GLAST-bright?

Structure Formation

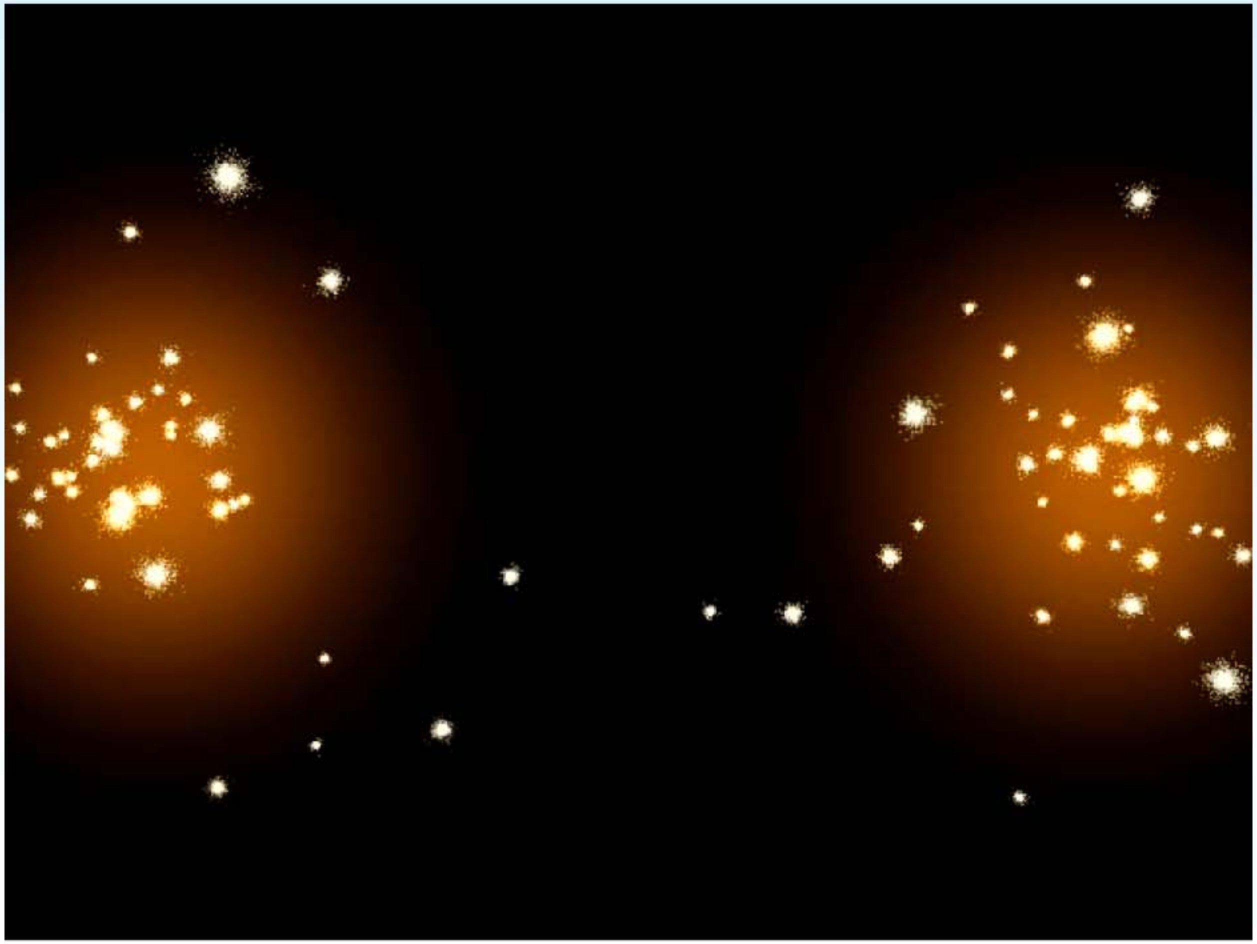
- Density fluctuations cause region to collapse.
  - **Magnitude of the density fluctuation determines the formation time**
  - **Larger structures form by accreting smaller clumps--hierarchical merging**
  - **Lumpy, continuous accretion**



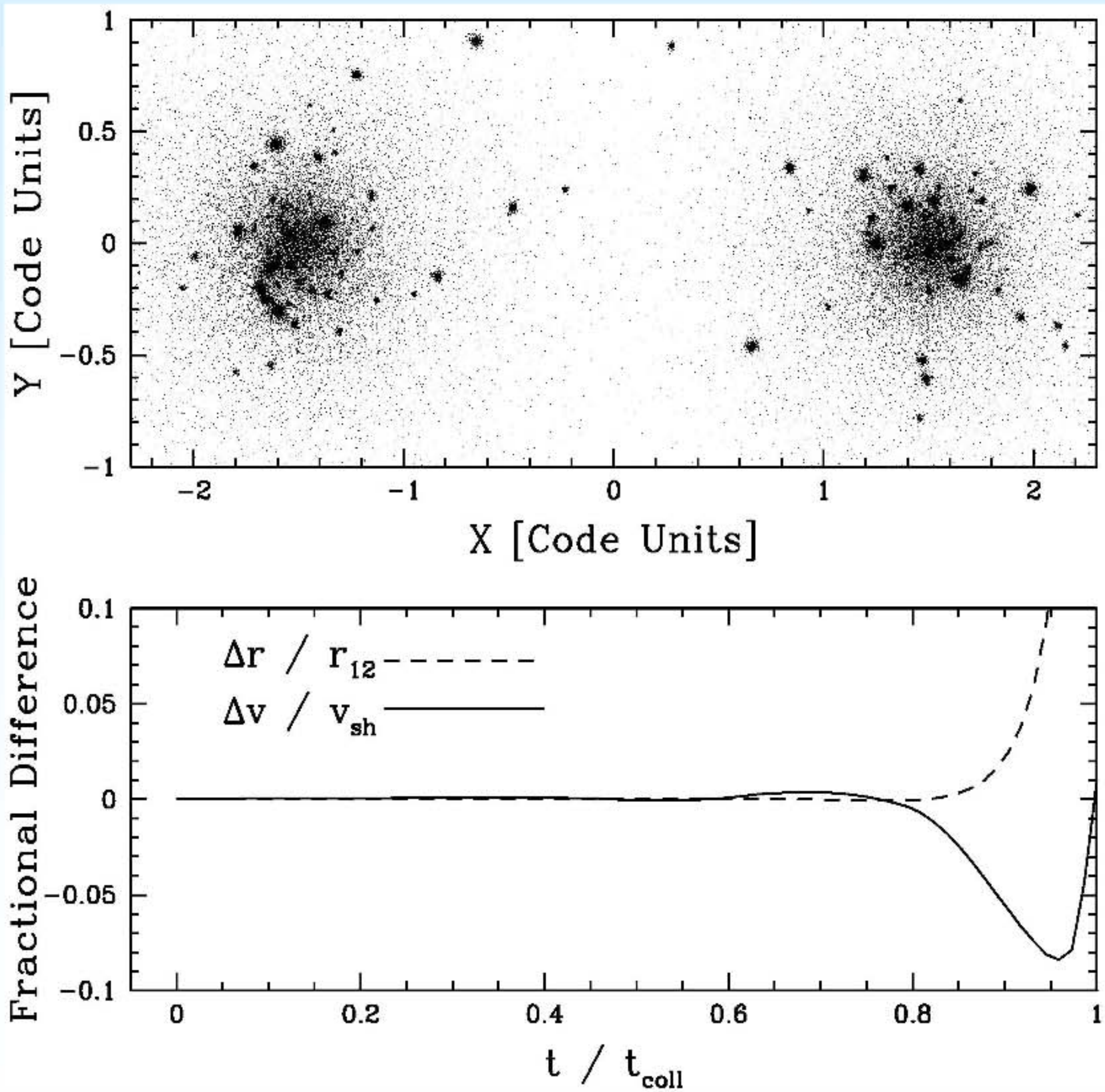


Cluster Merger

- Simulation of merging clusters of galaxies

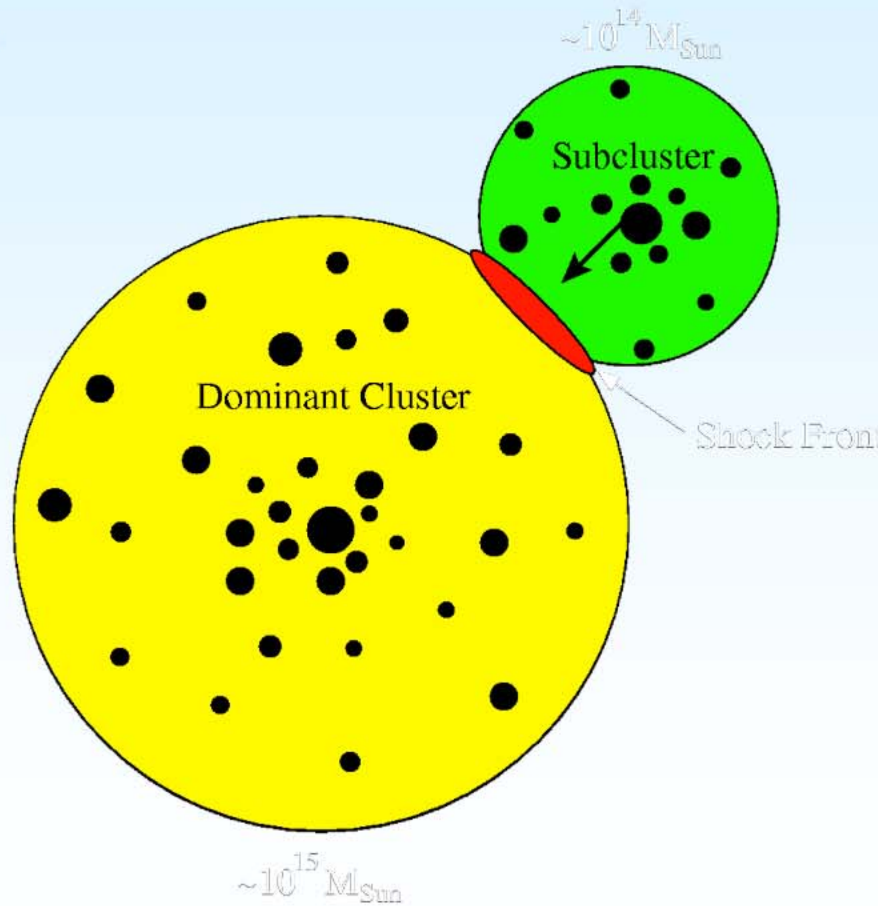


Infall Velocity



Shocks in Merging Clusters

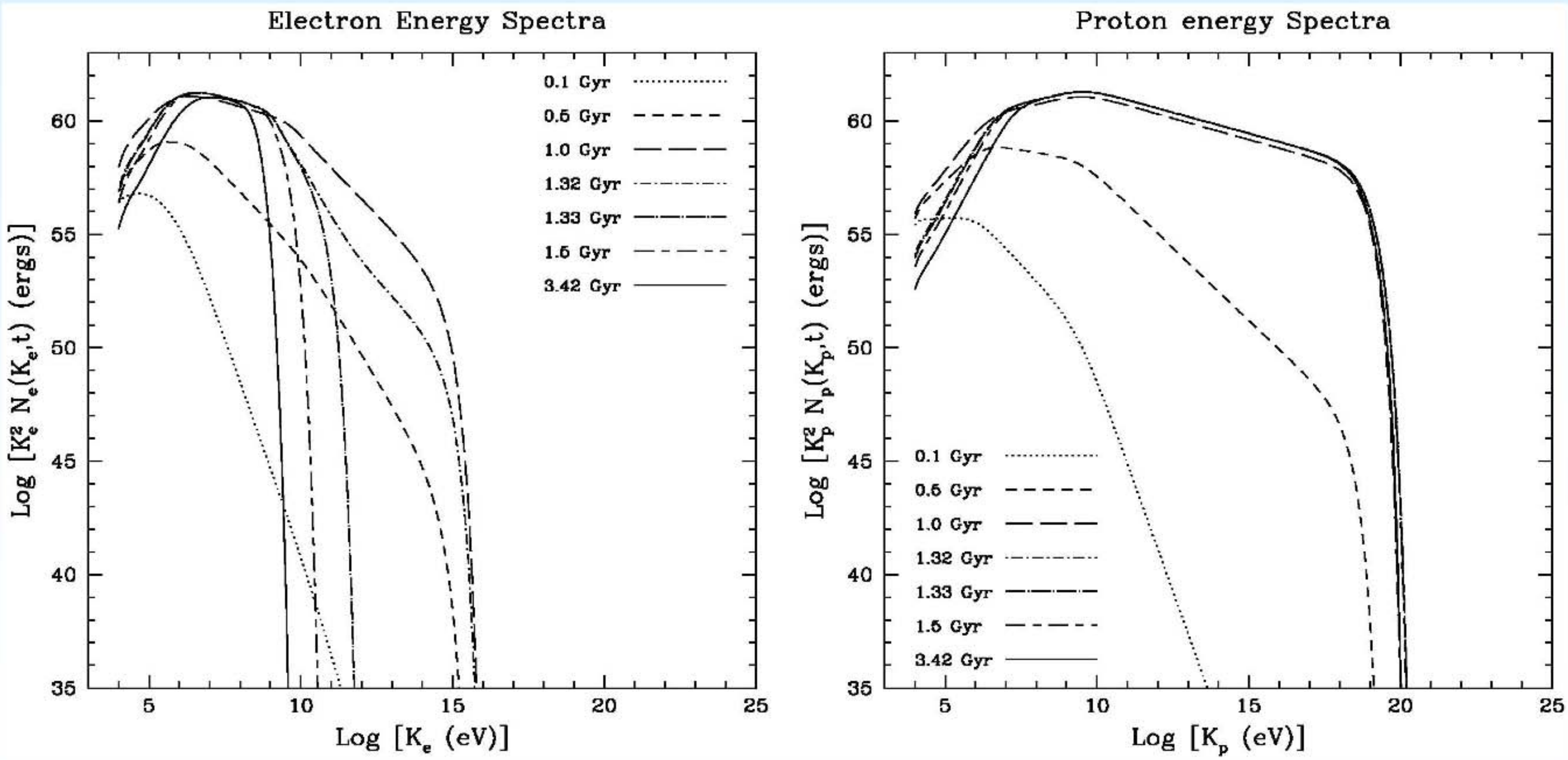
- $(\Omega_0, \Omega_R, \Omega_\Lambda)$ (mass, curvature, and dark energy)= (0.3, 0.0, 0.7)
  - Redshift of cluster:
  - Cosmic Microwave Background (CMBR) dependence
    - $U_{CMBR}(z) = U_{CMBR}(z=0)\ (1 + z)^4$
    - Rich clusters from by accreting poor clusters
    - Shocks in Merging Clusters



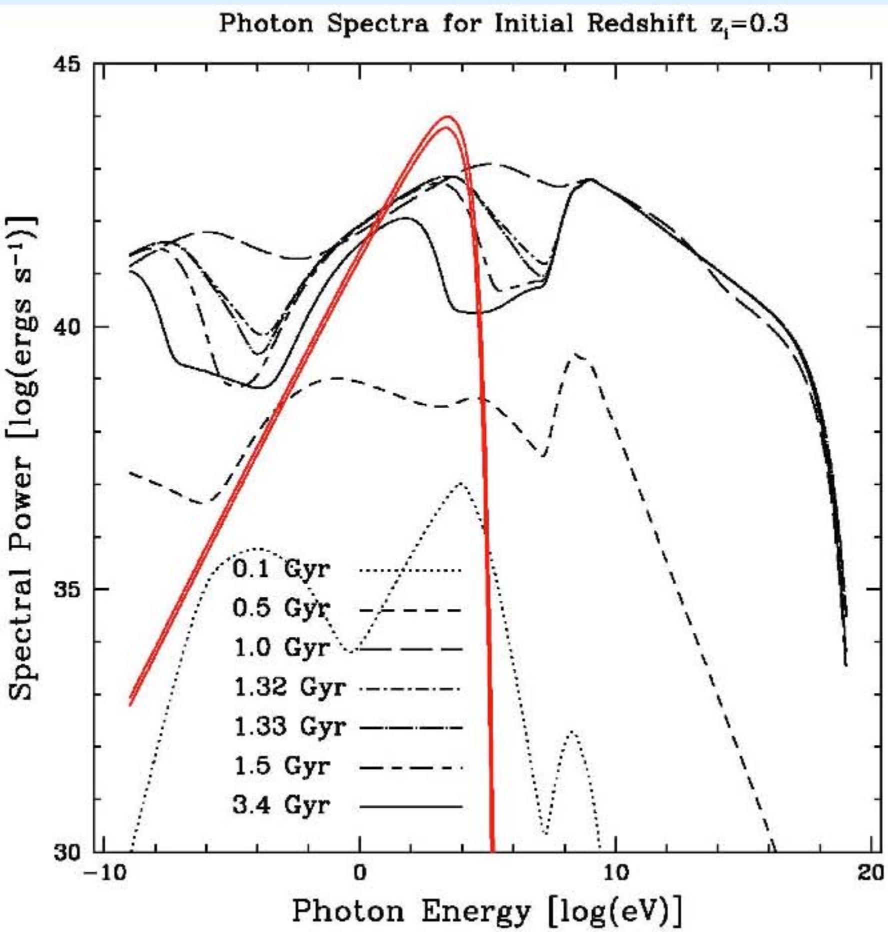
Particle Injection

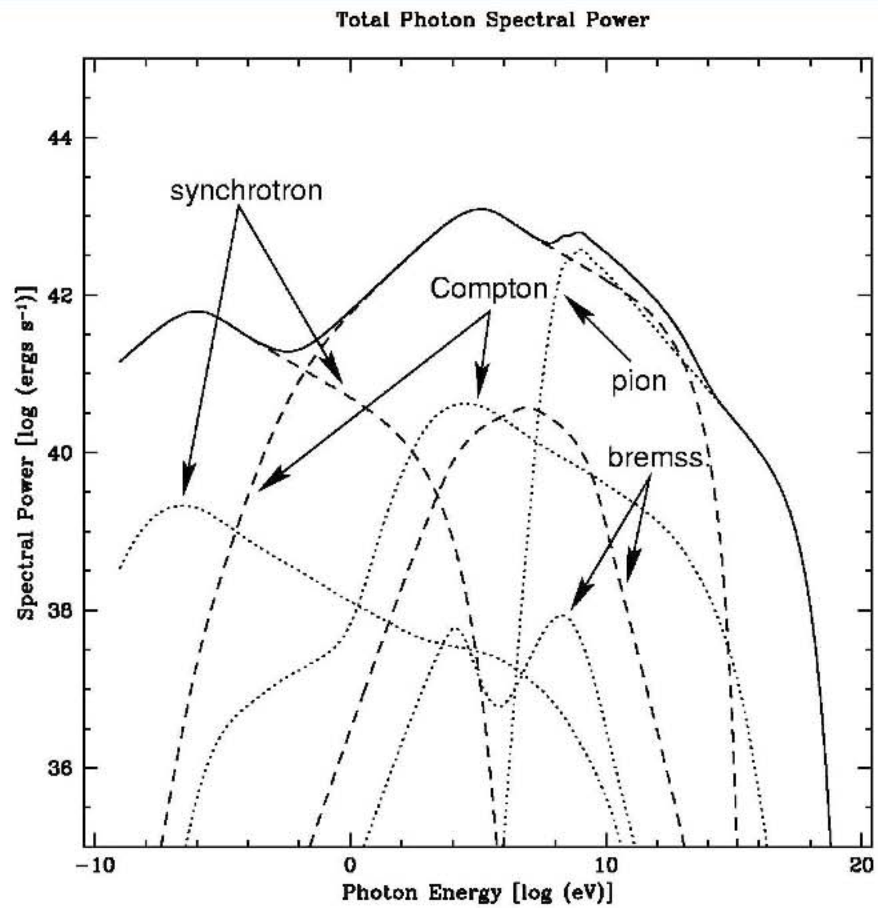
- Power law distribution with exponential cutoff $$Q_{e,p}(E,t) = Q^0_{e,p}\left[\frac{(pc)^{-\alpha}}{\beta}\right]\exp\left[-\frac{E}{E_{\max}(t)}\right]$$
  - Occurs only if M ≥ 1.0
  - Occurs only during lifetime of shock
- Normalization
$$\int_{E_{\min}}^{E_{\max}} E_{e,p}Q_{e,p}(E,t)\,dE = \eta_{e,p}\left(\frac{1}{2}\langle n_{\mathrm{ICM}}\rangle \eta^{e}_{\mathrm{He}} m_p v_s^2\right)(A_s v_s)$$
  - Where $\eta_{e,p}$ is an efficiency factor, and is set to 5%.
  - Typical values are $E_{tot} \approx 10^{63\text{-}64}$ ergs

Particle Energy Spectra



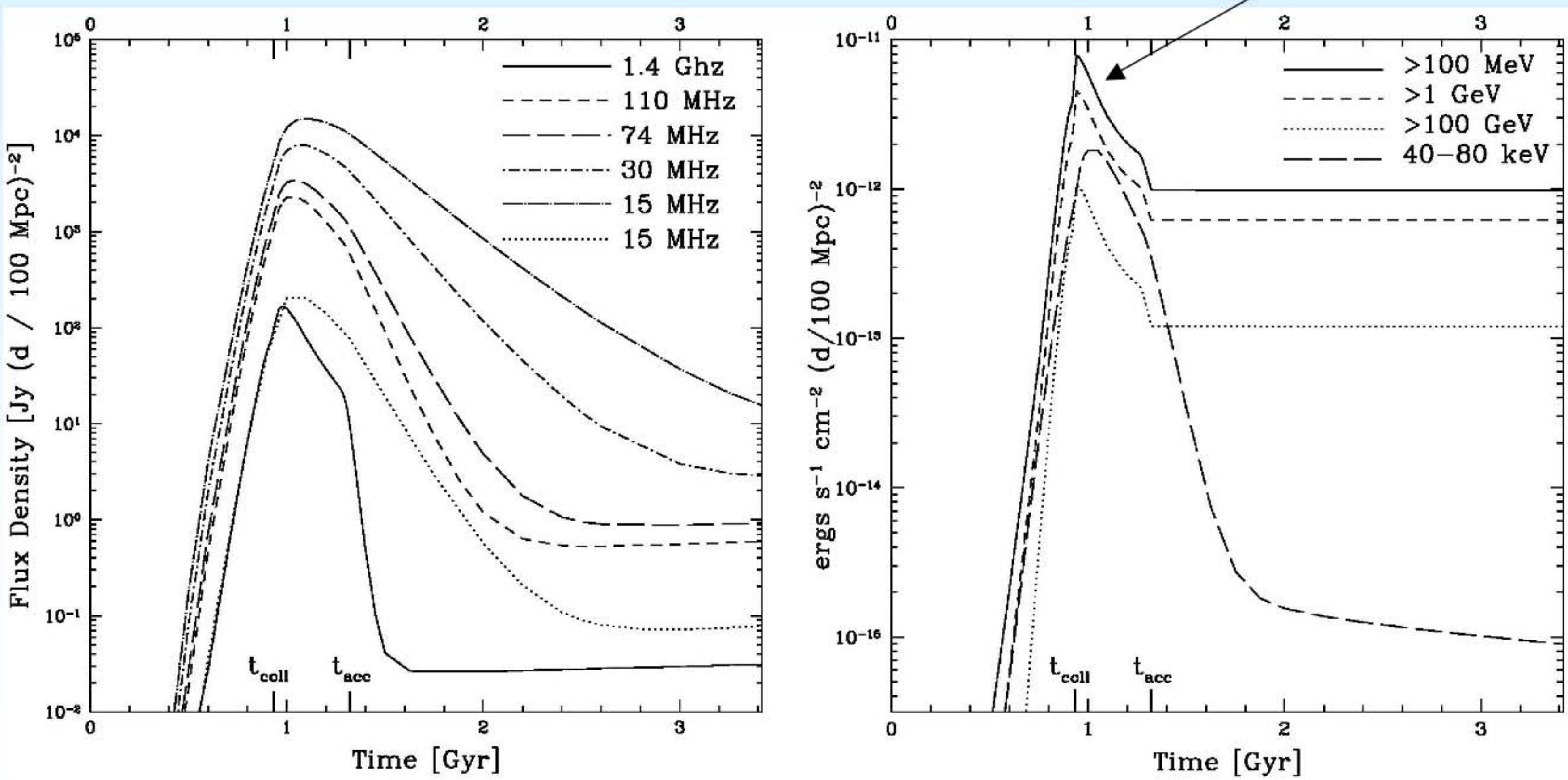
Nonthermal Particle Spectra





Galaxy Cluster Nonthermal Brightness

GLAST
range



Nonthermal Emission from Cluster Merger Shocks

- Unidentified EGRET sources?
- Diffuse Extragalactic γ-ray Background?
- Nonthermal Particle Pressure
- Detectability with GLAST and LOFAR

  - Should be able to detect these features with the next generation of γ-ray observatories
  - Possible indicator of the dark matter profiles
  - Not a dominant contributor to the Diffuse Extragalactic γ-ray Background
  - Will significantly alter thermal X-ray emission

3. GRB-Supernova-Cosmic Ray Relationship

Gamma Ray Burst puzzle is far from solved

(Long Duration) GRBs Linked to Massive Stars

SN 1998bw/GRB 980425

X-ray Lines and Features in 5 GRBs

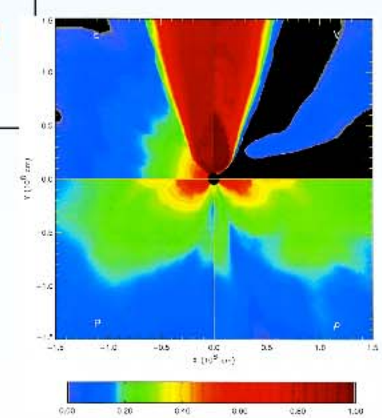
Supernova-Like Reddened Excesses in Optical Afterglows

Constant Energy Reservoir Result ?

Supranova Model
Two-step collapse to Black Hole

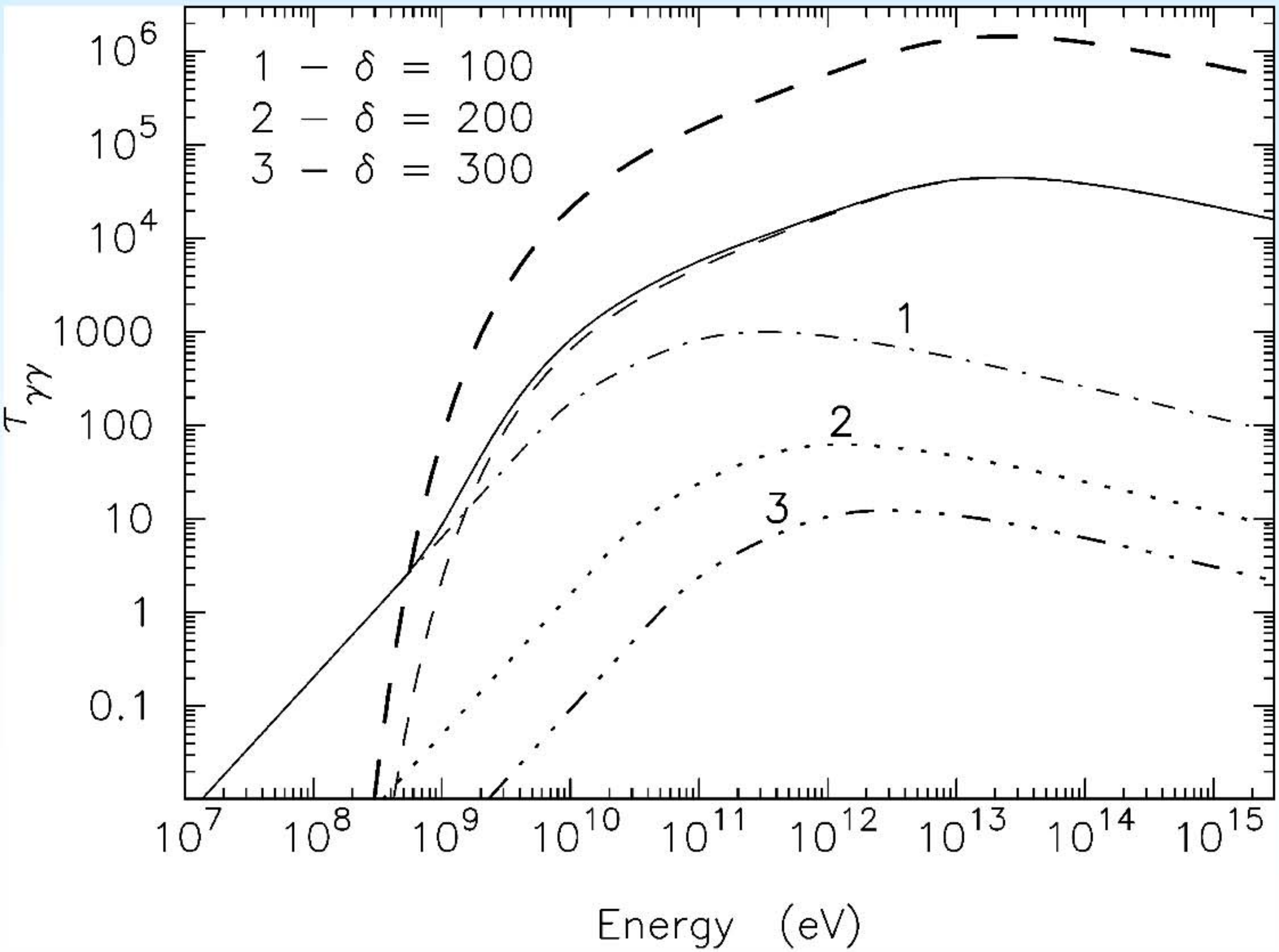
Collapsar Model
Direct collapse to Black Hole

External or Internal Shock Model for Prompt GRB Emission



γγ Optical Depth

Photon attenuation strongly dependent on δ in collapsar model



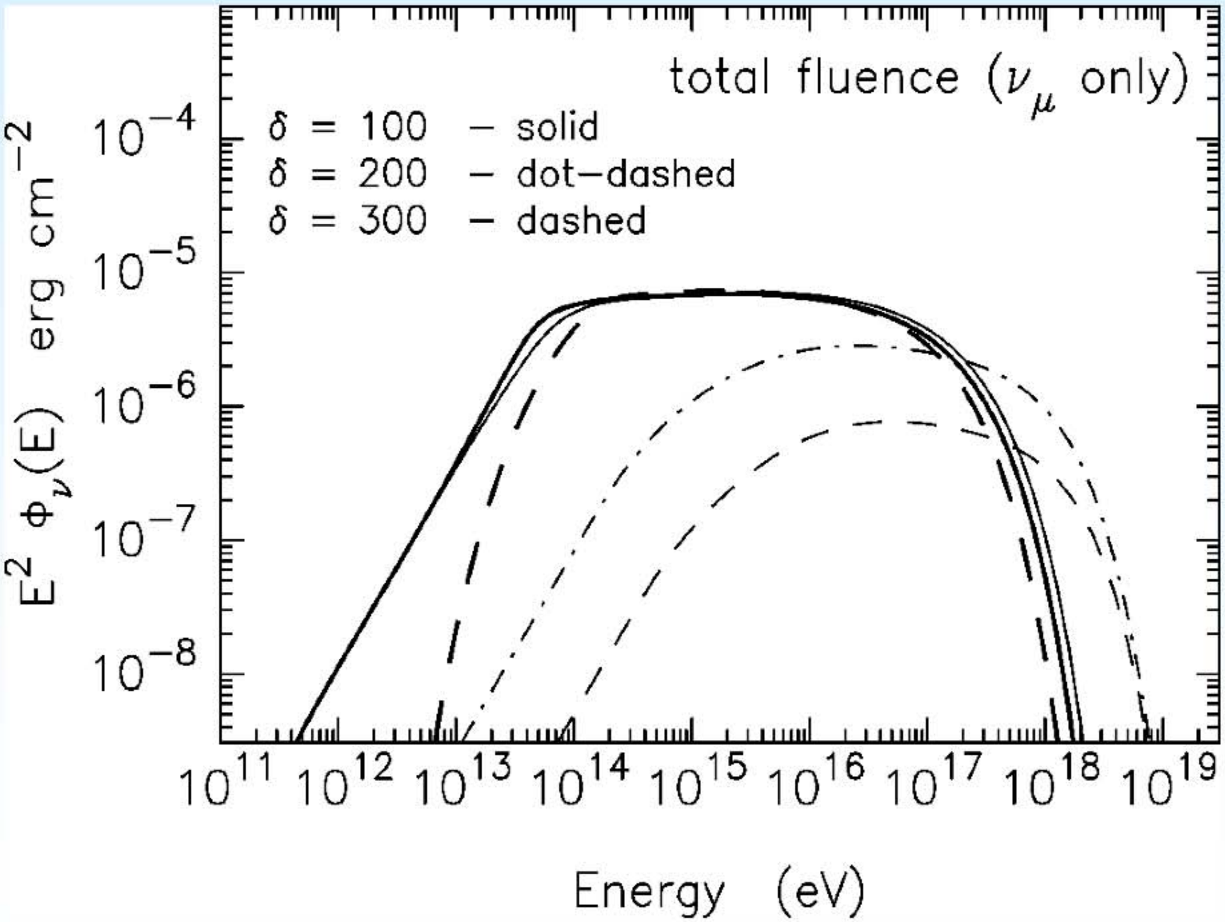
Energy Fluence of Photomeson Muon Neutrinos

For a fluence of $3x10^{-5}$ ergs/cm^2,

N_ν predicted by IceCube:

$N_\nu \approx$ 0.0032, 0.00015, 0.00001 for δ = 100, 200, and 300, respectively in collapsar model

$N_\nu \approx$ 0.09 for δ = 100 and 300 in supranova model



t_{var} = 1 sec

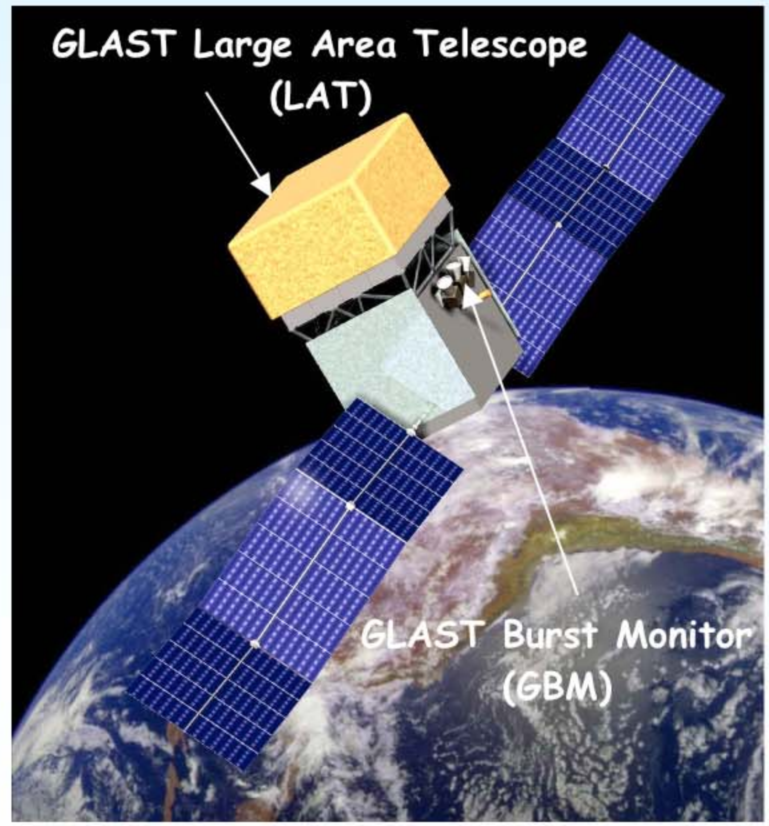
Gamma Ray and High-Energy Neutrino Observations

Neutrinos ⇒ Cosmic Ray Sources

Gamma-rays: Sites of cosmic ray acceleration in Galaxy

Gamma-rays: Clean fireball bursts/supranova model

Gamma-rays + Neutrinos: test collapsar and supranova models



Cosmic Rays originate from the stars that produce the subclass of SNe whose core collapses a second time to a black hole and makes a GRB

GLAST detection of enhanced radiation from GRB remnant