CTAとマルチメッセンジャー観測で明らかにするガンマ線バーストとその他トランジエント天体

井上進（東大宇宙線研）

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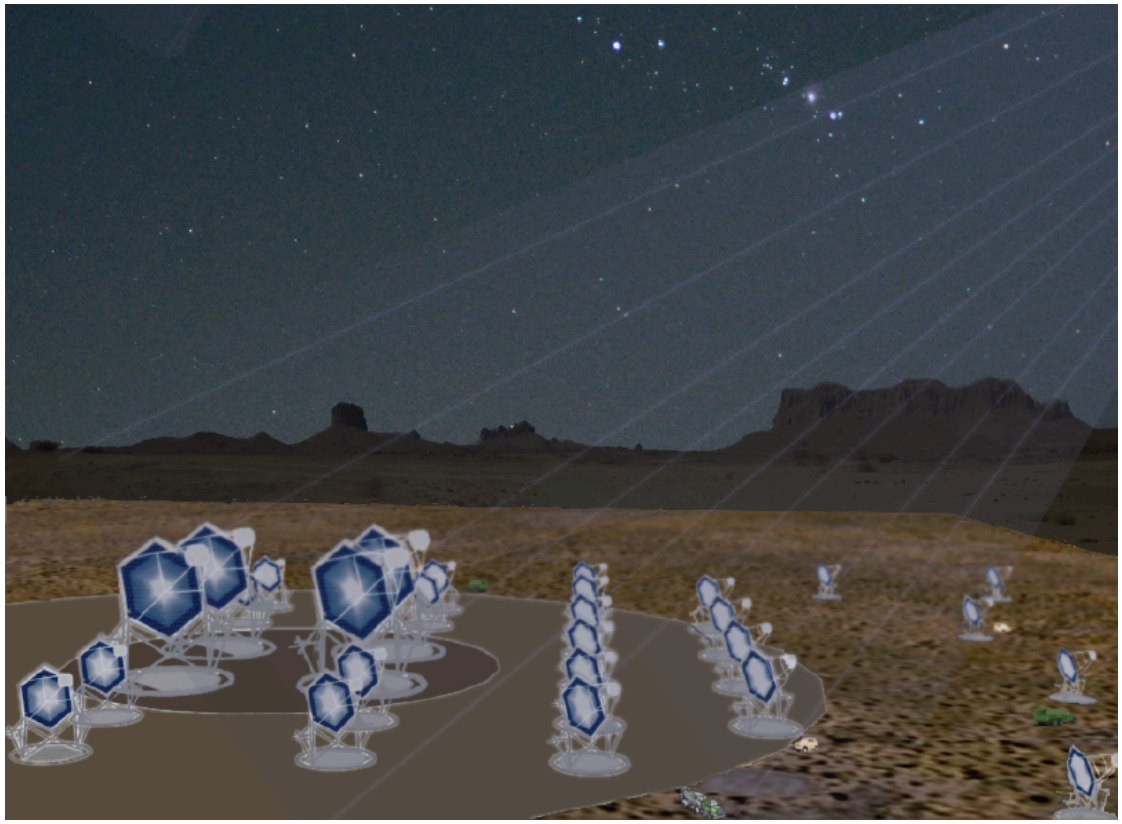
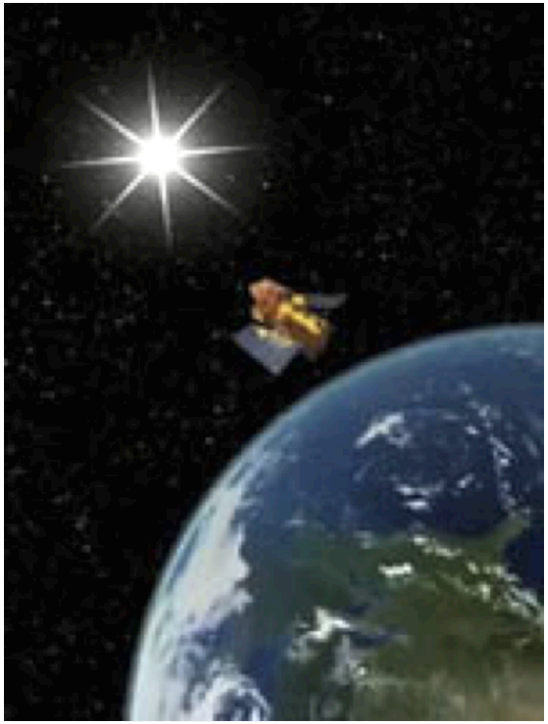
当真賢二、浅野勝晃、井岡邦仁、吉越貴紀、手嶋政廣、
Jim Hinton、Rhaana Starling、Valerie Connaughton、
Paul O'Brien、Jonathan Granot、ほか CTA Consortium





スペクトル
光度曲線
検出率
short GRB
その他

Astroparticle Physics special issue

Prospects for Gamma-Ray Burst Science in the CTA Era (tentative title for Astroparticle Physics special issue)

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Abstract

Gamma-ray bursts (GRBs) are the most powerful explosive phenomena in the Universe, and are also the leading candidates for the origin of ultra-high-energy cosmic rays and neutrinos. They can also serve as valuable beacons for observational cosmology as well as tests of fundamental physics. However, many basic aspects of their nature remain shrouded in mystery. The Cherenkov Telescope Array (CTA), the next-generation ground-based gamma-ray facility, with its high sensitivity, large effective area, and fast slewing capabilities, is expected to break new ground in our quest for elucidating GRBs. This article discusses the science prospects for GRBs with CTA, including expectations for the measurements of spectra and light curves, detection rates, multiwavelength and multimessenger aspects, etc.

Additional remarks to be added...

Keywords: gamma-ray bursts, gamma-rays: theory, gamma-rays: observations

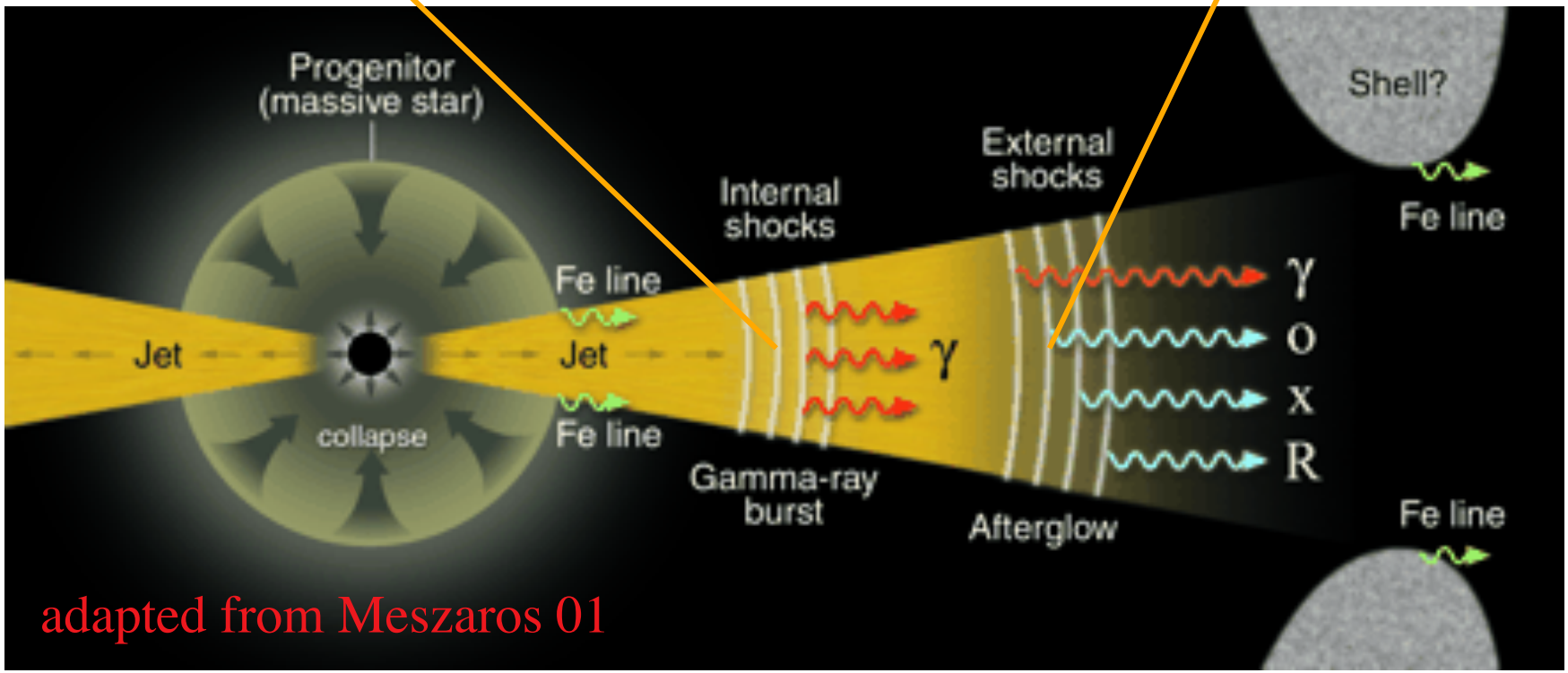
著者23人中11人が日本人

ガンマ線バースト (GRB)

宇宙最大・最強・最速の爆発
宇宙最遠方級の天体

long GRB (T>~2s):

大質量星崩壊時に超相対論的速度ジェット発生
ジェット内部から即時放射+外部衝撃波から多波長残光放射



中心駆動天体? ジェット形成機構? 粒子加速・放射機構?
異なる種族 (short GRB, T~<2s) の起源? 宇宙論的進化?

宇宙で最も謎めいた天体の一つ

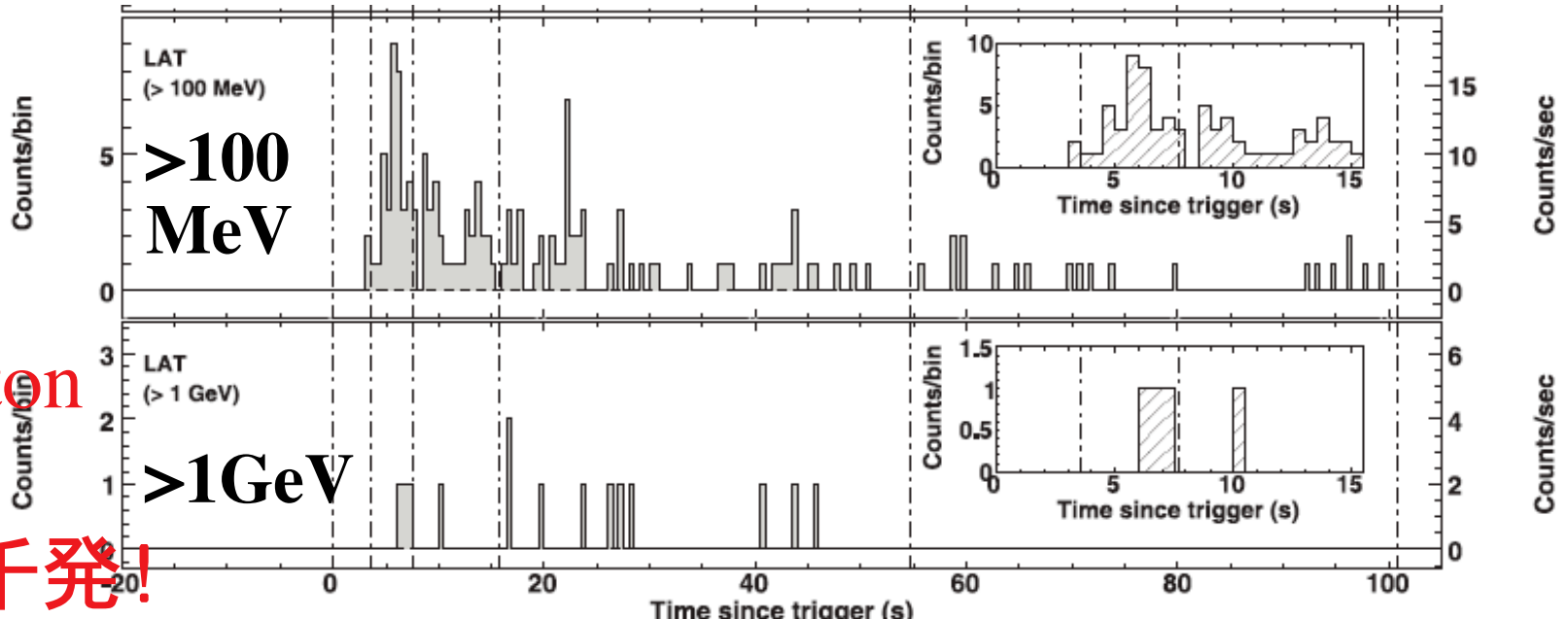
CTAによるGRB観測

1. 10 GeVに迫るエネルギー閾値 (<<現行IACT)
-> 宇宙背景放射光 (EBL) によるγγ吸収を受けにくい

2. 高速指向性能:180deg/20sec for LST (MAGIC2と同等)
-> long GRBの即時放射中に観測開始

3. 莫大な有効面積:>$10^4 m^2$@30GeV (Fermiの1万倍)
-> 圧倒的な光子統計、詳細なスペクトル・時間変動の情報

Fermi LAT GRB 080916C Abdo+ 09



> 10 GeV photon
Fermi数発 ->
CTA 数百-数千発!

CTAによるGRB観測で目指すサイエンス

GRBの起源

- 放射体運動速度の確実な測定（内部γγ吸収カットオフ）
- 即時放射機構、残光の物理の解明
（多波長スペクトル・時間変動）

宇宙線の起源

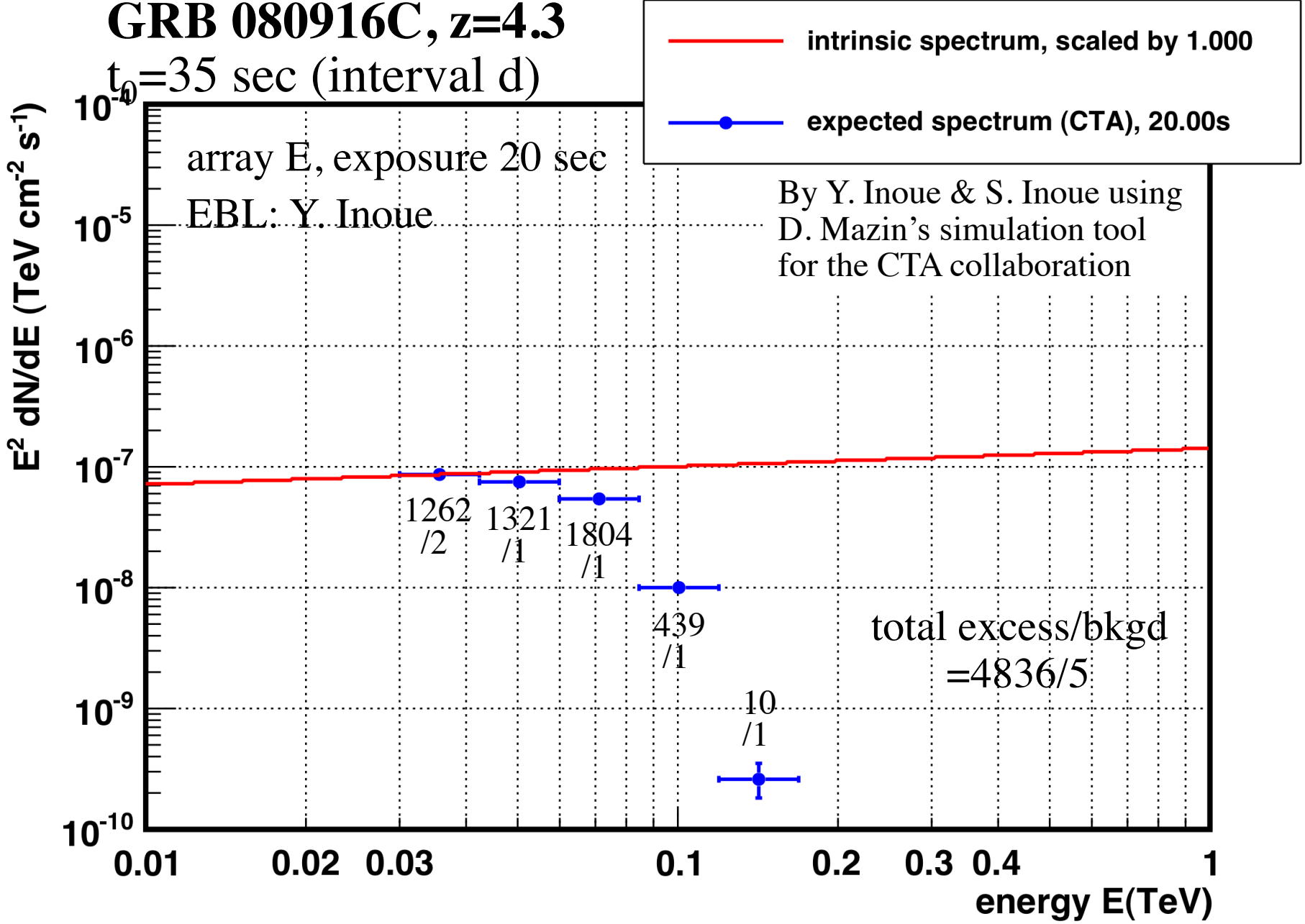
- 最高エネルギー宇宙線・高エネルギーν生成の兆候
（陽子・原子核シンクトロトロン、カスケード成分…）

観測的宇宙論

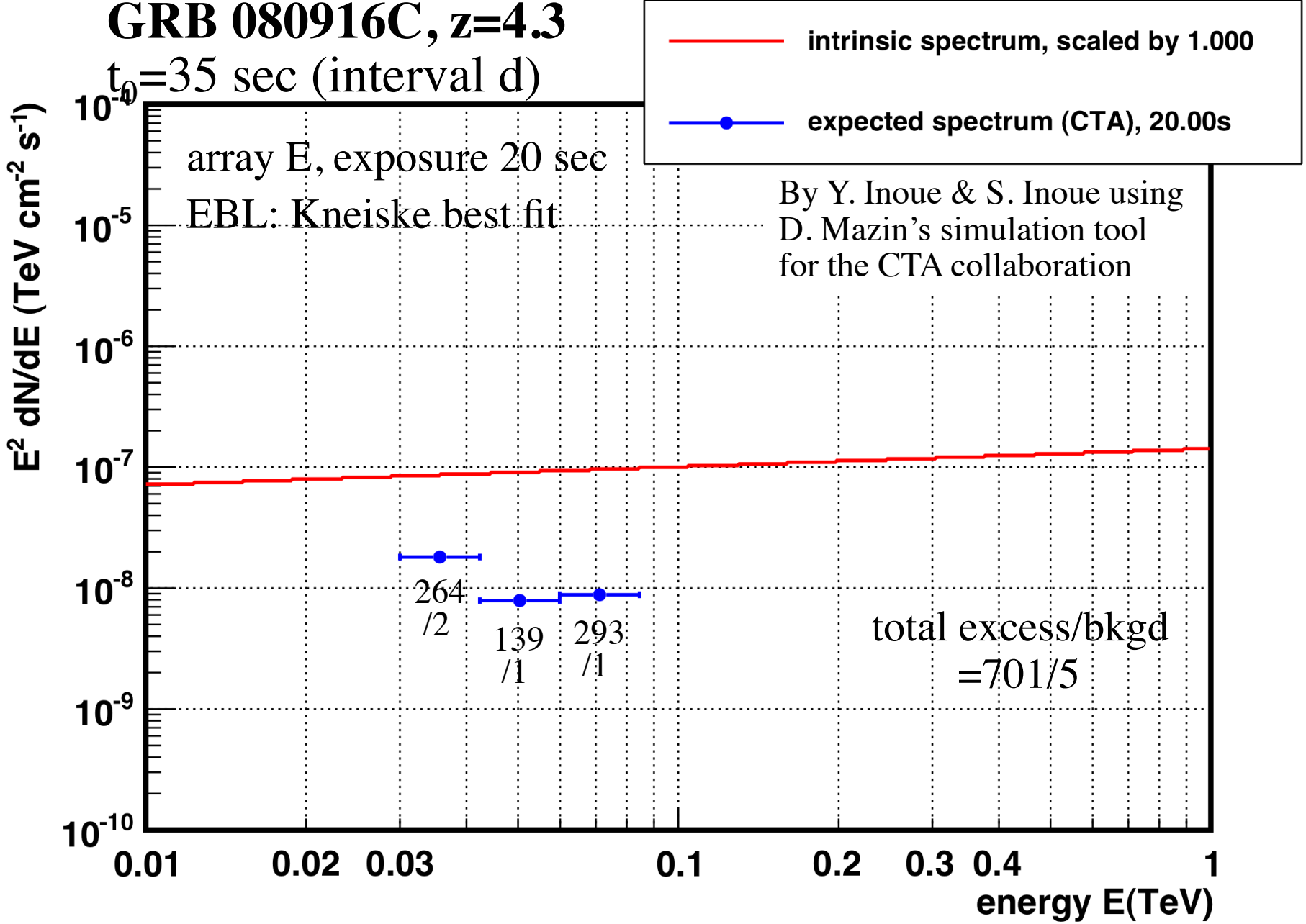
- 遠方宇宙背景放射の精査（γγ吸収カットオフ）
- 銀河間弱磁場の精査（pair echo=二次ガンマ線）

基礎物理学

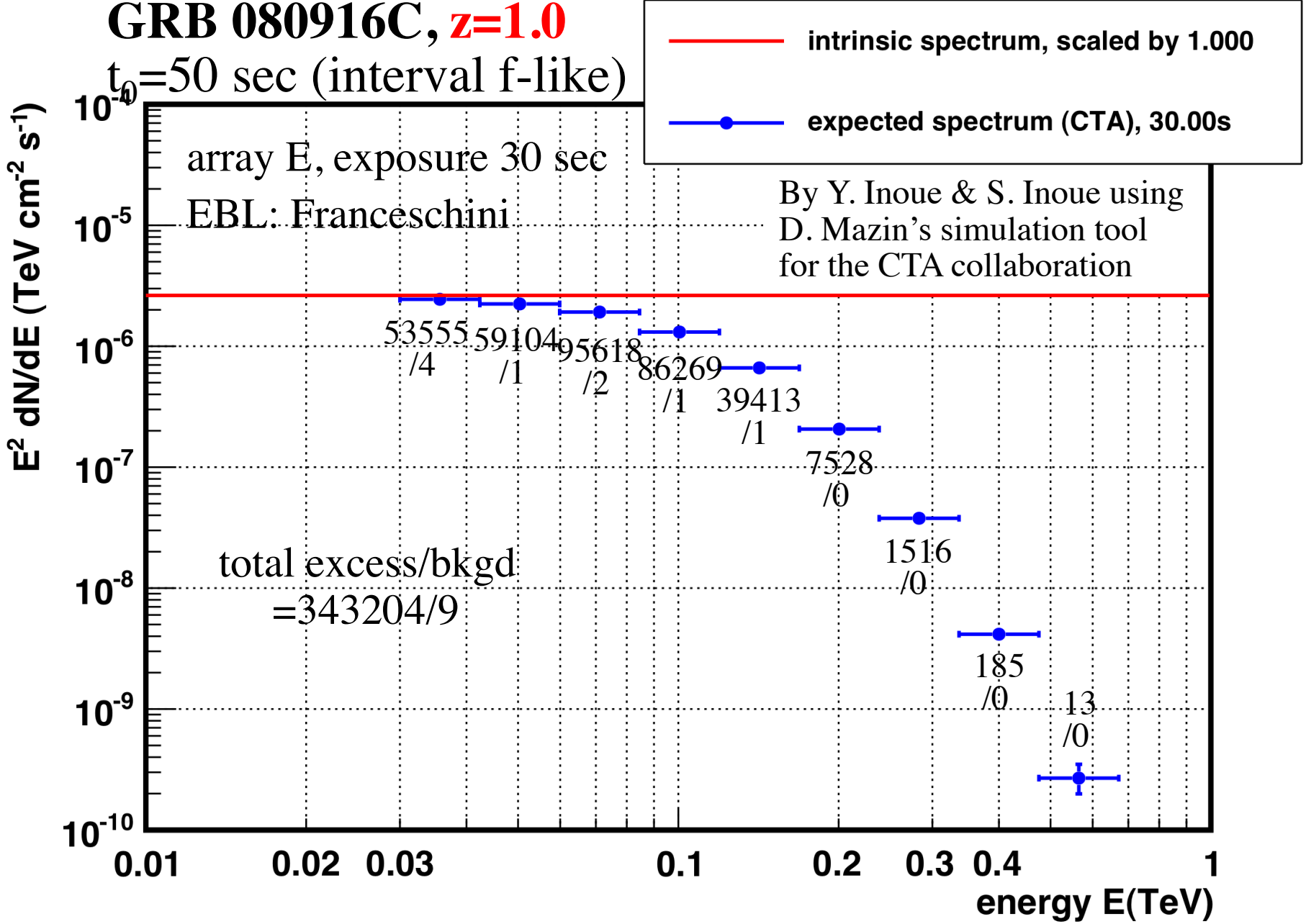
- Lorentz不変性破れ、新粒子への制限…



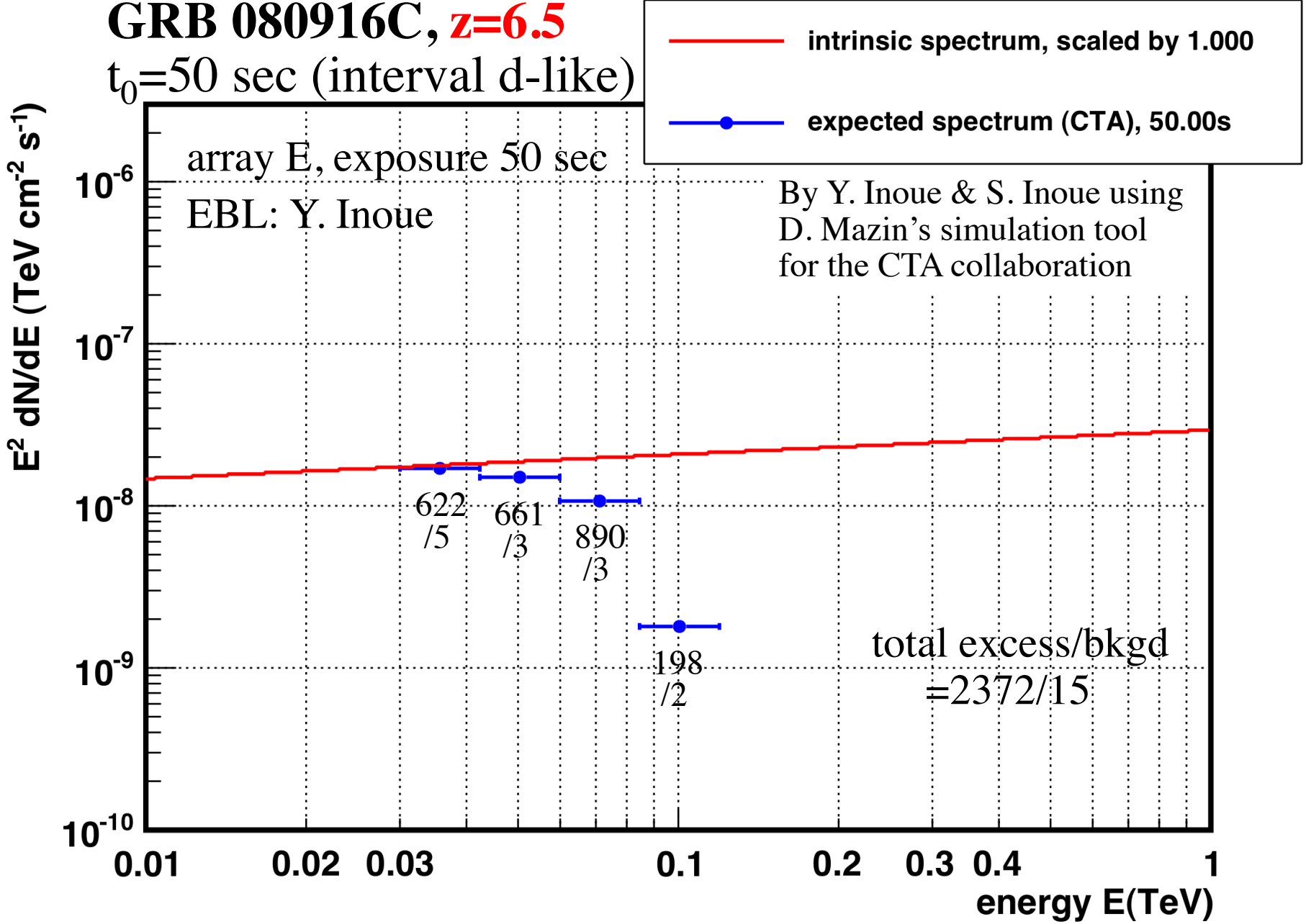
NB: array sensitivity~<200 GeV almost due to LSTs alone

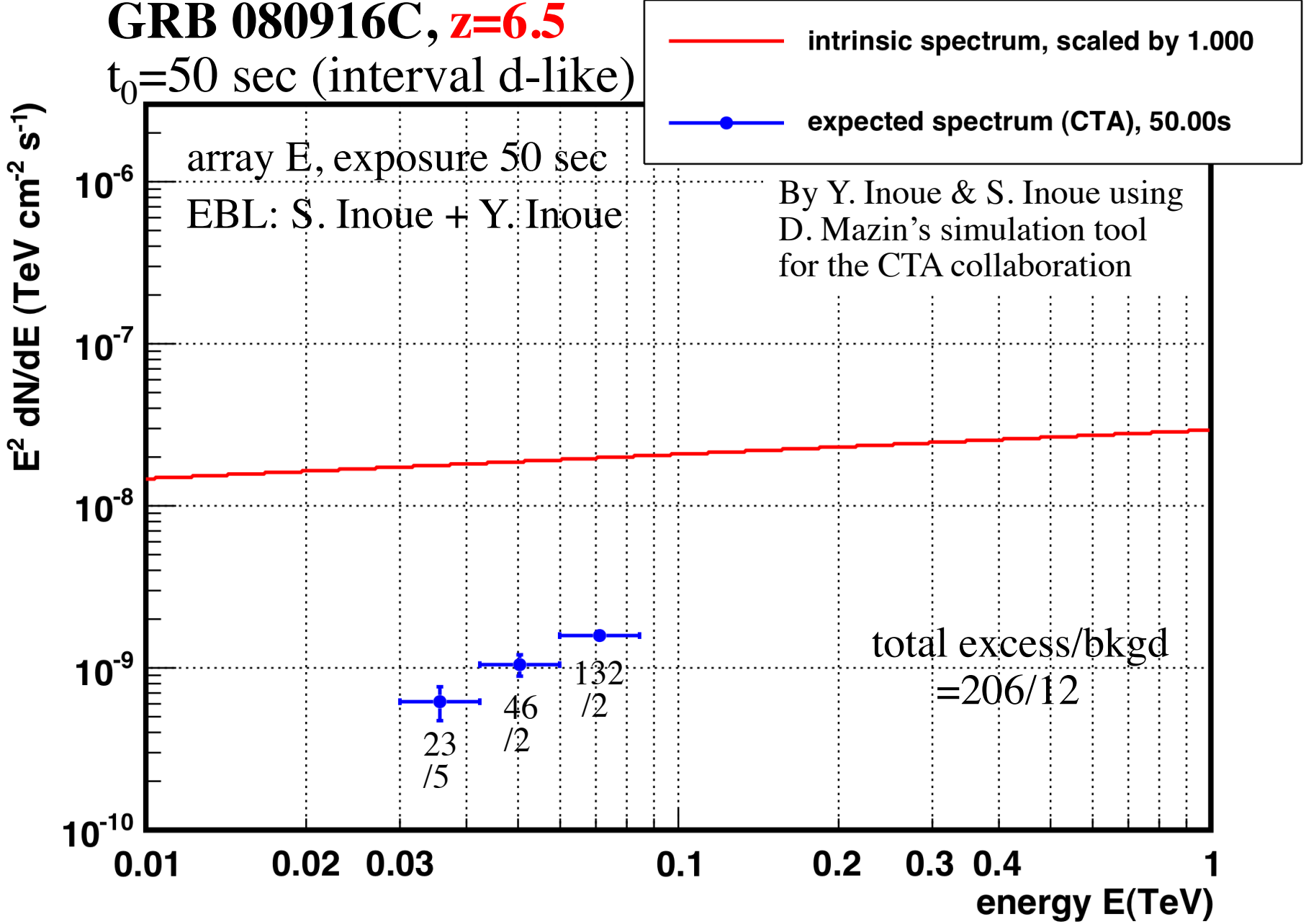


effective probe of high-z EBL:
unique info on cosmic star formation/galaxy formation

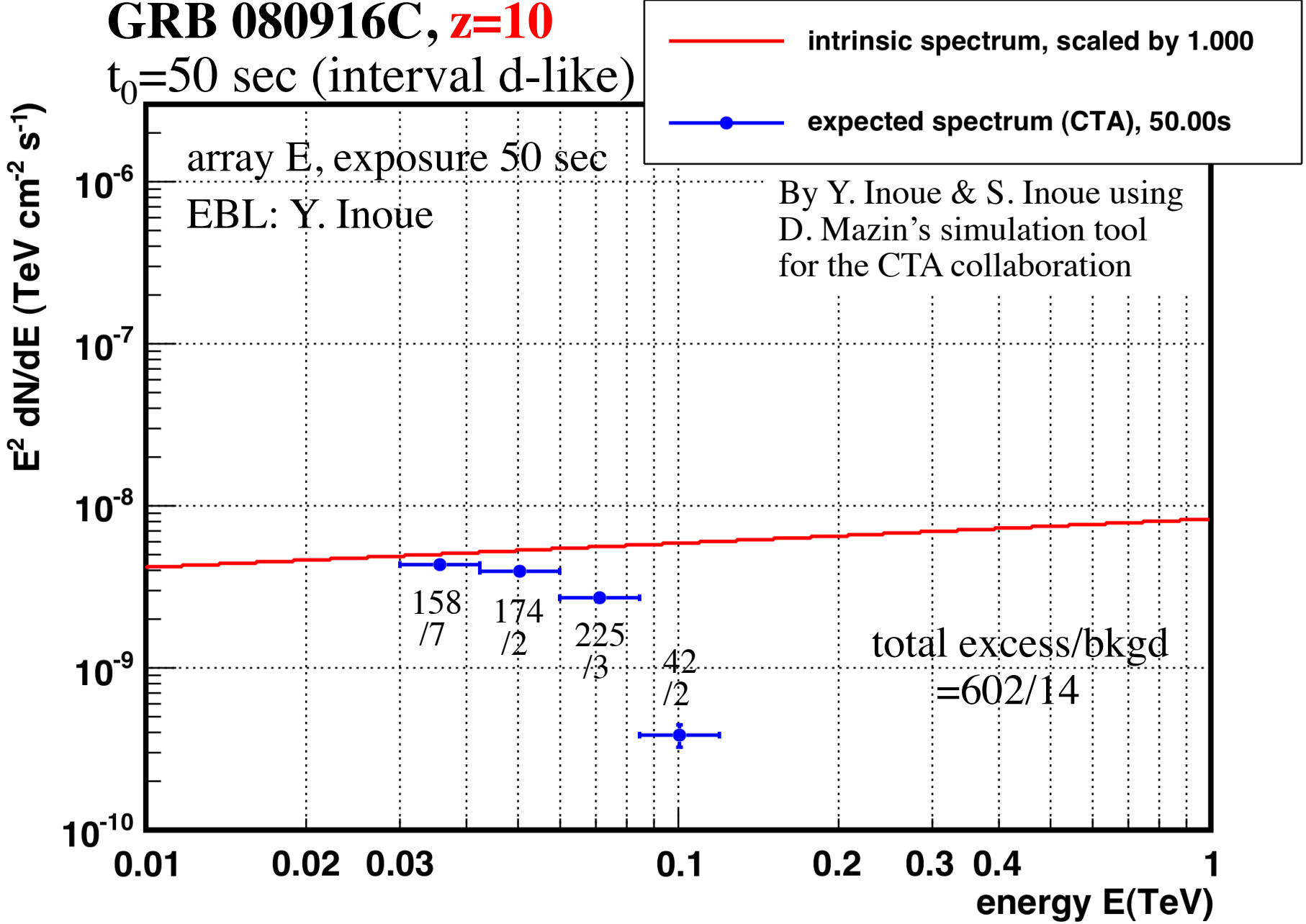


hugh photon statistics! detailed spectral variability info
lower E threshold seems possible

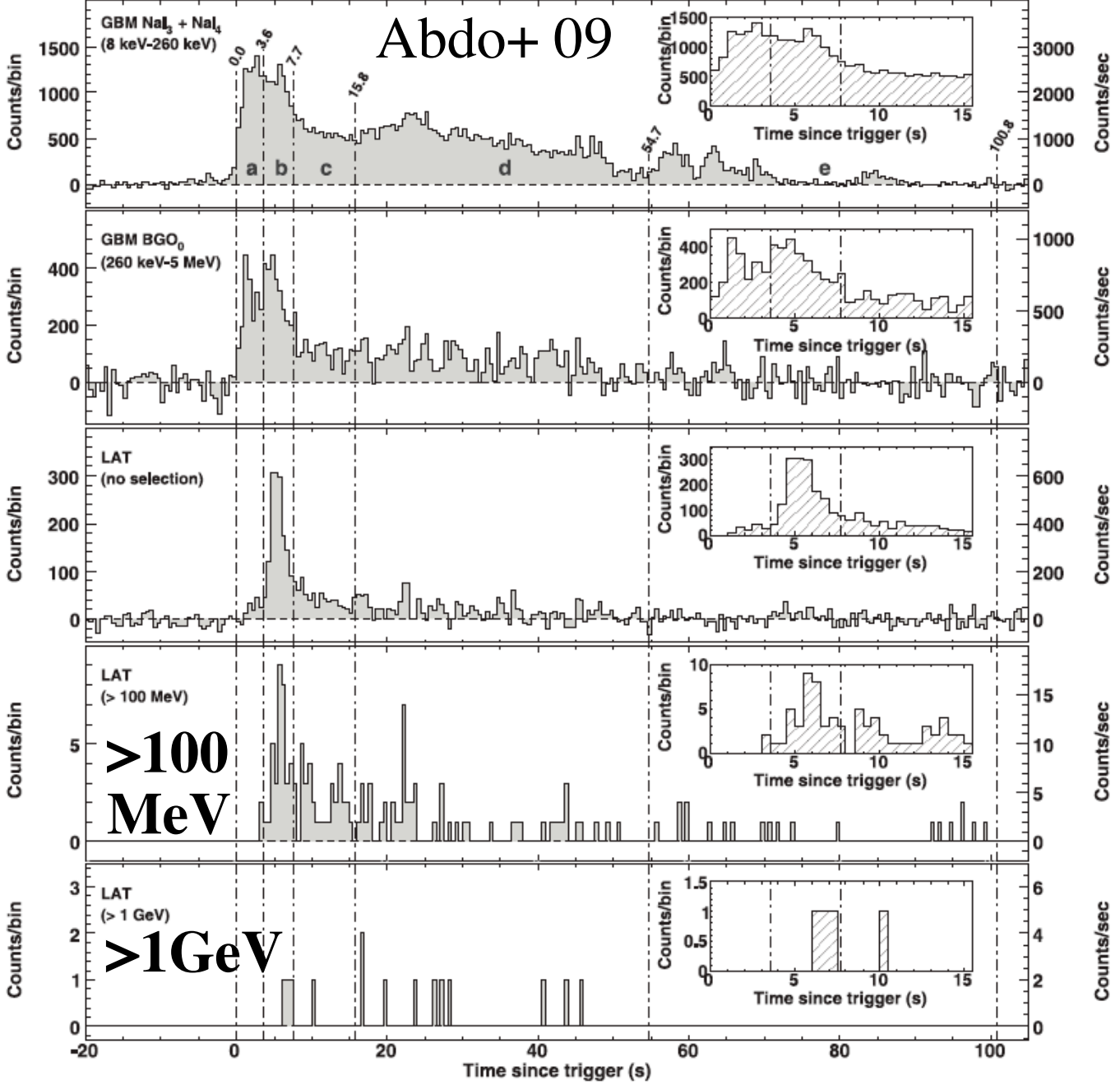

GRB 080916C, z=6.5
t0=50 sec (interval d-like)
intrinsic spectrum, scaled by 1.000
expected spectrum (CTA), 50.00s
array E, exposure 50 sec
EBL: Y. Inoue
By Y. Inoue & S. Inoue using
D. Mazin's simulation tool
for the CTA collaboration
622
/5
661
/3
890
/3
198
/2
total excess/bkgd
=2372/15
E2 dN/dE (TeV cm-2 s-1)
10-6
10-7
10-8
10-9
10-10
0.01
0.02
0.03
0.1
0.2
0.3
0.4
1
energy E(TeV)



unique info on cosmic dawn (cosmic reionization)!


GRB 080916C, z=10
t0=50 sec (interval d-like)
intrinsic spectrum, scaled by 1.000
expected spectrum (CTA), 50.00s
array E, exposure 50 sec
EBL: Y. Inoue
By Y. Inoue & S. Inoue using
D. Mazin's simulation tool
for the CTA collaboration
158
/7
174
/2
225
/3
42
/2
total excess/bkgd
=602/14
E2 dN/dE (TeV cm-2 s-1)
10-6
10-7
10-8
10-9
10-10
0.01
0.02
0.03
0.1
0.2
0.3
0.4
1
energy E(TeV)

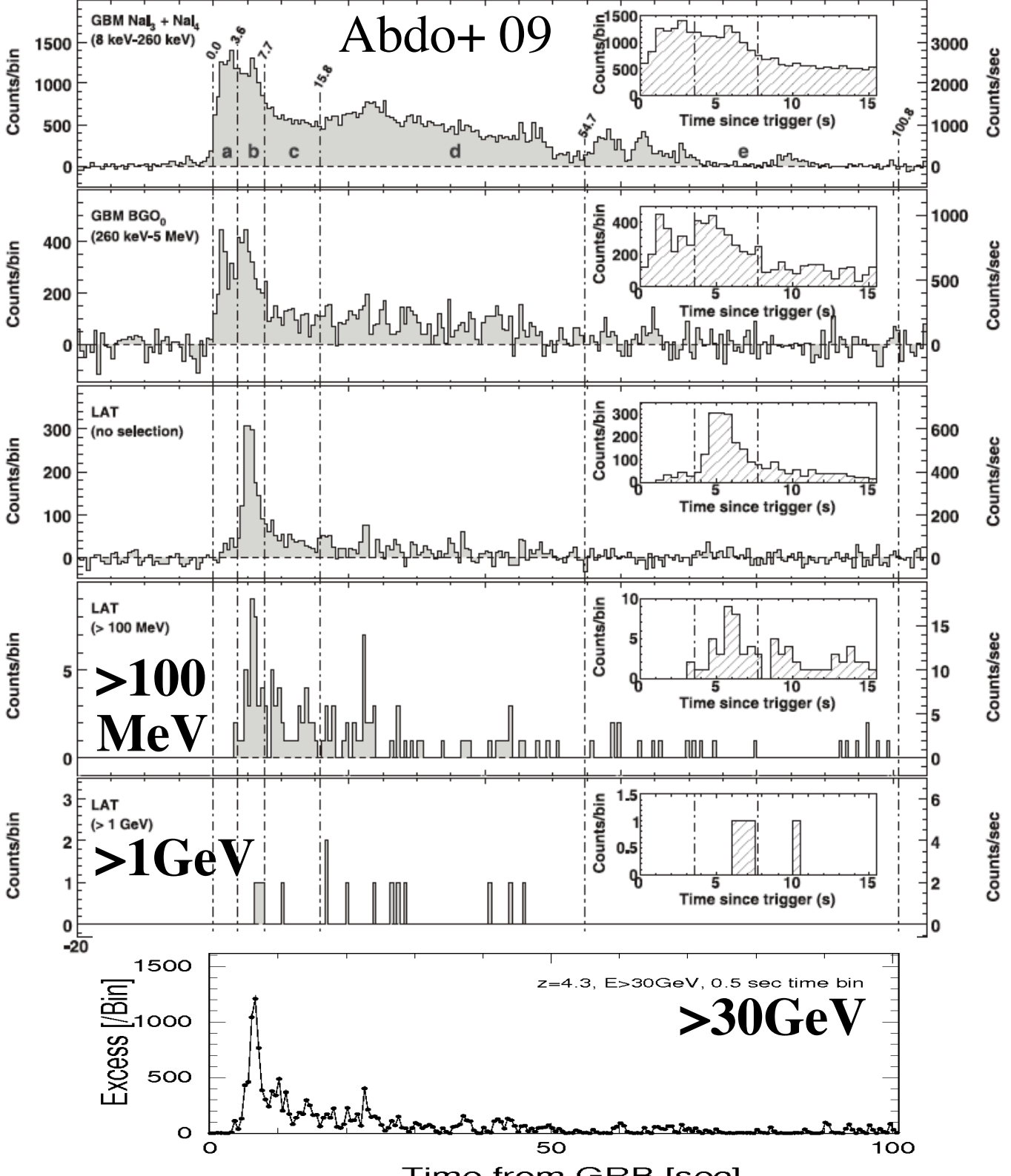
GRB 080916C
Fermi results



GRB 080916C Fermi results +CTA simulation

- normalize to GBM light curve
- extrapolate GBM+LAT spectra with Y. Inoue EBL
- simulate with D. Mazin's tool

T. Yamamoto, Y. Inoue, R. Yamazaki, SI

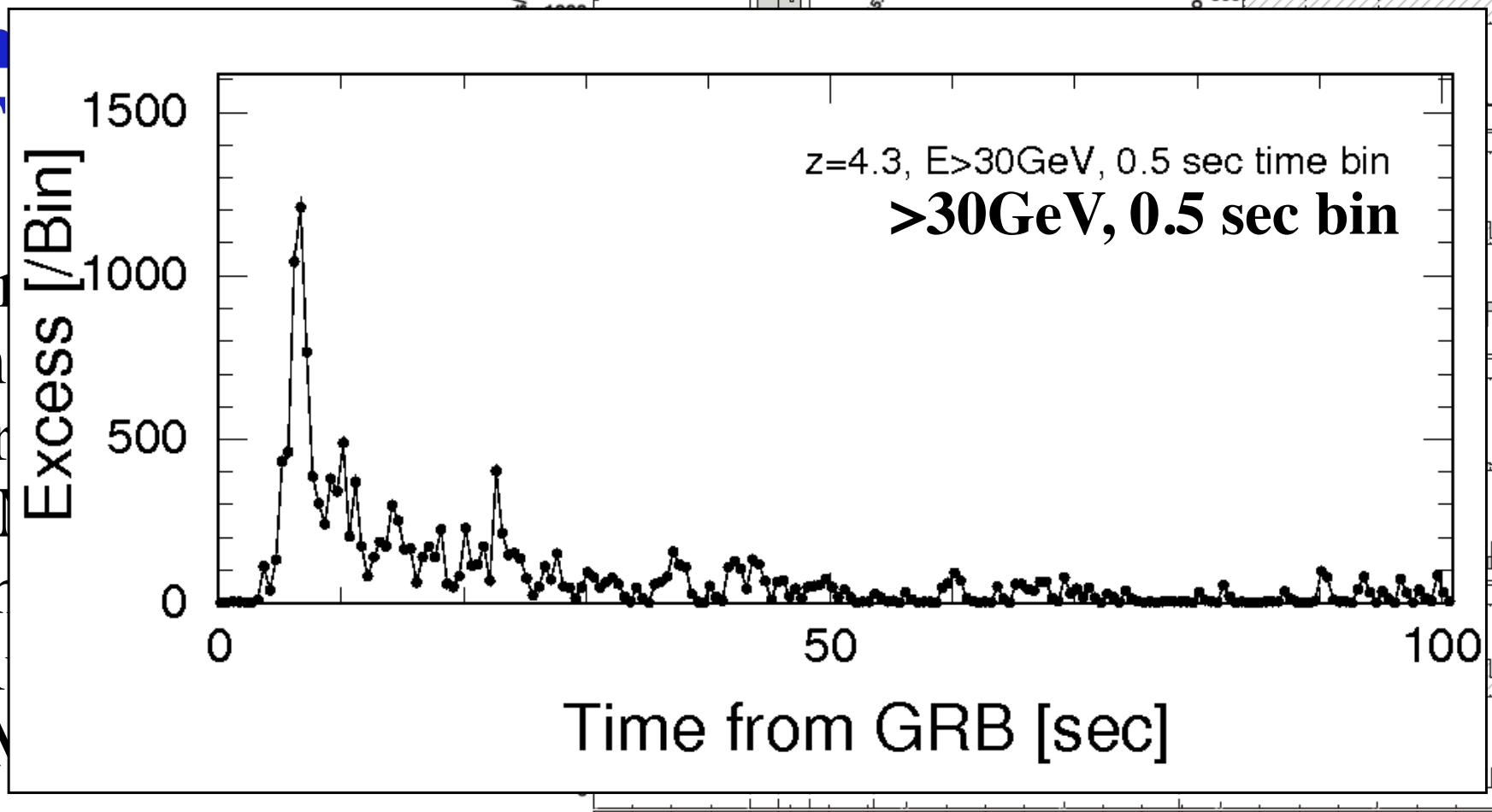


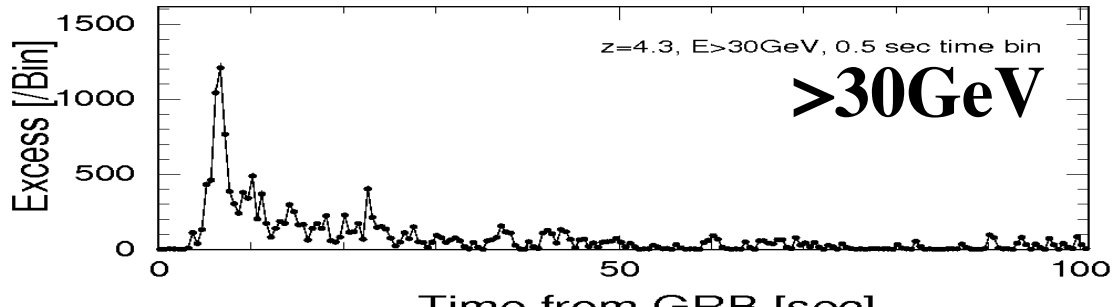
GRB 080916C
Fern
+CT

- nor
  ligh
- extr
  GBI
  with
- sim
  D. M

T. Yamamoto, Y. Inoue,
R. Yamazaki, SI

Abdo+ 09





GRB 080916C

Fern

+CT

- nor
  ligh
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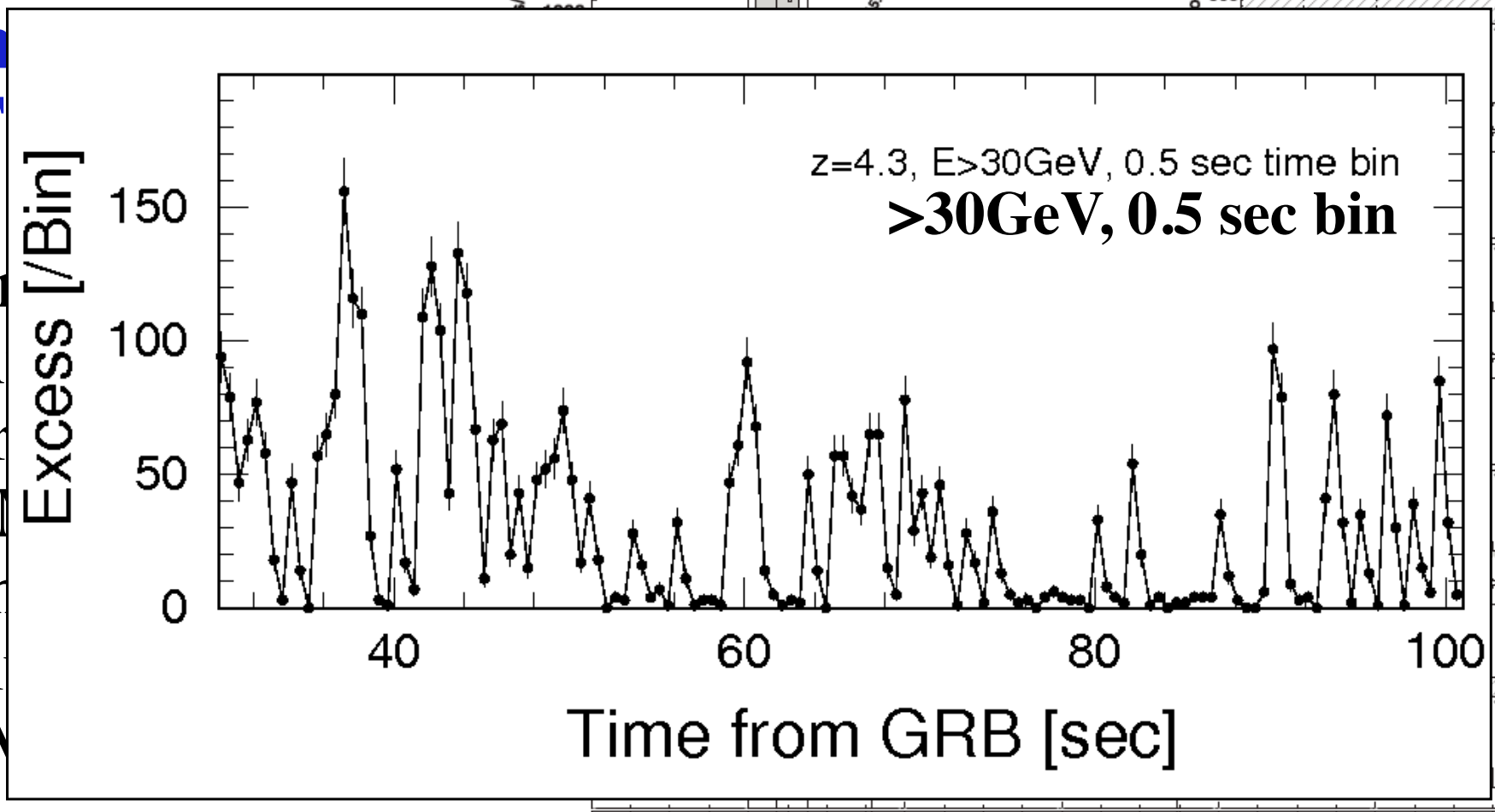
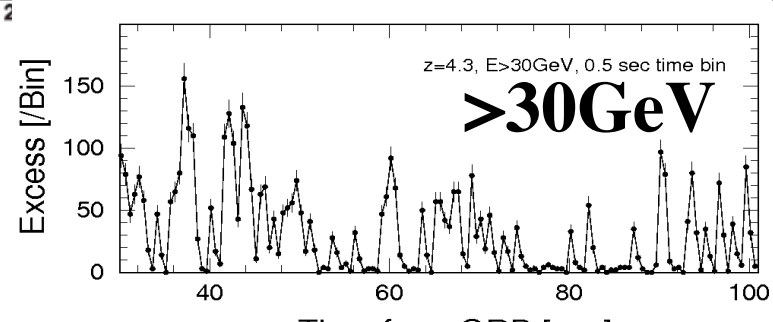
R. Yamazaki, SI

Abdo+ 09





GRB 080916C

Fern

+CT

- nor
  ligh
- extr
  GBI
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  D. M

T. Yamamoto, Y. Inoue,
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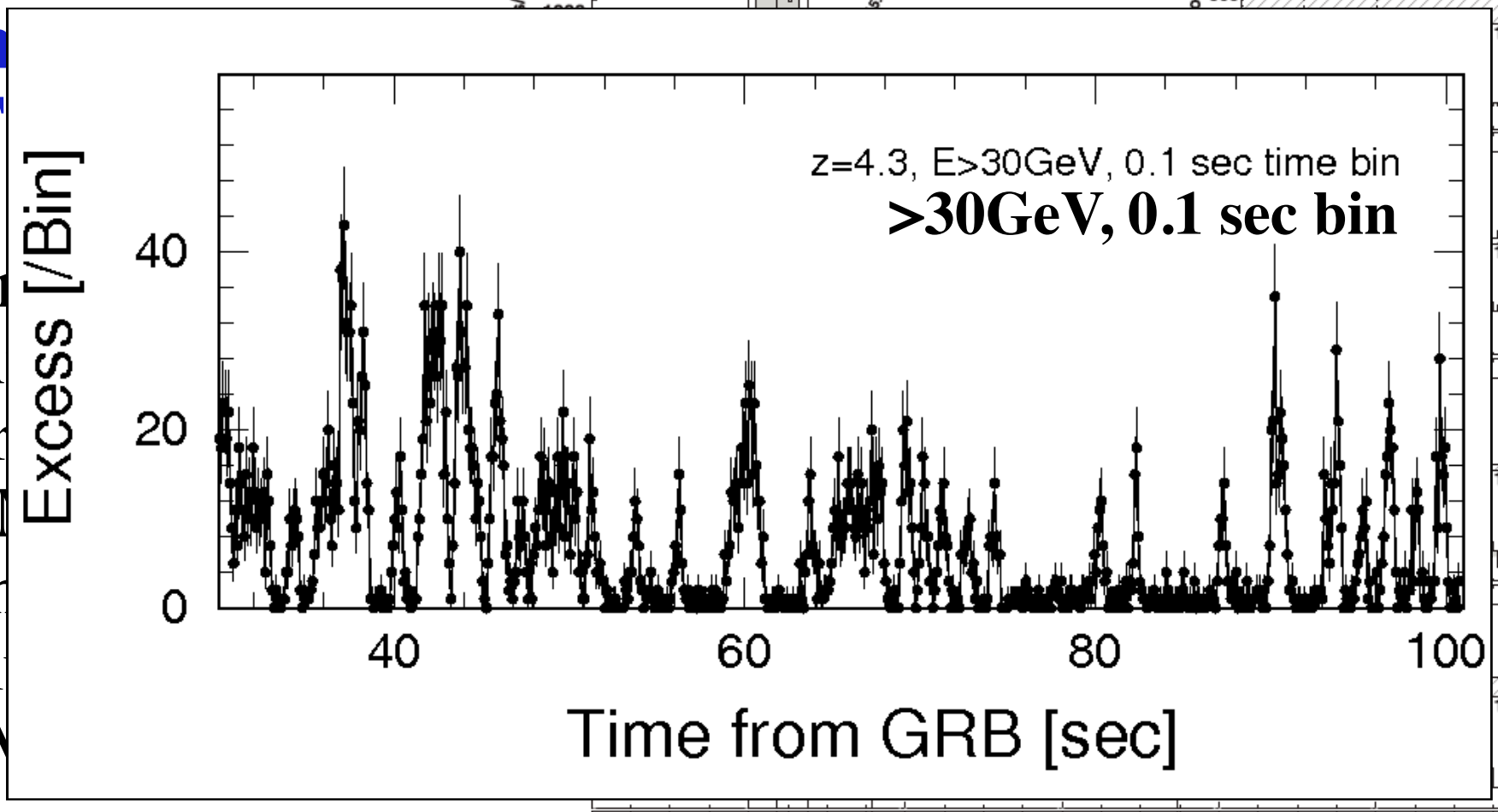
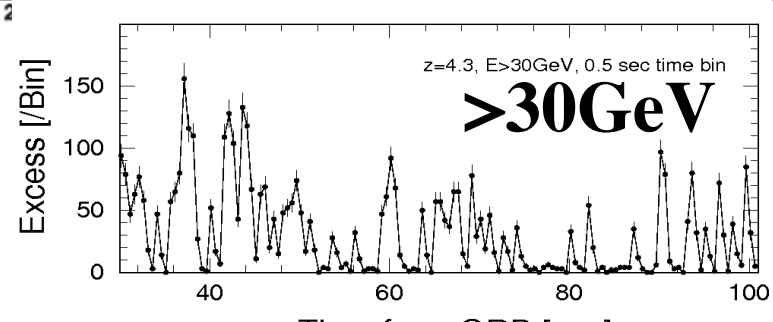
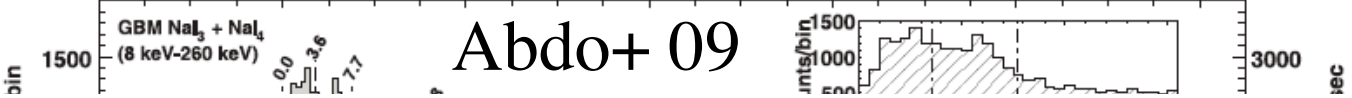
Abdo+ 09

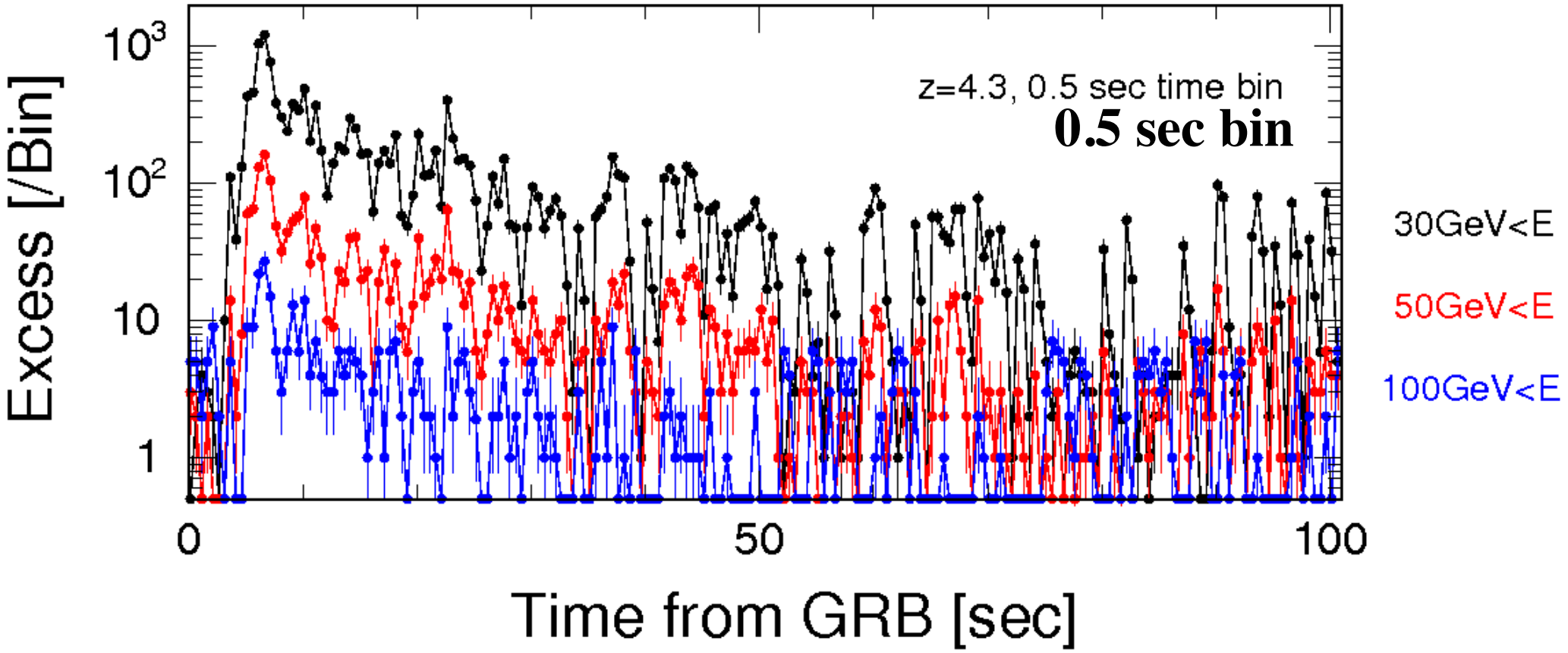




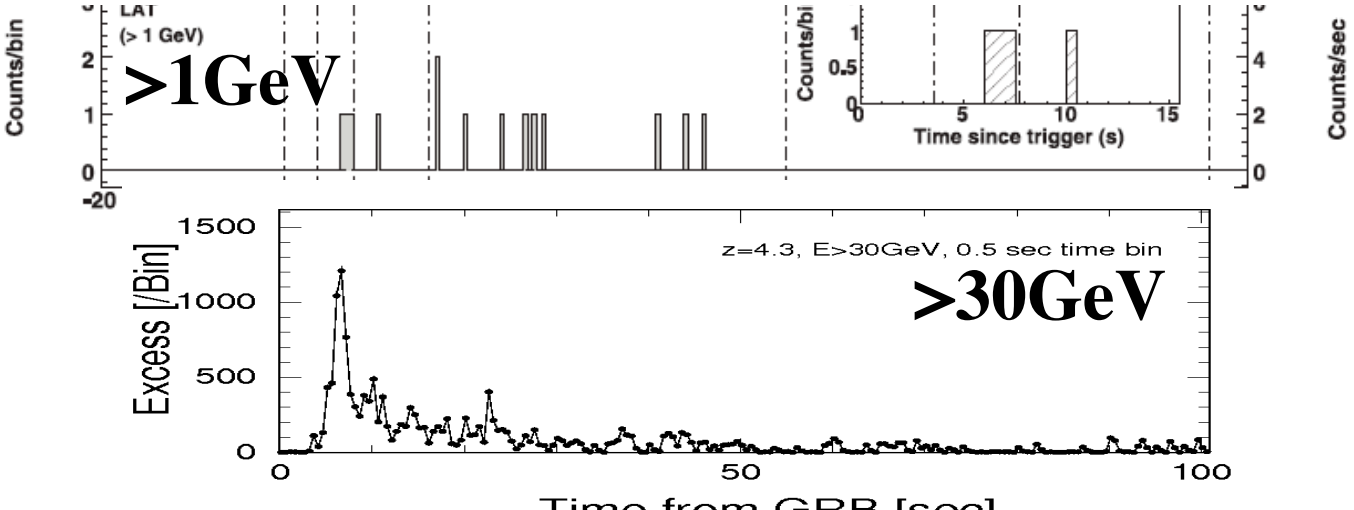
GRB 080916C

Abdo+ 09





T. Yamamoto, Y. Inoue,
R. Yamazaki, SI

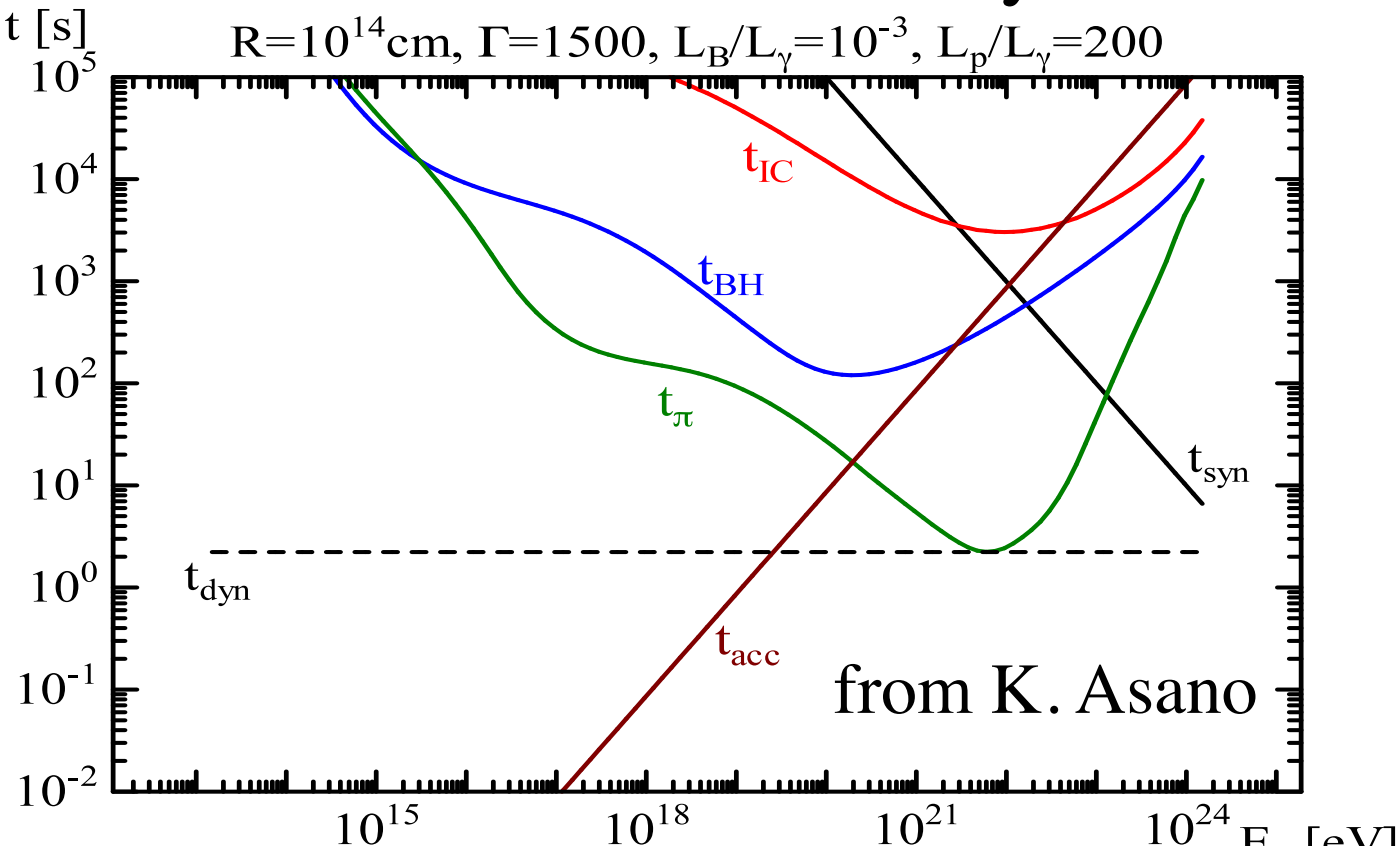


science from detailed light curves

1. extract physics from E-dependent variability
   - decipher UHECR signatures from variability timescales
   - distinguish intrinsic vs EBL cutoffs

   …

2. devise GRB-optimized analysis methods utilizing timing signatures
   -> lower E threshold + increase low-E sensitivity



GRB detection rate

Kakuwa, Yamazaki, Toma, Murase, SI+

alert rate GRB facility

× sky coverage 0.25x2 × duty cycle 0.1(->0.15)

× slewing+detection efficiency spectrum, T_{90} , luminosity, z dist. EBL attenuation

↓

prompt: 0.37 (T_{90}>T_{delay}=100s) x0.15-0.37 (detect)

afterglow: 0.34-0.79 (detect)

assume:
z & peak L. dist. Wanderman
Band spec. extension & Piran 10
E_p-E_{iso} corr.
prompt: no structure, T_{dur} dist.
afterglow: $f_\nu \sim \nu^{-1} t^{-1.5}$
EBL: Razzaque (z<5 only)
array I integral sensitivity

Fermi/GBM alert 50/yr (loc.< 3.5 deg)

prompt: 0.1-0.3/yr
afterglow: 0.7-1.6 yr
x2.5 with better loc.

SVOM alert 80/yr x1.6 anti-solar bias

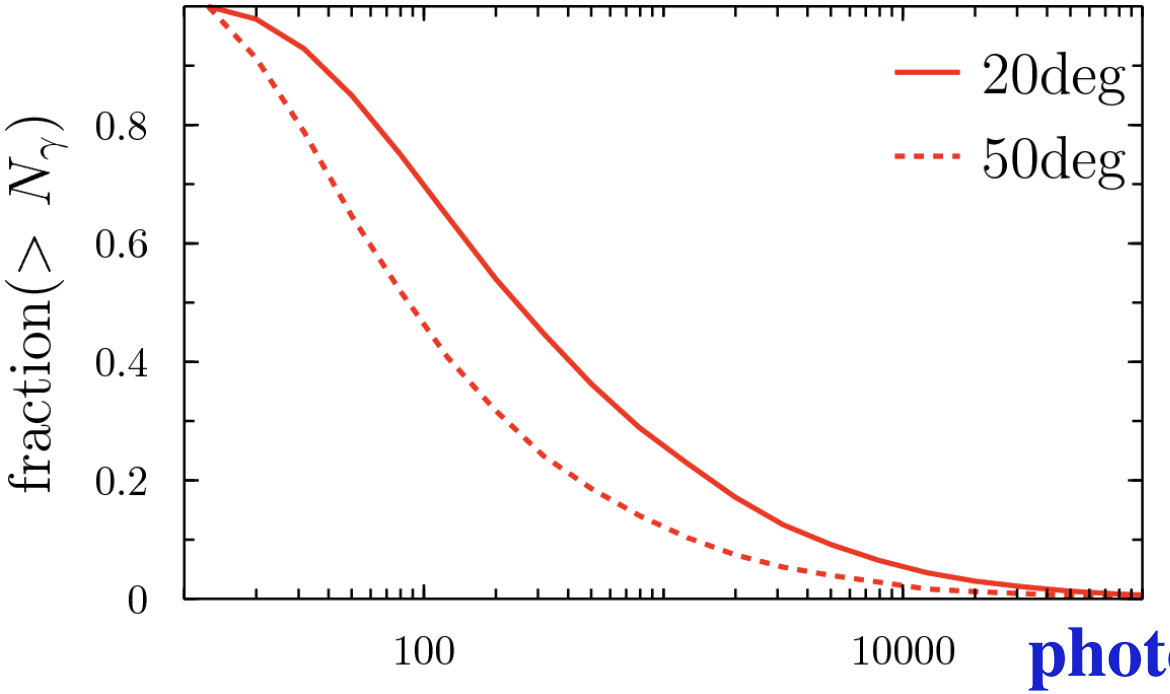
prompt: 0.3-0.7/yr
afterglow: 1.7-4.0 yr

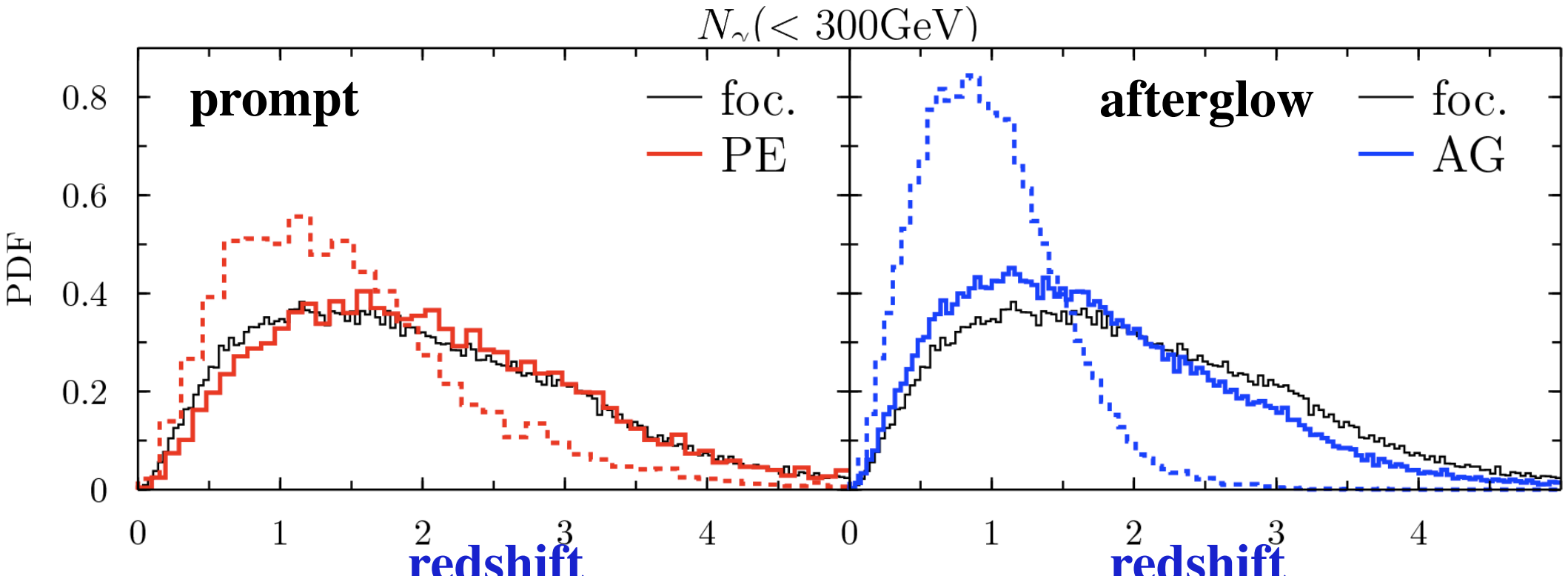
Swift alert 95/yr x 1.4 anti-solar bias x0.6 sky

prompt: 0.2-0.5/yr
afterglow: 1.1-2.5 yr

GBM+SVOM
prompt: >~0.5-1/yr
afterglow: >~2-6 yr

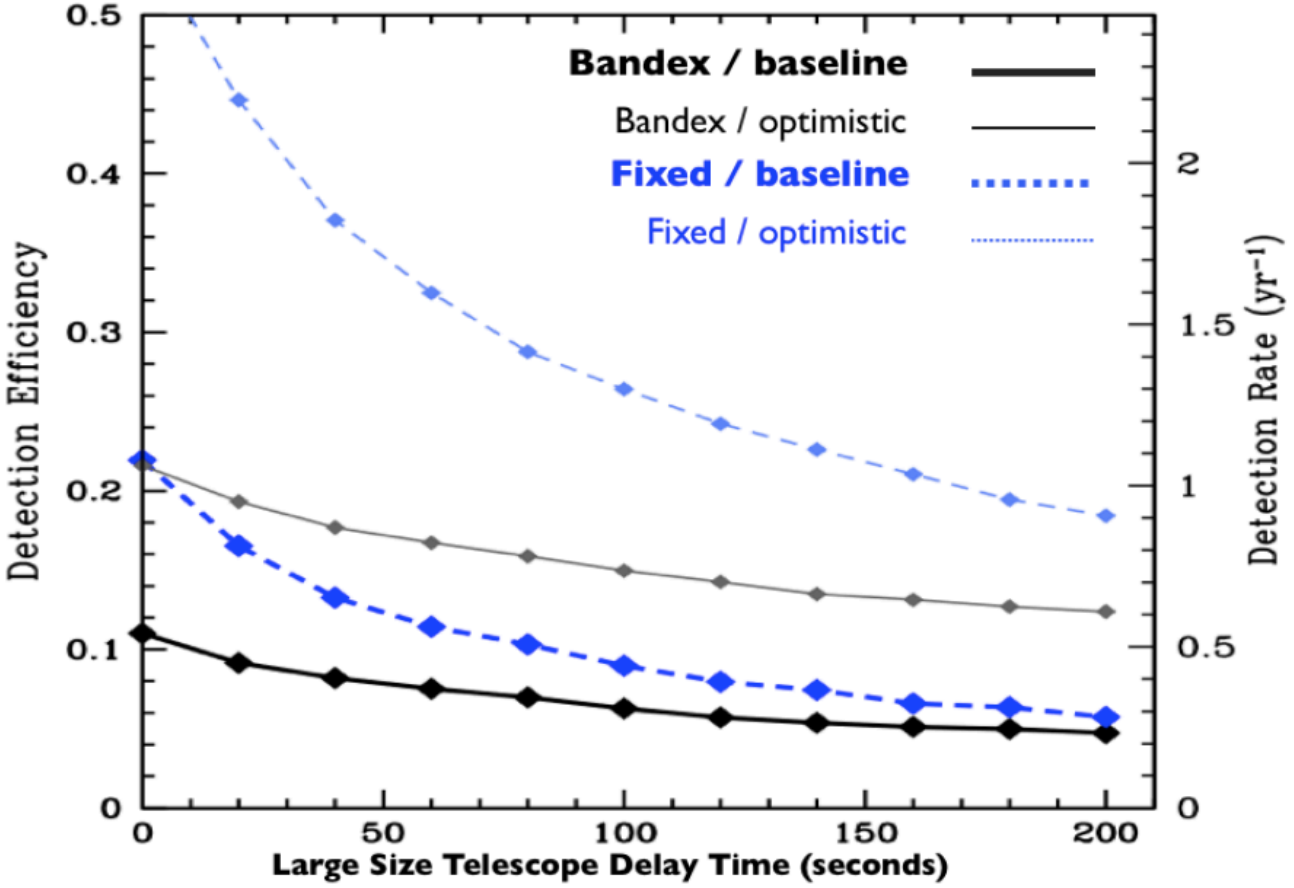
redshift & photon count distribution

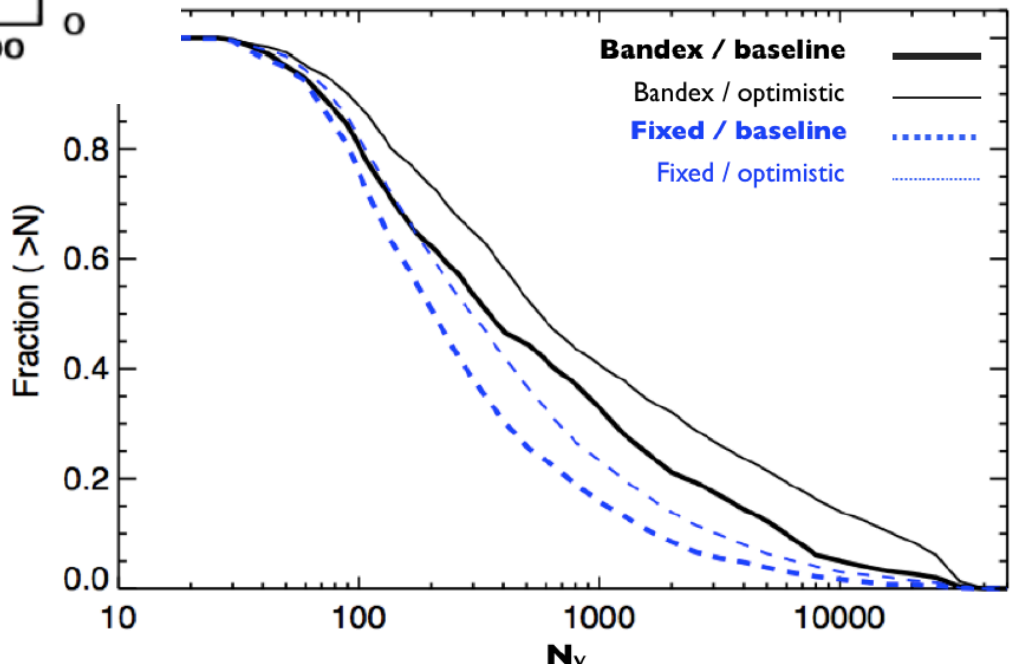




GRB detection rate

A. Bouvier +colleagues



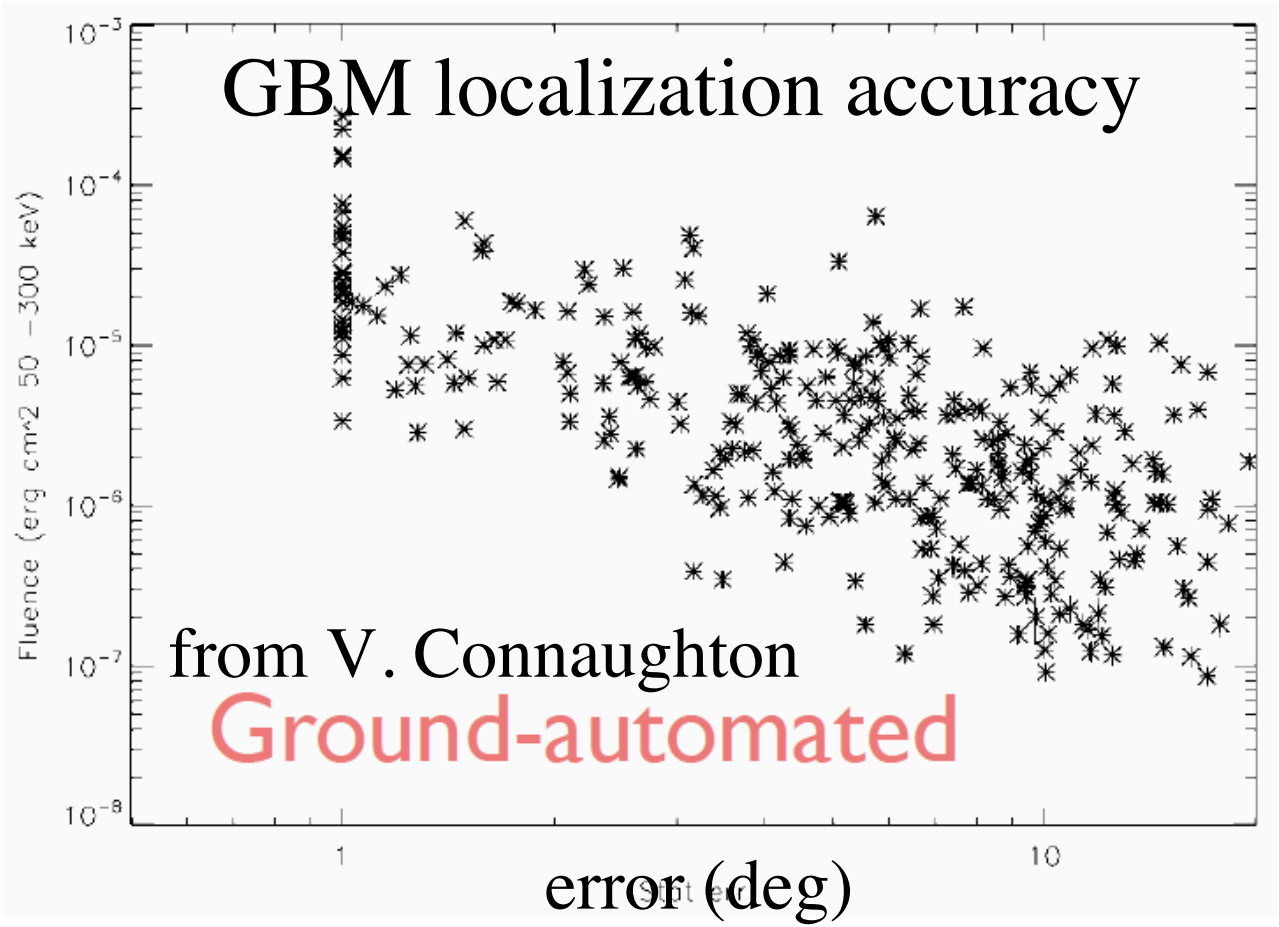


more questions

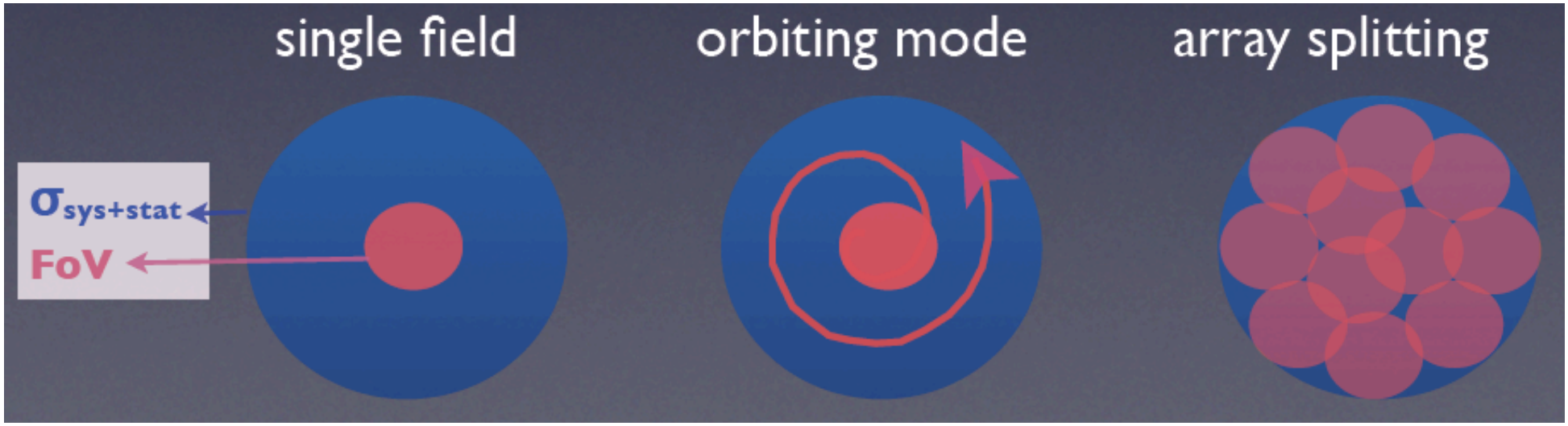
- Should MSTs/SSTs also be slewed?
  When, how many, how soon and how fast?
- How do we deal with large GBM error circles? Offset LSTs?
  -> under study by MC group
- How much can the duty cycle be increased under moonlight?
- How can we increase the alert rate?
  JANUS/Lobster -> GUNDAM?
  HAWC/LHAASO?
  CTA-dedicated satellite?
- Can we detect some (short) GRBs from t=0 during
  a wide-field survey mode?
- How can we obtain redshifts for all CTA GRBs?
  On-site optical/near-IR telescope? -> collab. with MOA?

...

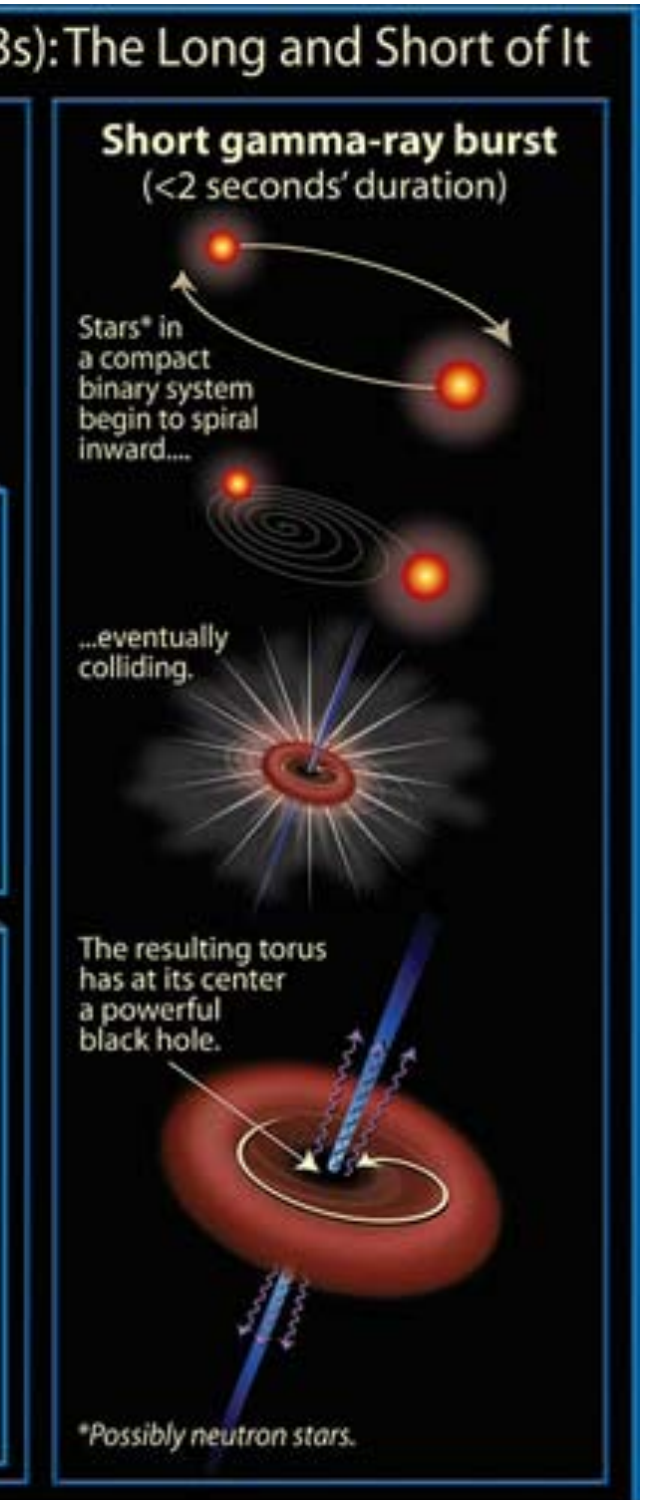
Fermi/GBM bursts with CTA



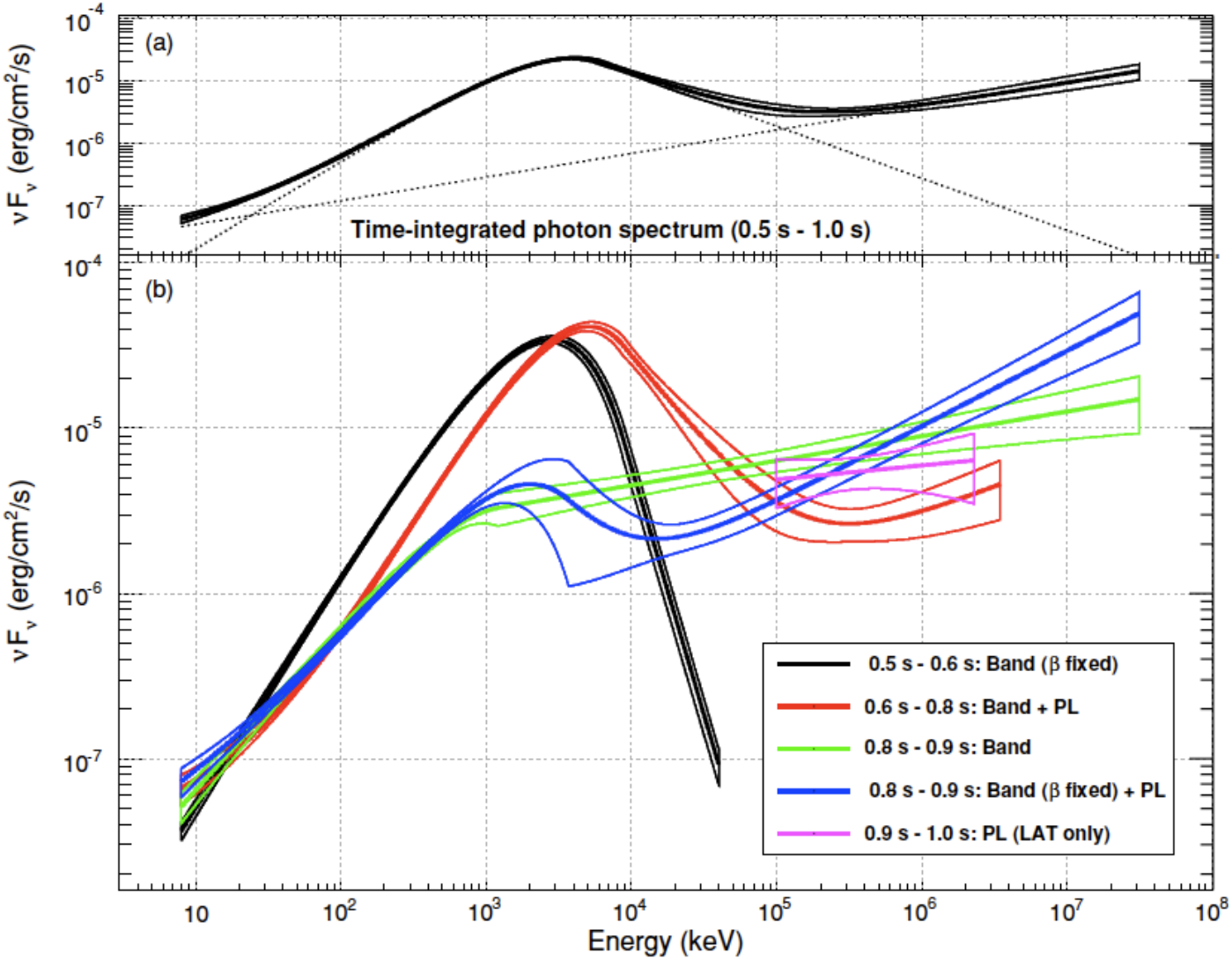
from A. Bouvier



short GRBs compact binary merger=GW source?

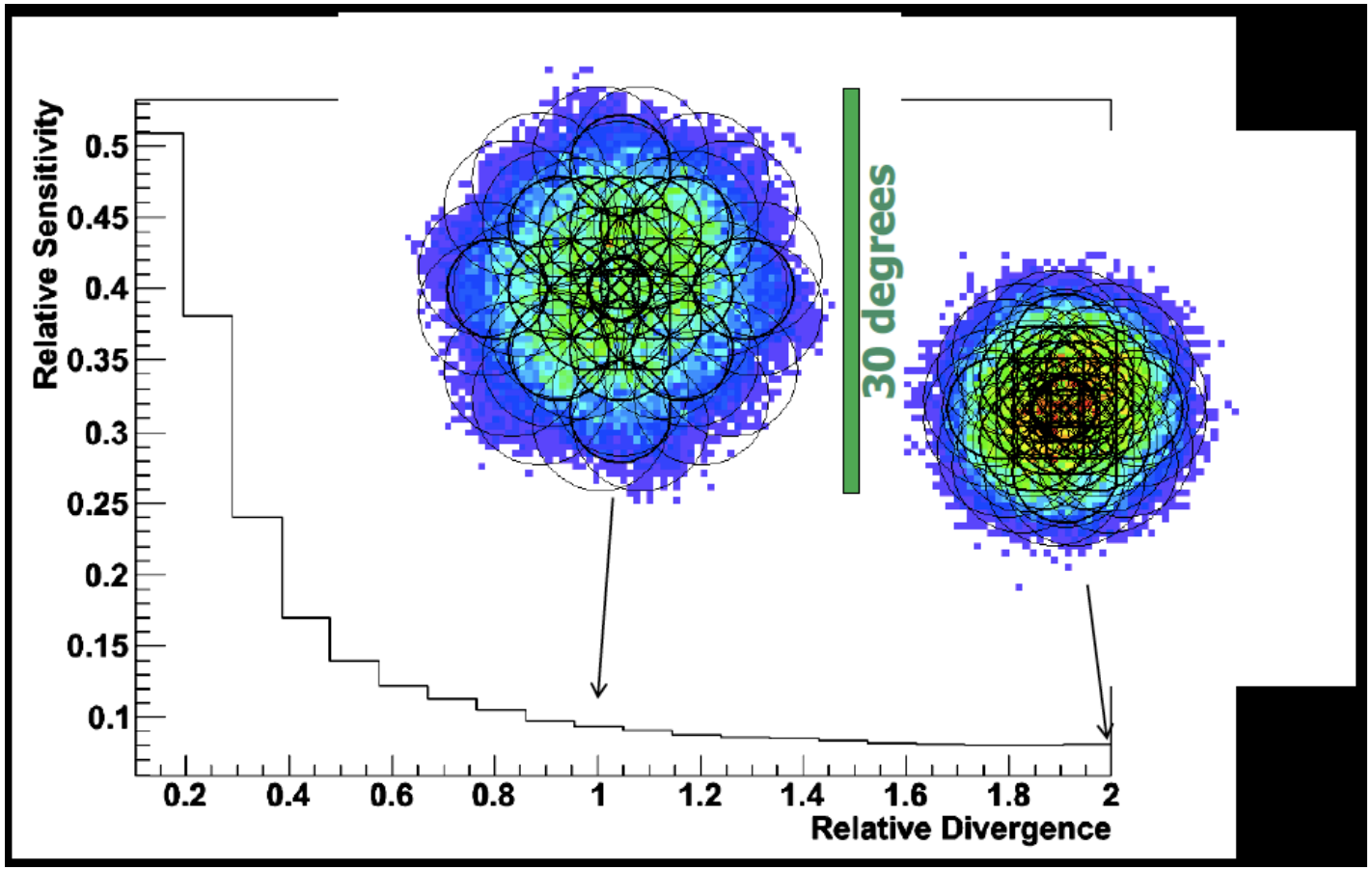


Fermi GRB 090510



Γ_{bulk}? emission mechanism?
CR acceleration? LIV test? -> CTA!

short GRBs with CTA: wide field mode?

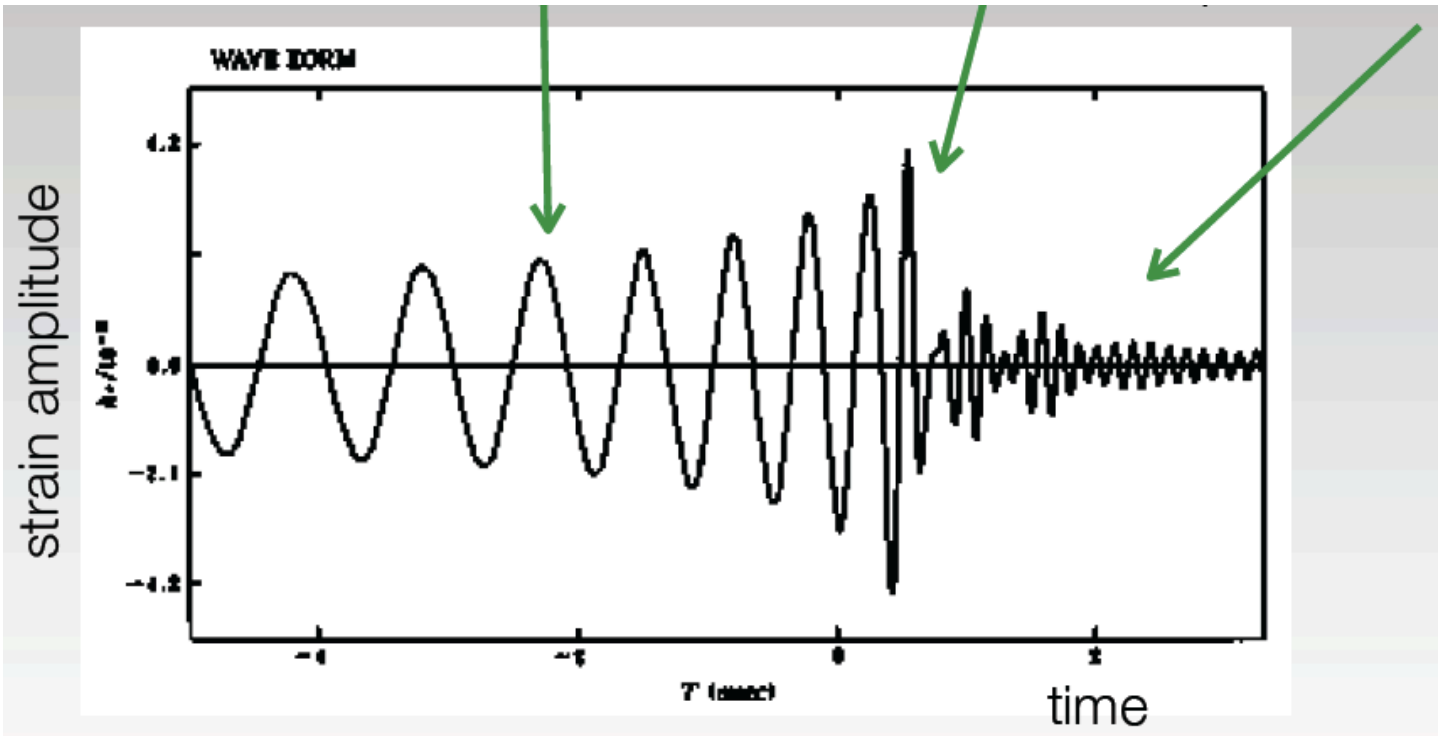


under study
by J. Hinton+

short GRBs
long GRBs from T=0
unbiased transient search

GRB detection rate ~<few/yr?

short GRBs with CTA: GW alert?



localization ~5 deg after merger

-> localize before+alert? inclination?

Bohdan Paczynski, on discovery of microlensing by MACHO: "It is a real tribute to the high-energy physicists, who did know that it cannot be done, so they did it."

まとめ　CTAによるGRB観測

- GRBは宇宙で最も謎めいた天体の一つ
  CTAによる>10 GeVガンマ線観測で新境地開拓
  大きな光子数統計

- 予想検出数は年間当たりGRB数発
  がGRB毎の詳細なスペクトル・時間変動データ

- 多様なサイエンス:
  GRBの起源、宇宙線の起源、観測的宇宙論、基礎物理学…

- 日本がサイエンスを主導:
  LST(大口径望遠鏡)チーム、MCグループと連携

- wide field modeによるshort GRB+トランジエント探査
- 重力波アラートによるshort GRB観測?