# Catching GRBs with IACTs

Joel Primack (UCSC) & Rudy Gilmore (SISSA)

This talk is based on Gilmore's 2009 PhD dissertation research with me and our continuing collaborations, including the following papers:

Gilmore, Madau, Primack, Somerville, Haardt 2009 MNRAS, GeV Gamma Ray Attenuation and the High-Redshift UV Background

Gilmore, Prada, Primack 2010 MNRAS, Modeling GRB Observations by *Fermi* and MAGIC Including Attenuation by Extragalactic Background Light

Gilmore and Ramirez-Ruiz 2010 ApJ, Local Absorption of High-Energy Emission from Gamma-Ray Bursts

Abdo et al. 2010 ApJ, Fermi LAT Constraints on the Gamma-Ray Opacity of the Universe

Somerville, Gilmore, Primack, Dominguez 2010, Galaxy Properties from the UV to the Far-IR: ΛCDM Models Confront Observations

Gilmore, Somerville, Primack, Dominguez 2010, Extragalactic Background Light and Gamma Ray Attenuation

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# Gamma Rays from High-z GRBs

While AGN have typically been the focus of extragalactic background light (EBL) studies, GRBs are also potentially useful:

- BATSE on CGRO detected thousands of GRBs at 20 keV - 2 MeV
- EGRET saw 5 bursts above 30 MeV (45 photons, 4 above 1 GeV) in 4 years of operations
- Swift has allowed us to systematically determine redshifts for many GRBs (467 events, ~140 with redshift) from launch in 2004 to 2009
- Fermi GBM detects many GRBs, and Fermi LAT has thus far detected 4 bright GRBs from $z > 1$ with $E_{obs} > 1$ GeV ($E_{rest}$ up to 93 GeV)
- A definite detection of GRB gammas from the ground has yet to occur, although campaigns are underway especially at MAGIC and VERITAS

Goals here:

- make a simple model for high energy GRB emission, including z-dependence
- make predictions for current experiments (Fermi and MAGIC) after factoring in EBL attenuation
- make predictions for proposed new ACT arrays (CTA, AGIS, ACTA)

# The High Redshift UV Background

• Affects gamma-rays from distant sources, observed in 10-100 GeV energy range.

• Fermi LAT is studying the little-understood energy decade of 10-100 GeV.

• Next generation of ground based experiments (MAGIC-II, H.E.S.S.-II, VERITAS upgrade) will observe gamma-rays down to ~ 50 GeV.

We attempted to compute this background component with various models to bound the uncertainty

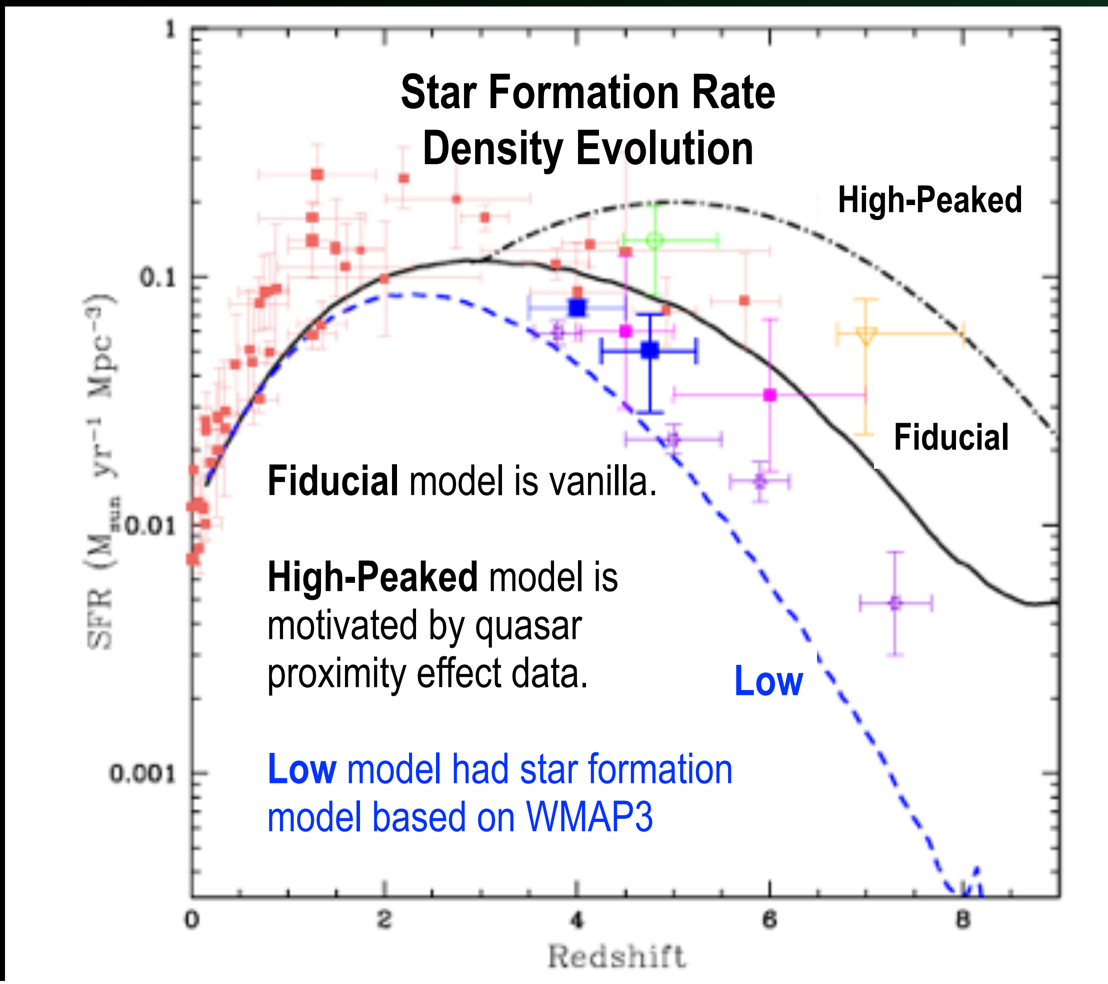
Gilmore, Madau, Primack, Somerville, Haardt 2009, GeV Gamma-Ray Attenuation and the High-Redshift UV Background

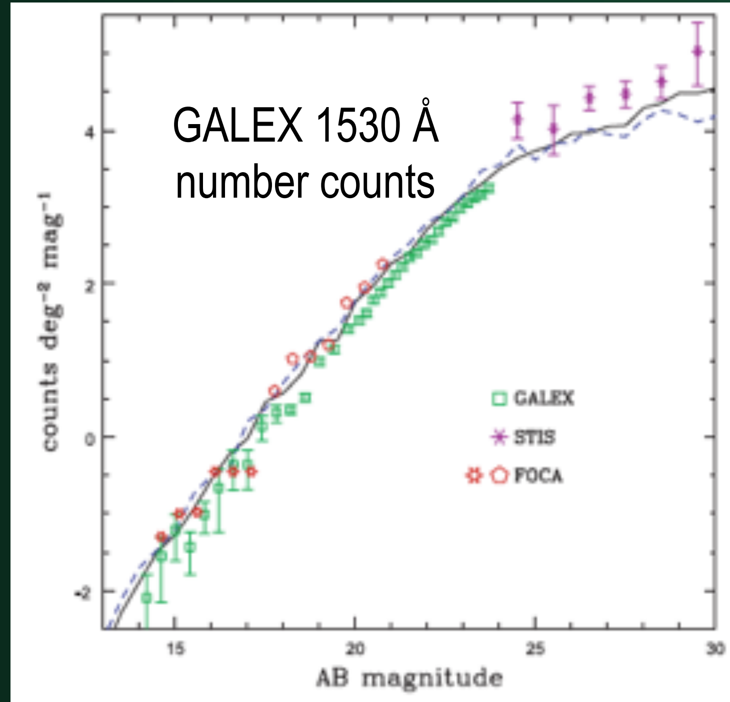
- Quasar contribution based on observational estimates (Hopkins et al. 2007)
- Transfer of ionizing radiation through IGM calculated with CUBA code (Haardt & Madau 2001, now being updated)
- Reasonable estimates of ionizing escape fraction from star-forming galaxies

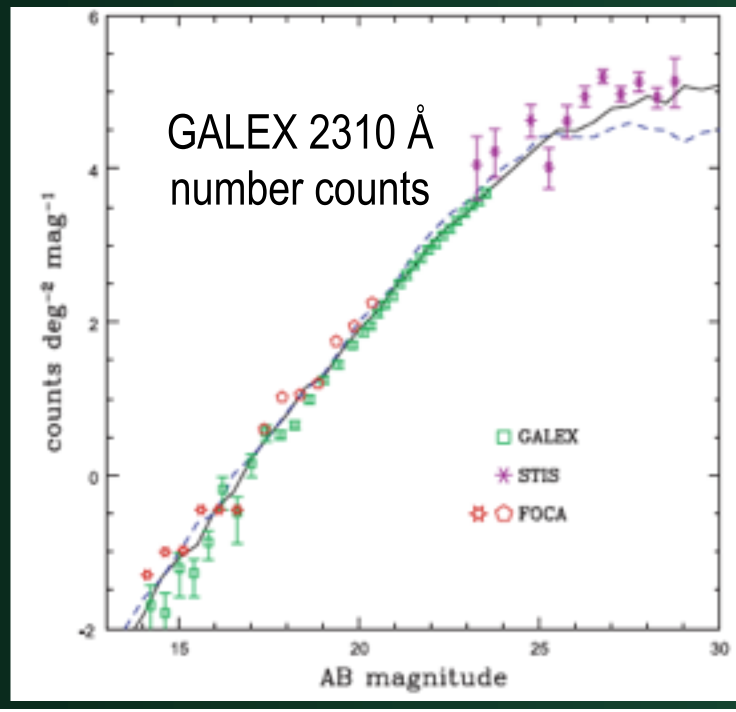
**Fiducial**, **Low**, and **High-Peaked** UV EBL evolution models -- consistent with CMB, z~6 H reionization, z~3 He reionization, realistic star formation evolution, and GALEX data.

Gilmore, Madau, Primack, Somerville, Haardt 2009 MNRAS, GeV Gamma Ray Attenuation and the High-Redshift UV Background

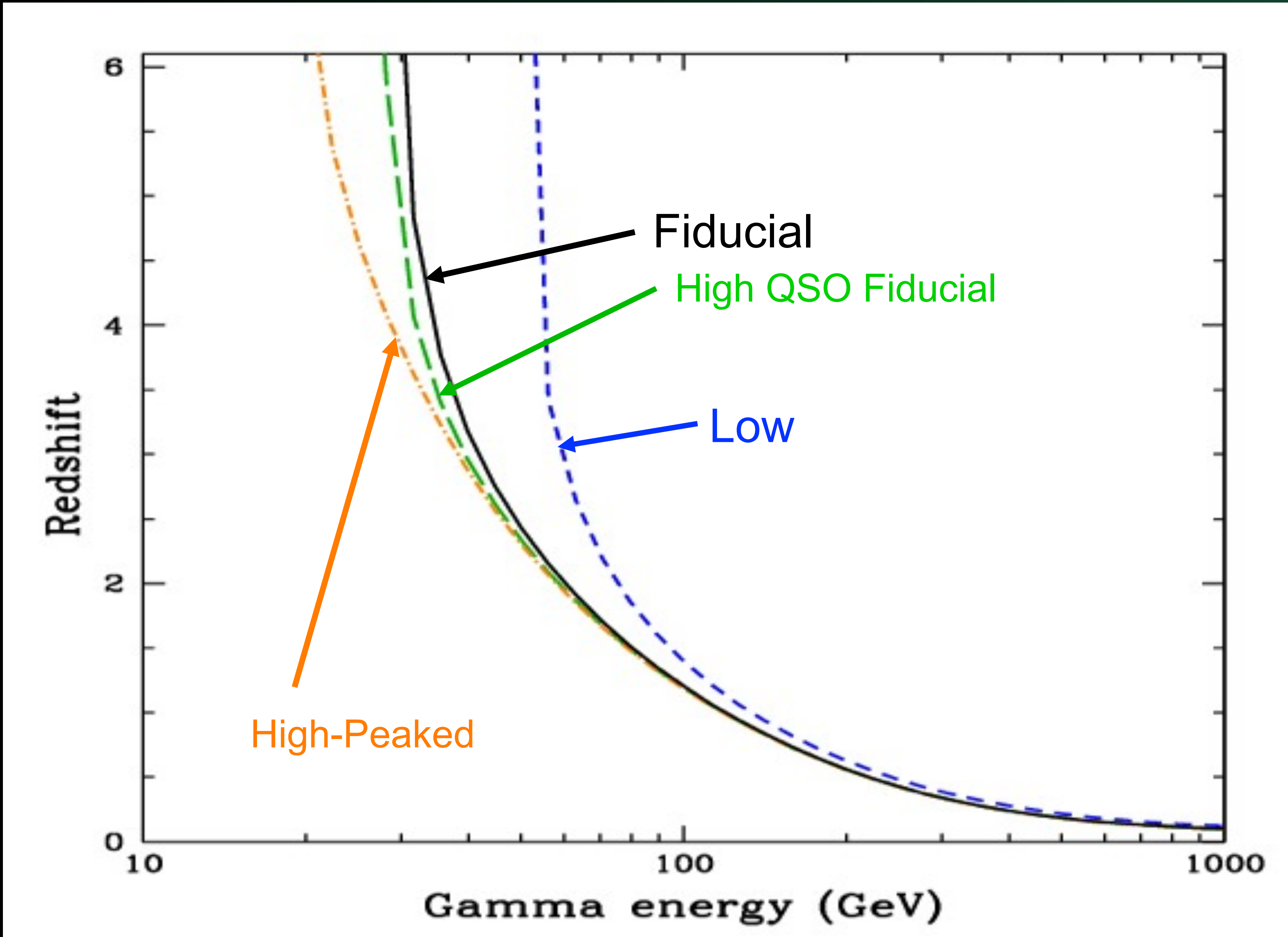
**Fiducial**, **Low**, and **High-Peaked** UV EBL evolution models -- roughly consistent with CMB, z~6 H reionization, z~3 He reionization, realistic star formation evolution, and GALEX data.



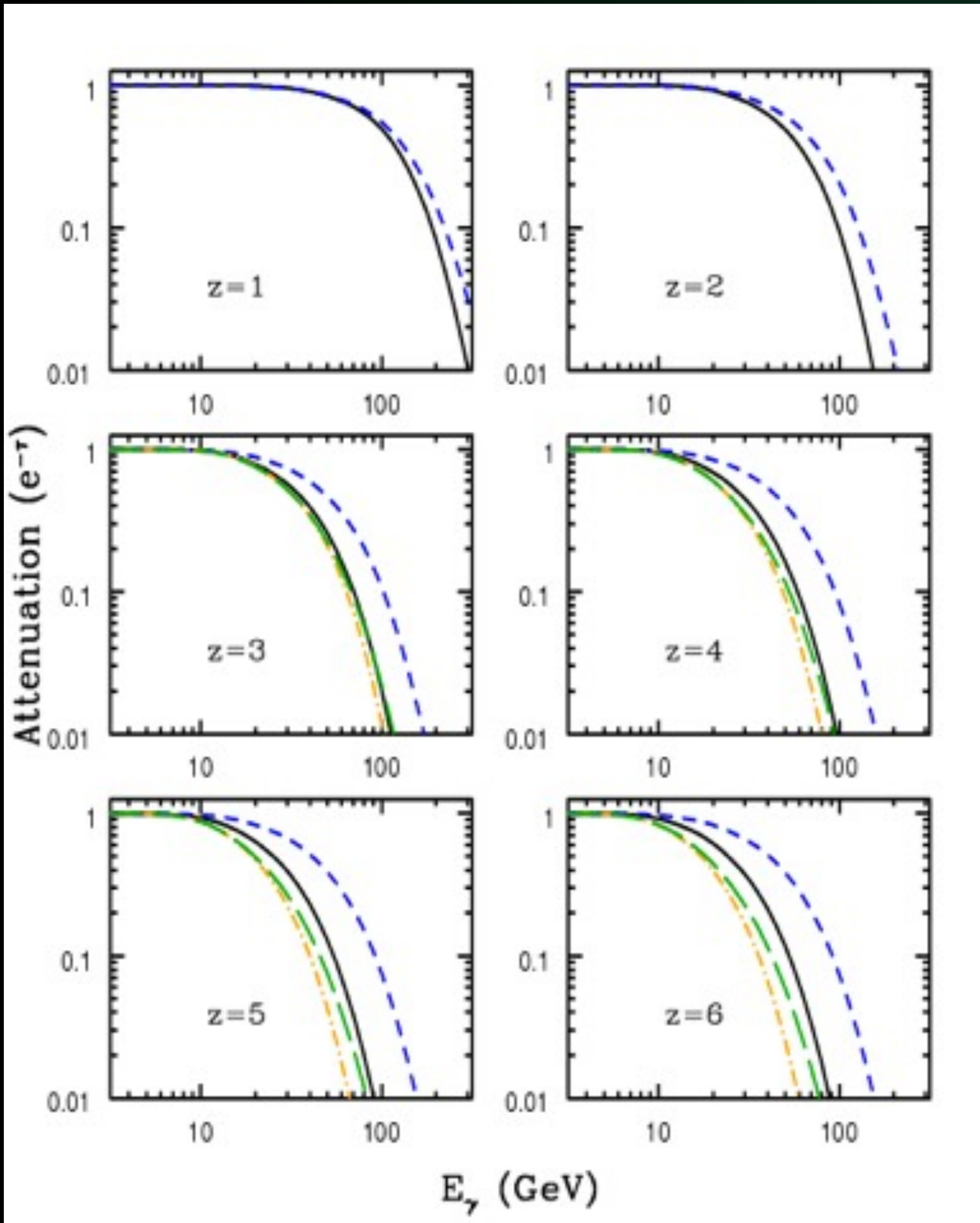



# Gamma-ray `Attenuation Edge' ($\tau = 1$)



# Prelude: Optical Depths to Gamma-rays




Gilmore, Madau, Primack, Somerville, Haardt 2009, GeV Gamma Ray Attenuation and the High-Redshift UV Background

Low Model, Hopkins LF, $f_{esc}$ = 0.2

Escape Fraction $f_{esc}$ = 0.2 - 0.02

High-QSO Fiducial $f_{esc}$ = 0.02

Fiducial Model, Hopkins LF, $f_{esc}$ = 0.1

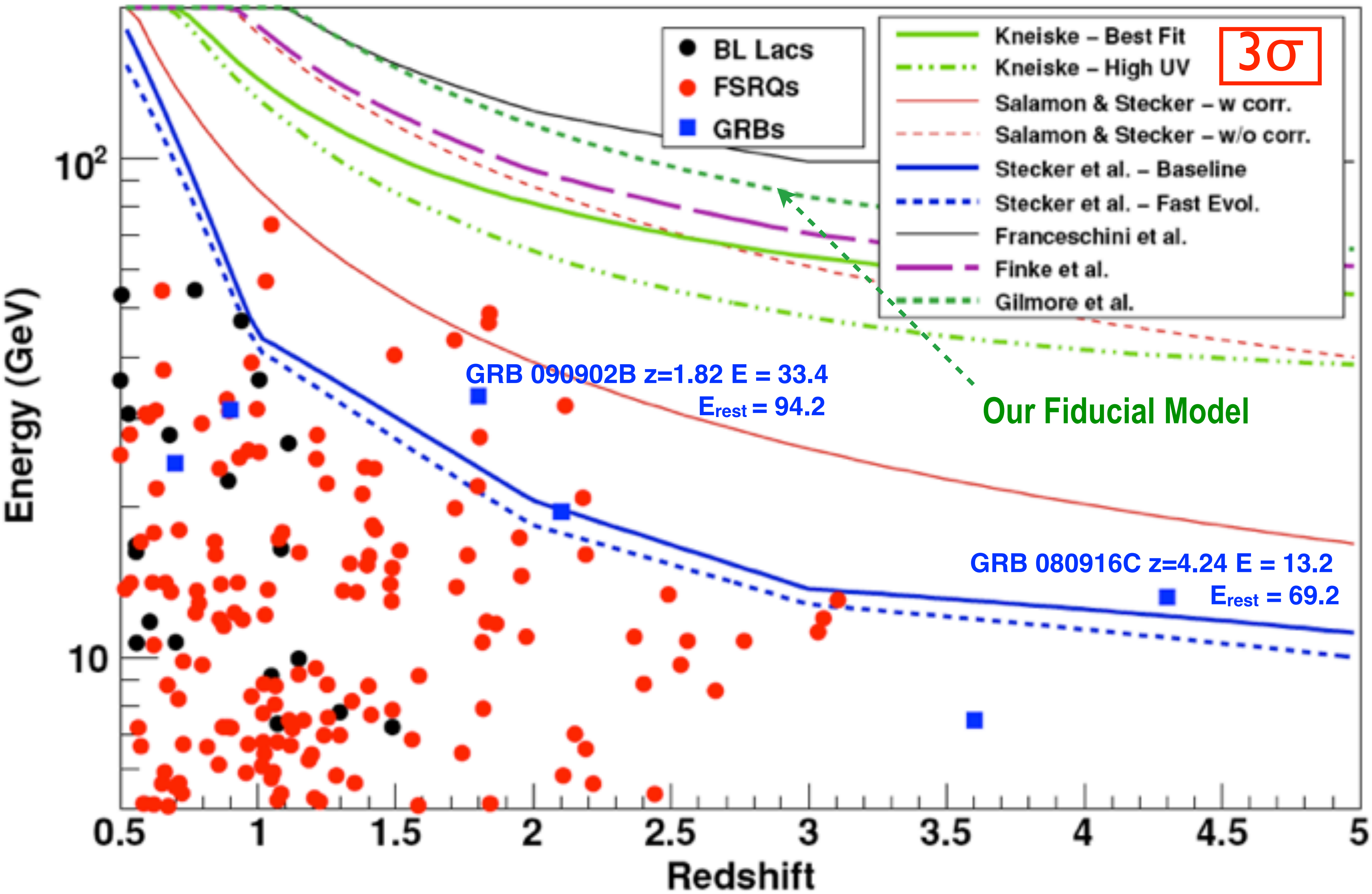
High-Peaked Fiducial, Hopkins LF, $f_{esc}$ = 0.1

Joel Primack (UCSC) & Rudy Gilmore (SISSA)

Abdo et al.

The Astrophysical Journal, 723:1082–1096, 2010 November 10

**Using Fermi LAT photons of E >10 GeV from blazars up to z ~ 3 and GRBs up to z ~ 4.3, we constrain EBL models. The models of Stecker et al. can be ruled out with high confidence.**



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **402**, 565–574 (2010) doi:10.1111/j.1365-2966.2009.15909.x

# Modelling gamma-ray burst observations by Fermi and MAGIC including attenuation due to diffuse background light

Rudy C. Gilmore,[1★] Francisco Prada[2†] and Joel Primack[1]

[1] *Department of Physics, University of California, Santa Cruz, CA 95064, USA*

[2] *Instituto de Astrofísica de Andalucía, CSIC, Apdo. Correos 3004, E-18080 Granada, Spain*

## ABSTRACT

Gamma rays from extragalactic sources are attenuated by pair-production interactions with diffuse photons of the extragalactic background light (EBL). Gamma-ray bursts (GRBs) are a source of high-redshift photons above 10 GeV, and could be therefore useful as a probe of the evolving ultraviolet background radiation. In this paper, we develop a simple phenomenological model for the number and redshift distribution of GRBs that can be seen at GeV energies with the *Fermi* satellite and Major Atmospheric Gamma-ray Imaging Cherenkov Telescope (MAGIC) atmospheric Cherenkov telescope. We estimate the observed number of gamma rays per year, and show how this result is modified by considering interactions with different realizations of the evolving EBL. We also discuss the bright *Fermi* GRB 080916C in the context of this model. We find that the Large Area Telescope on *Fermi* can be expected to see a small number of photons above 10 GeV each year from distant GRBs. Annual results for ground-based instruments like MAGIC are highly variable due to the low duty cycle and sky coverage of the telescope. However, successfully viewing a bright or intermediate GRB from the ground could provide hundreds of photons from high redshift, which would almost certainly be extremely useful in constraining both GRB physics and the high-redshift EBL.

Wednesday, November 3, 2010

# Modeling Instrument Properties

## Fermi

- 20500 sr · cm$^2$ integrated field of view
- assume telescope in survey mode full time
- we do not account for triggered rotations to burst events

## MAGIC

results are sensitive to effective area at low energies, and slew time (for prompt phase)

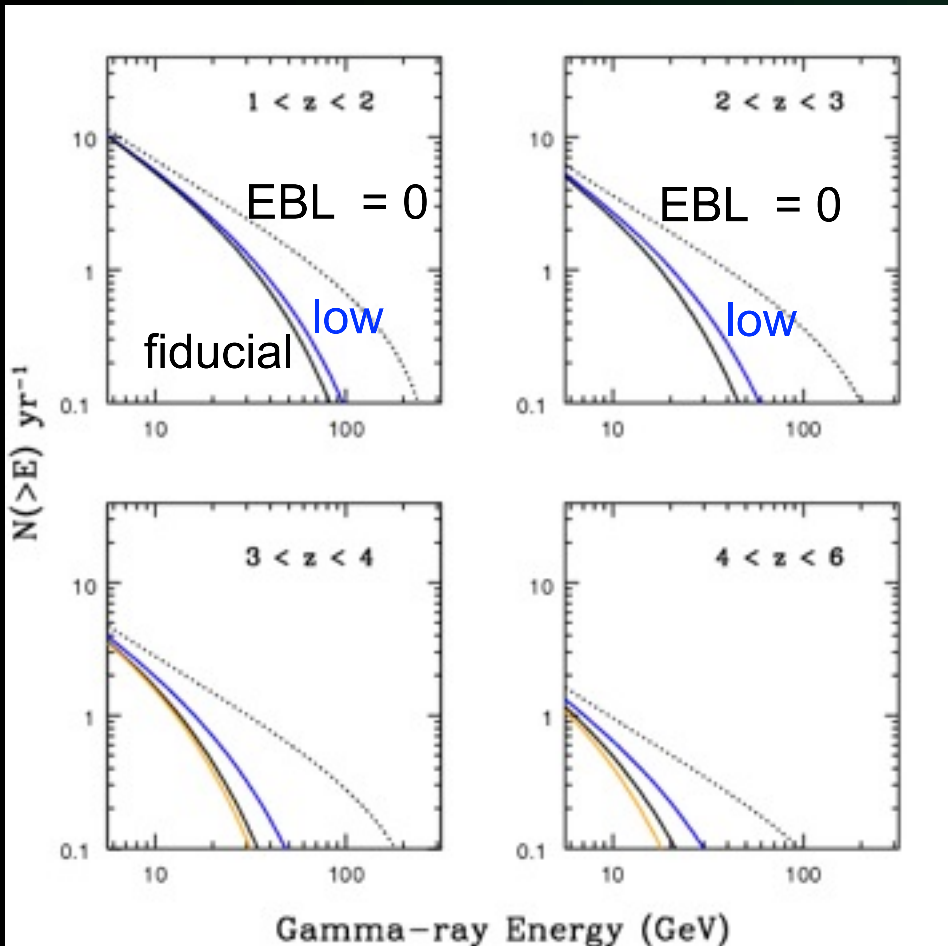
- effective area vs. energy from published data
- assume threshold energy of
  $E_{th}(\theta) = E_{th}(0) \cdot \cos(\theta)^{-2.5}$

  with $E_{th}(0)$ = 50 and 100 GeV

Gilmore, Prada, Primack 2010 MNRAS
Modeling GRB Observations by *Fermi* and MAGIC Including Attenuation by Extragalactic Background Light

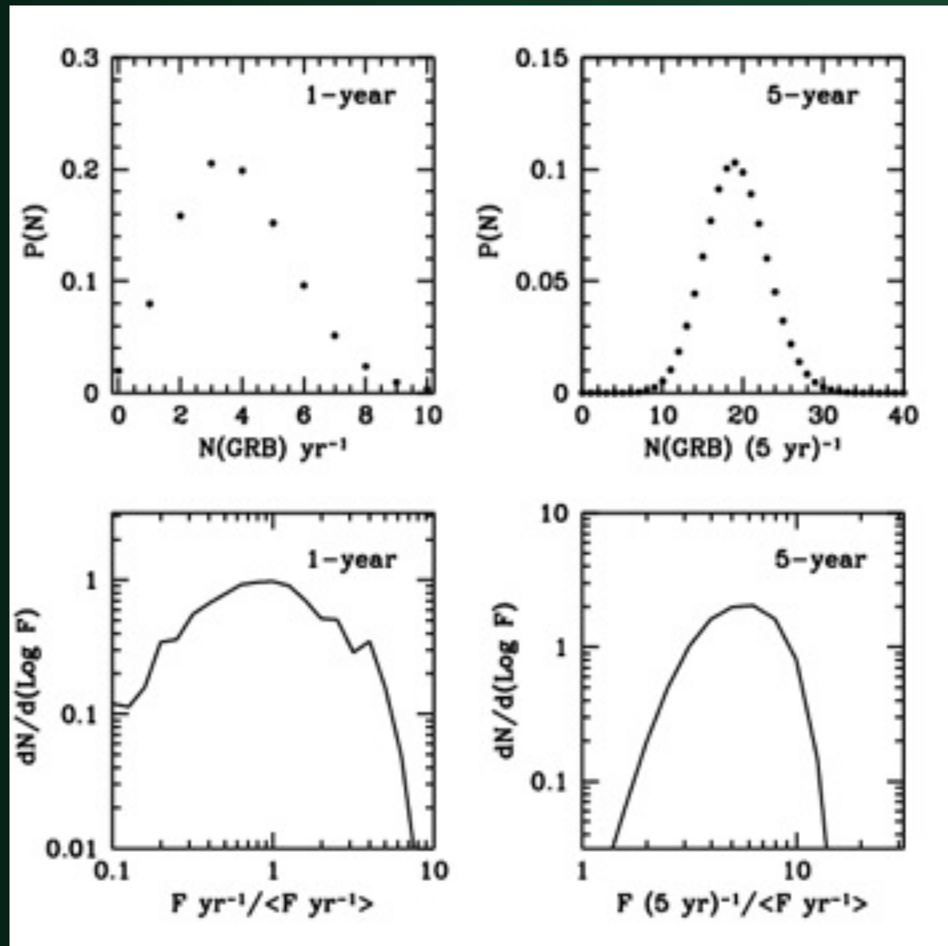
# Results for Fermi

Annual # of integrated GRB photons for 4 redshift bins, with attenuation from low, fiducial, and high-peaked models




Gilmore, Prada, Primack 2010 MNRAS Modeling GRB Observations by *Fermi* and MAGIC Including Attenuation by Extragalactic Background Light

Annual number of LAT GRBs w/ redshifts

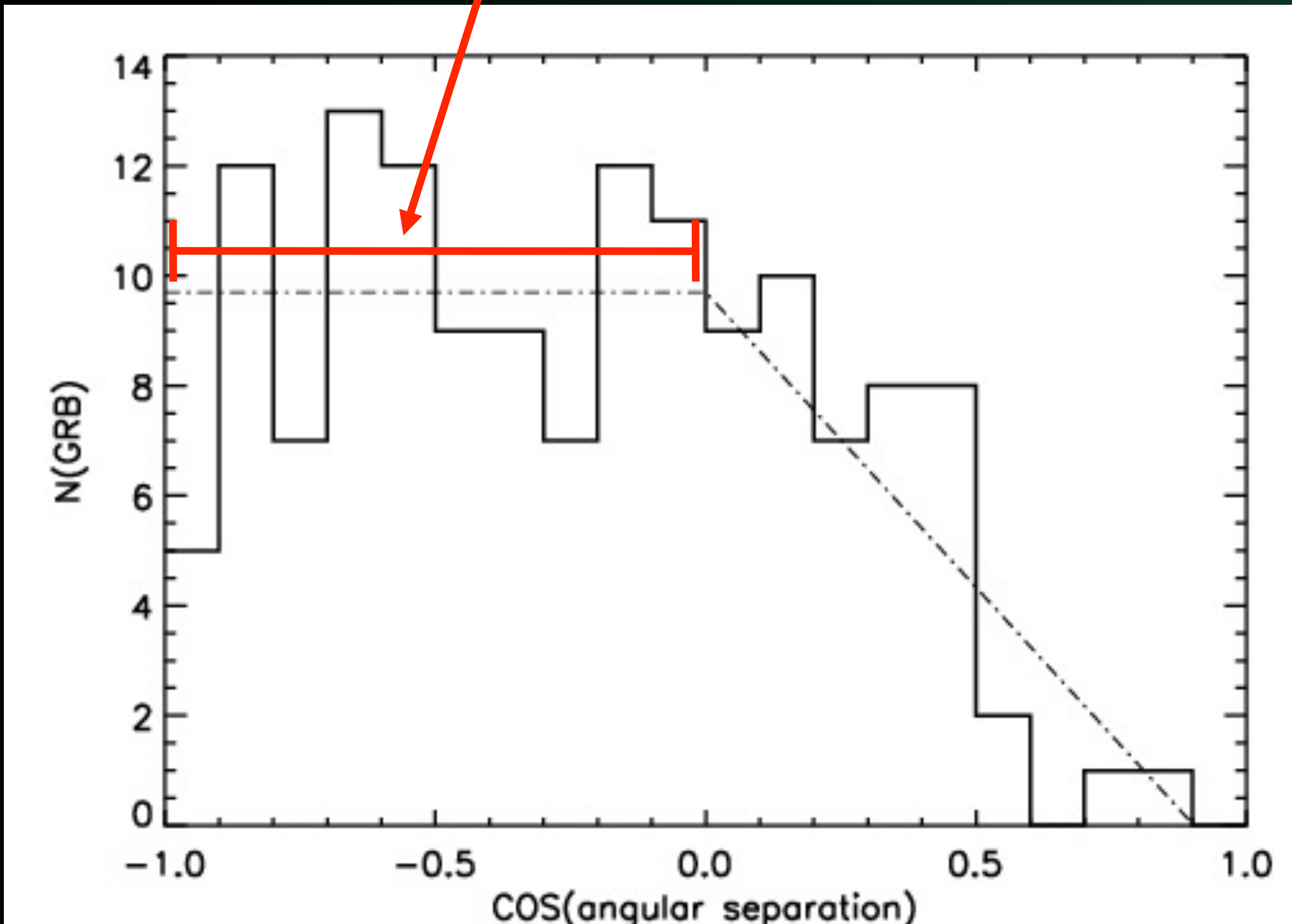


# Results for MAGIC

Anti-solar bias in Swift GRBs

Gilmore, Prada, Primack 2010 MNRAS
Modeling GRB Observations by *Fermi* and MAGIC Including Attenuation by Extragalactic Background Light

IACT observations fall in this regime




Factor ~1.4 increase in detection rate

# Results for MAGIC

Gilmore, Prada, Primack 2010 MNRAS Modeling GRB Observations by *Fermi* and MAGIC Including Attenuation by Extragalactic Background Light

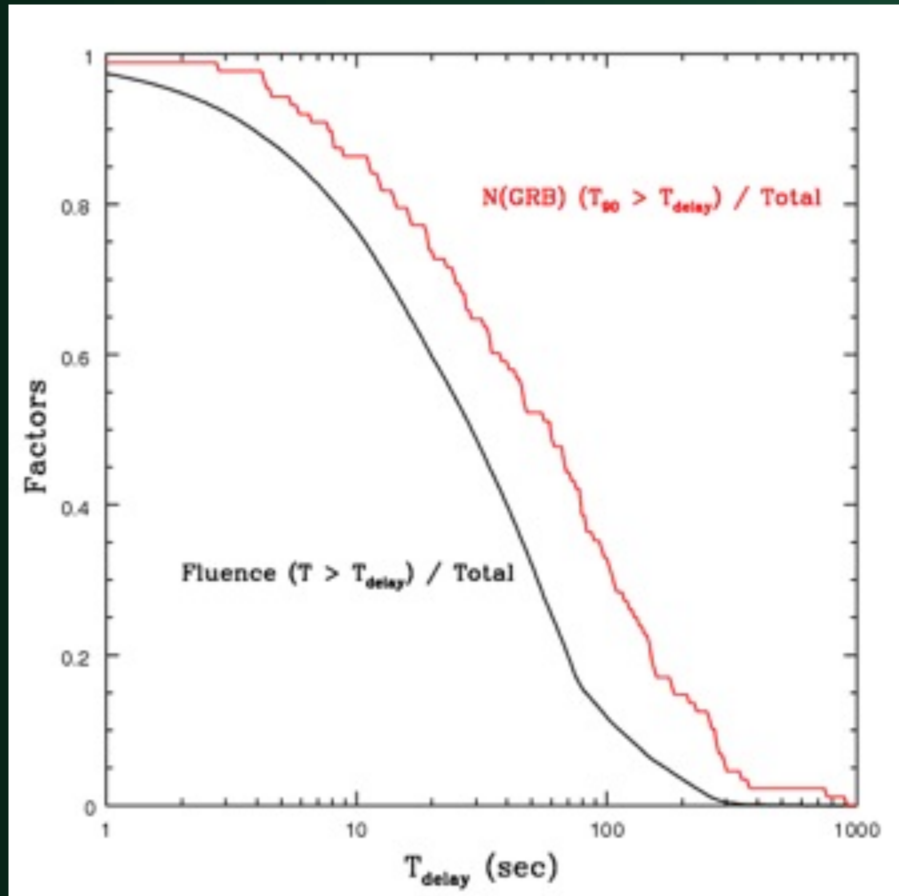
- IACT response time to GCN alert is same order as typical $T_{90}$
  - Fastest response to date: 43 sec; ≥100 sec more typical
  - We will be optimistic, and assume 45 sec

- assume approximately flat prompt phase: $(T_{90} - T_{slew})/T_{90}$ (flat emission)

- afterglows not affected by delay time

- For IACT like MAGIC:
  - duty cycle ~ 10%
  - sky coverage (θ<40) ≈ 11%
  - ∴ (duty cycle)·(sky coverage) ≈ 1%

## FLUENCE AND N(GRB) vs. $T_{delay}$

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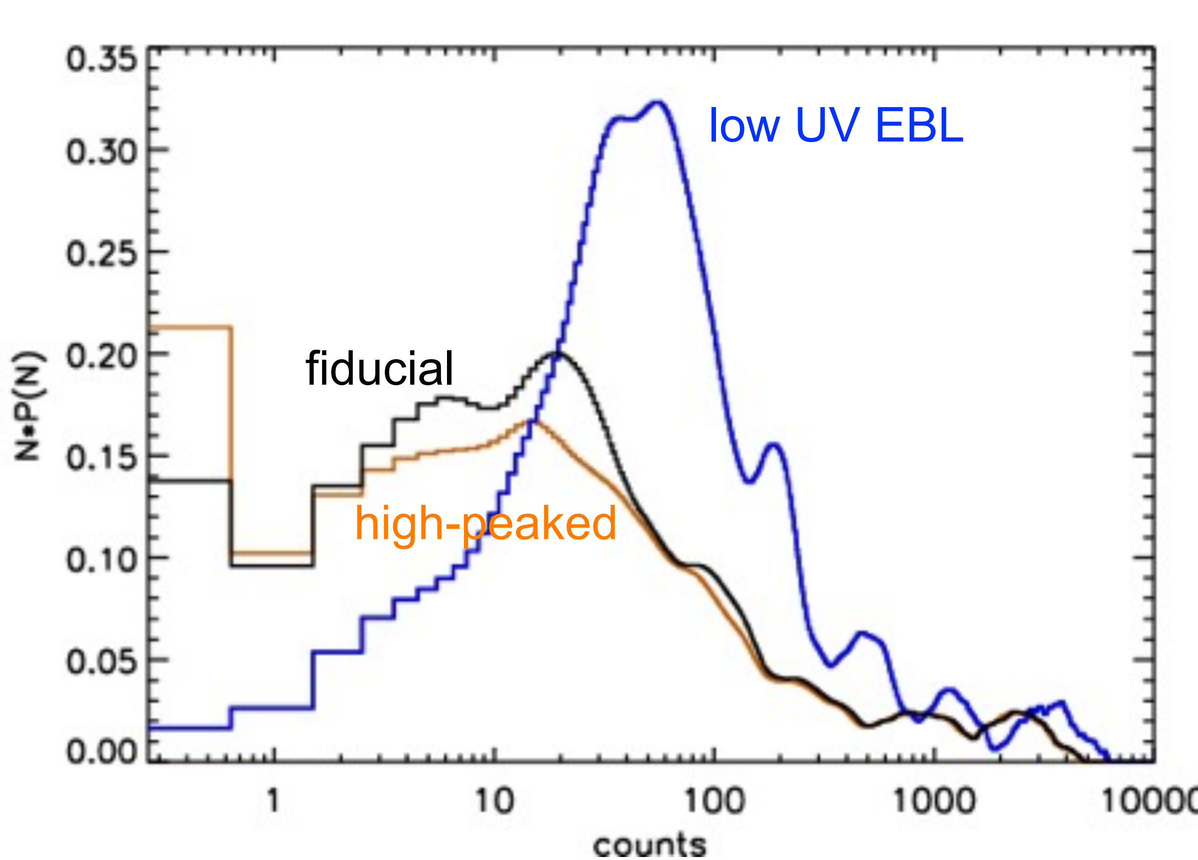
# Results for MAGIC

For IACT like MAGIC: (duty cycle)·(sky coverage) ≈ 1%

**Probability of seeing ≥1 GRB/yr ≈ 30%**

| | Prompt ($T_{delay} = 45s$) | | | Afterglow ($T_{delay} = 0$) | | |
|---|---|---|---|---|---|---|
| N(GRB) $yr^{-1}$ | 20 deg | 30 deg | 40 deg | 20 deg | 30 deg | 40 deg |
| 0 | 0.95 | 0.90 | 0.82 | 0.92 | 0.82 | 0.71 |
| 1 | 0.048 | 0.099 | 0.16 | 0.079 | 0.16 | 0.24 |
| $\geqslant 2$ | 0.0012 | 0.0057 | 0.016 | 0.0036 | 0.016 | 0.046 |




**Predicted number of MAGIC gamma-ray counts for a single GRB within sky coverage, with $E_{th}$ = 50 GeV**

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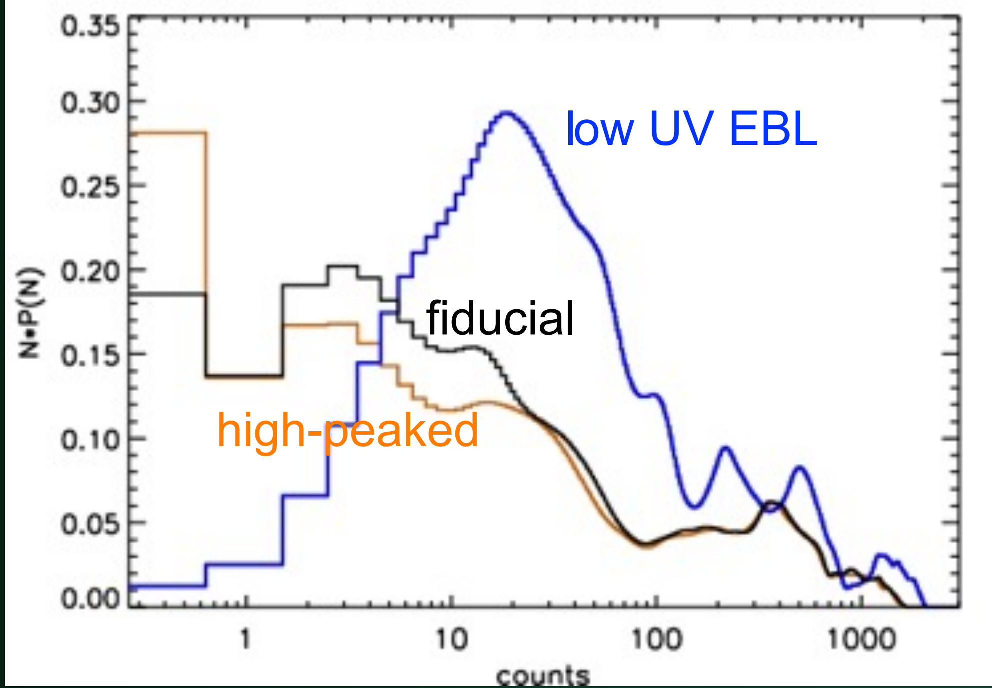
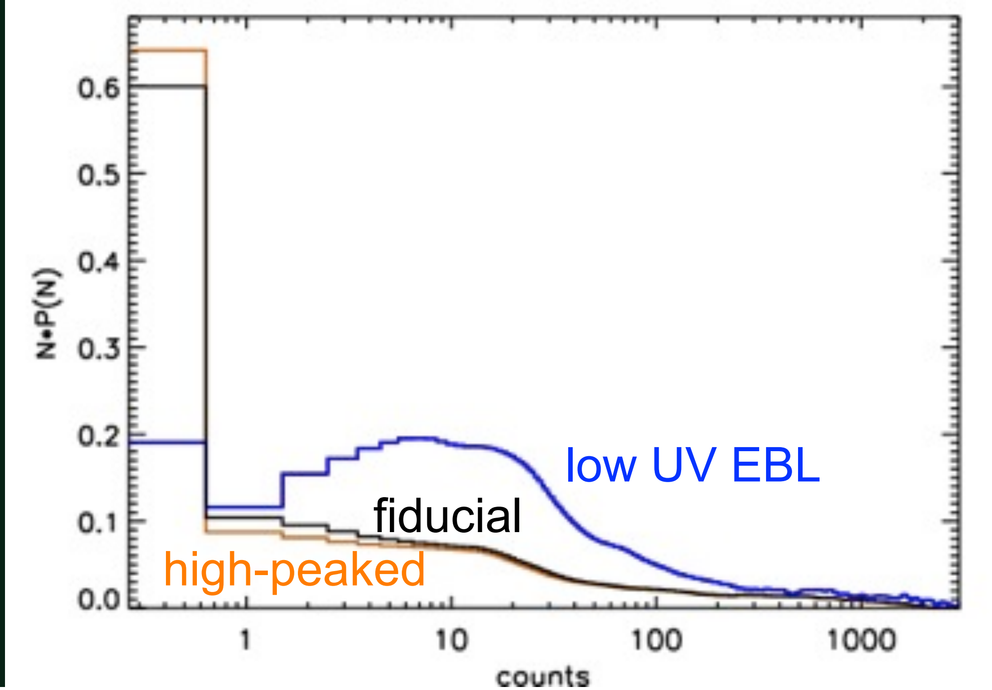
Gilmore, Prada, Primack 2010 MNRAS

Considering only prompt component with $E_{th}(0)$ = 50 GeV:




Setting $E_{th}(0)$ = 100 GeV:



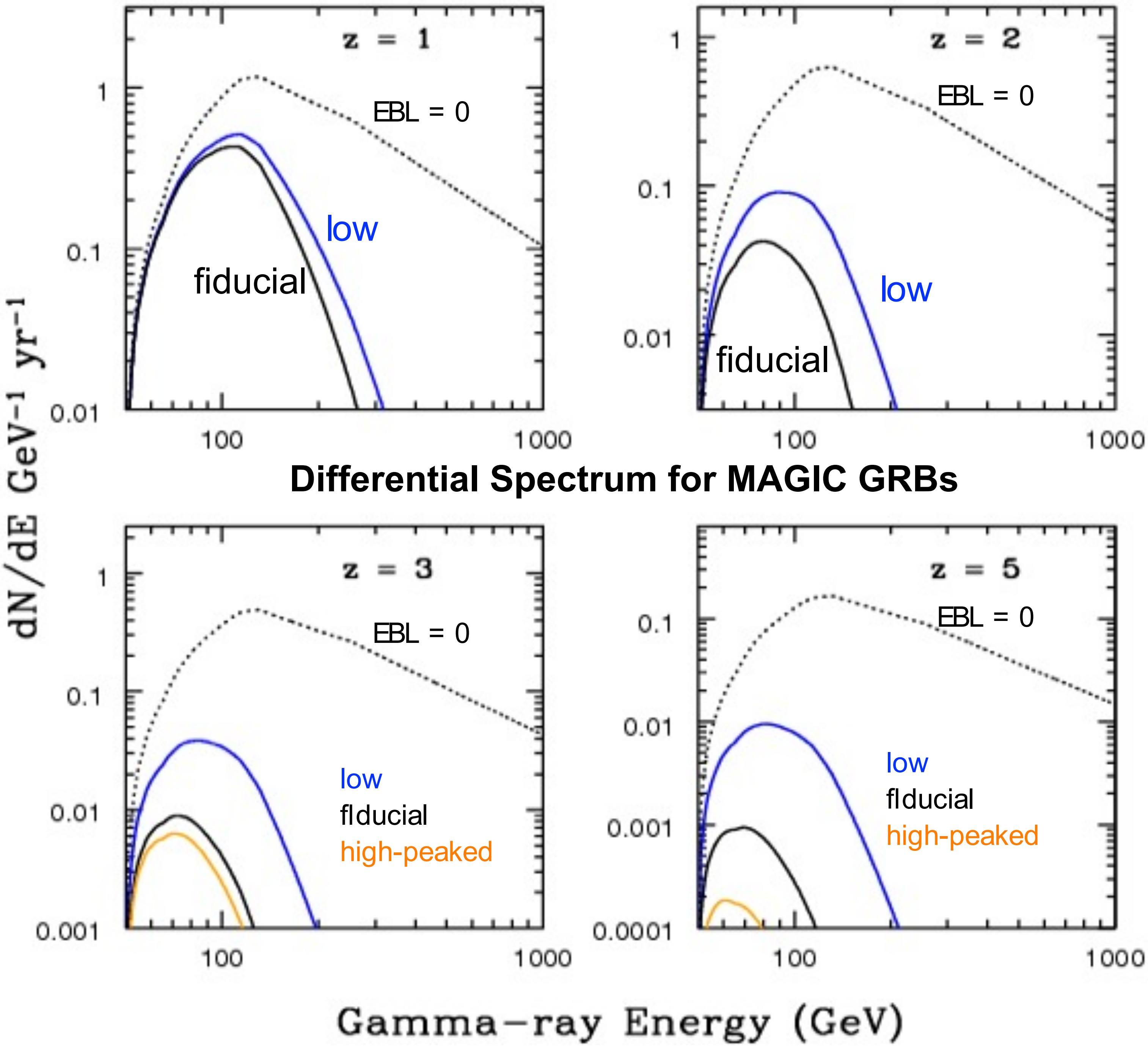

Joel Primack (UCSC) & Rudy Gilmore (SISSA)

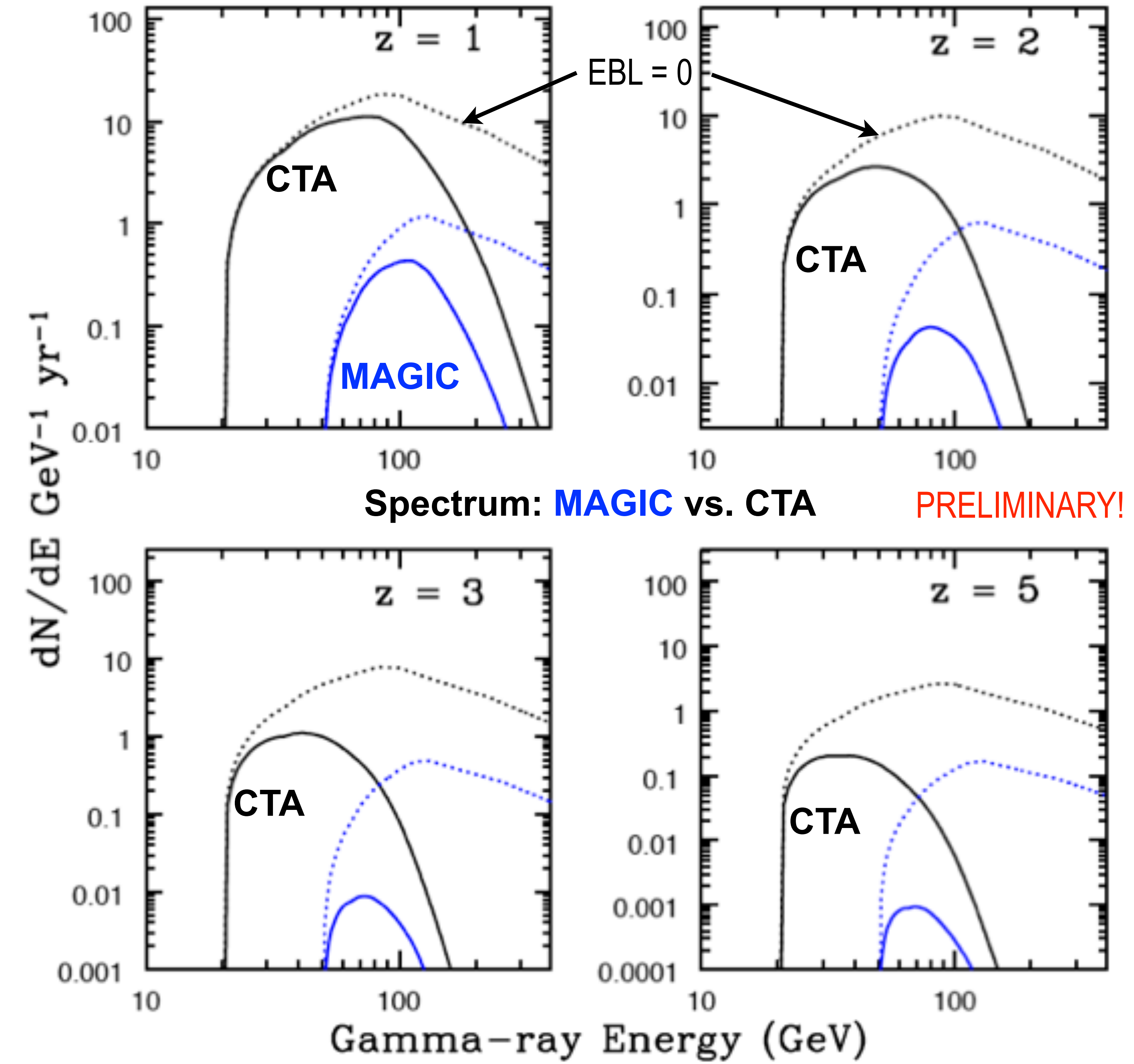
## Simulated Results for GRB 080916C

Gilmore, Prada, Primack 2010 MNRAS

- Seen Sep. 16, 2008 by Fermi LAT and GBM
- 145 gammas above 100 MeV, 14 above 1 GeV
- highest energy gamma ray 13.2 GeV
- redshift z = 4.35
- our model overpredicts number of gamma rays >1 GeV (~24 vs 14 detected) but does correctly predict the energy of the highest energy gamma ray observed: 11 to 15 GeV, depending on EBL model
- If MAGIC had observed it, the predicted number of gamma rays varies strongly with EBL model and angle from zenith (using $E_{th}(0)$ = 50 GeV):

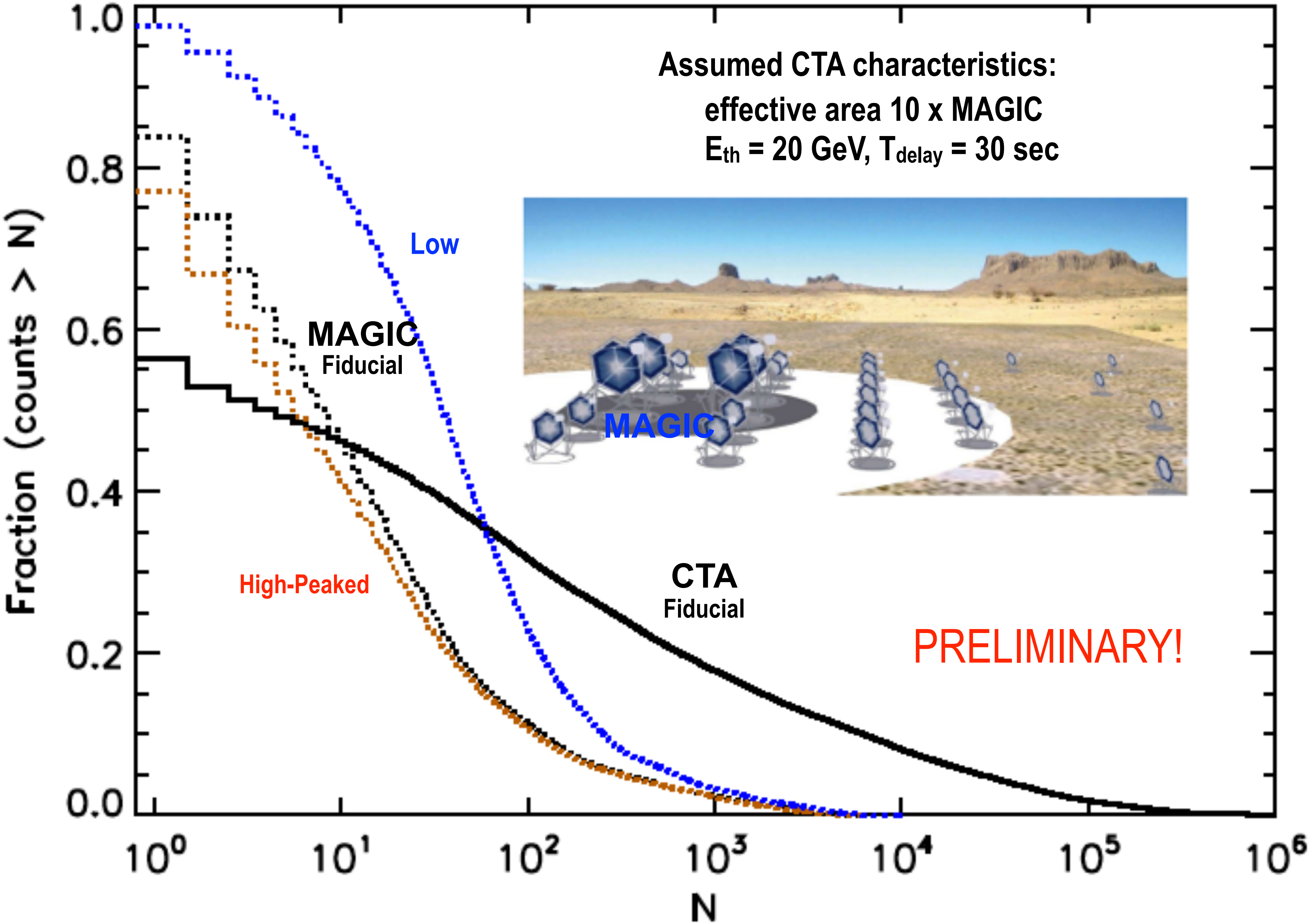
| EBL model | $\theta_{zenith}$ = 0 deg | $\theta$ = 45 deg |
|---|---|---|
| High-Peaked | 20 | <1 |
| Fiducial | 60 | 2 |
| Low | 350 | 60 |


z = 1
EBL = 0
low
fiducial
z = 2
EBL = 0
low
fiducial
Differential Spectrum for MAGIC GRBs
z = 3
EBL = 0
low
fiducial
high-peaked
z = 5
EBL = 0
low
fiducial
high-peaked
dN/dE GeV$^{-1}$ yr$^{-1}$
Gamma−ray Energy (GeV)
100
1000

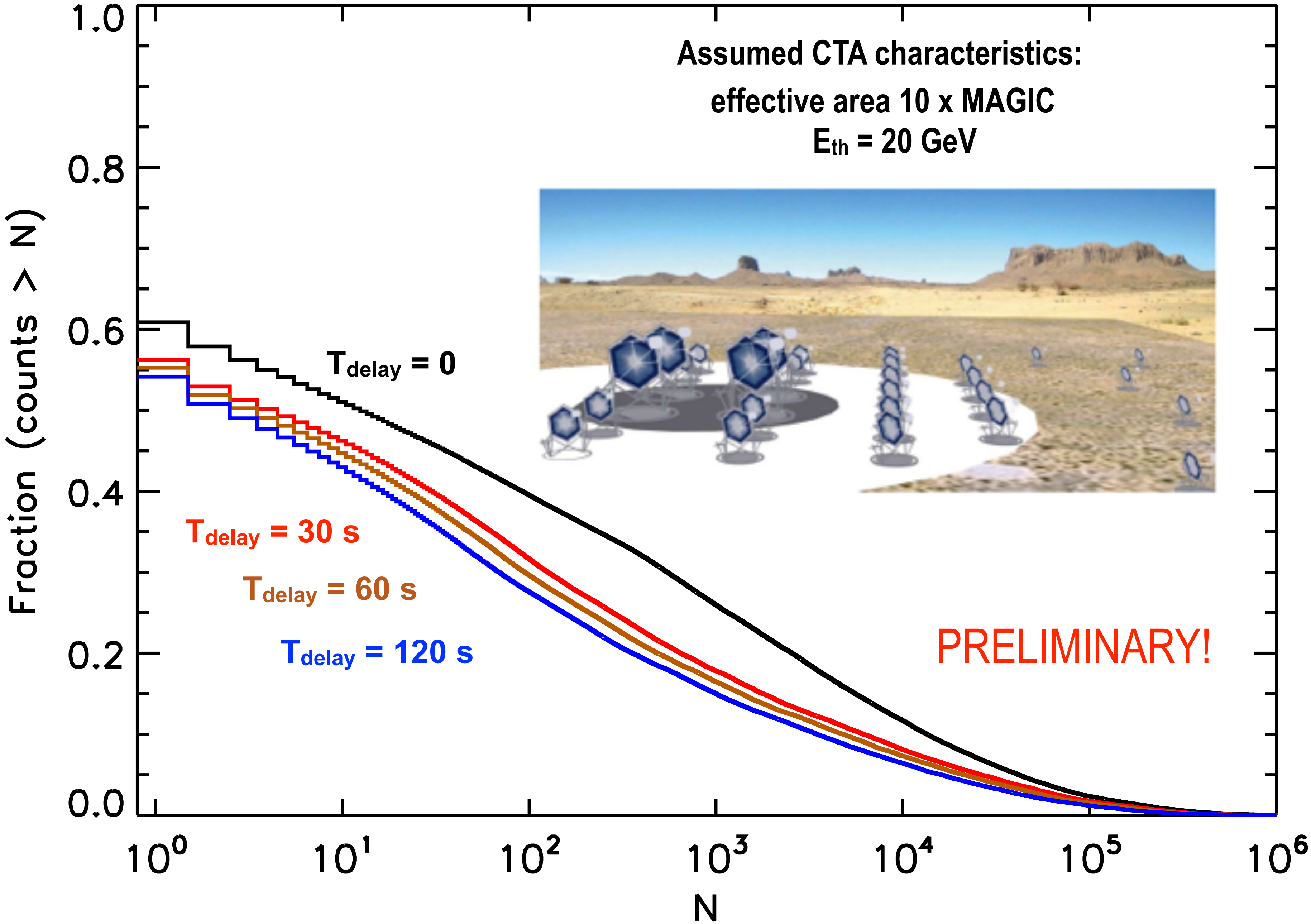


z = 1
z = 2
z = 3
z = 5
EBL = 0
CTA
MAGIC
Spectrum: MAGIC vs. CTA
PRELIMINARY!
dN/dE GeV$^{-1}$ yr$^{-1}$
Gamma-ray Energy (GeV)

# GRB PHOTON NUMBER DISTRIBUTION: MAGIC vs. CTA



# CTA GRB PHOTON COUNT DISTRIBUTION



# Conclusions

- GRBs are a potential source of high-energy gamma rays, but little is known about emission above a few10s of GeV
  - Intrinsic cutoff or internal absorption could be a problem

- Fermi may be able to constrain EBL with several years' stacked data for redshifts 1 ➔ 4 or above
  - more bright GRBs with redshifts over next few years?

- IACTs like MAGIC could detect a large number of gammas within a narrow energy band from single GRB, but annual probability of detection is low
  - Spectral hardening with time may help with slew time
  - Several multi-photon GRBs could constrain UV EBL

- Next-generation IACT arrays will have much larger effective areas and better low energy coverage with $E_{th}(0) \approx 20$ GeV, but will still have sky coverage and duty cycle limitations
  - Now is the time to study implications of various designs for GRB multi-GeV photon observations