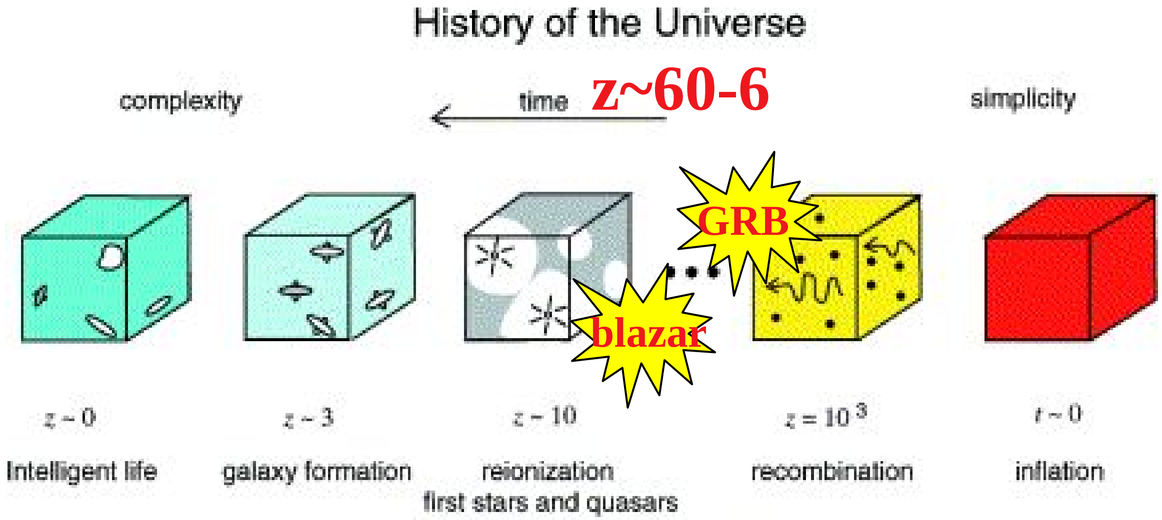
高エネルギー天体で探る初代星・銀河形成

GRB + blazar

井上 進（京大理）+共同研究者いろいろ

1. UV background
2. intergalactic magnetic fields
3. very first star (GRB)
4. dust

Fermi (GLAST)



first star epoch z~100-10

Pop 3 =metal/dust-free, H_2+HD-cooling

assume: no metal/dust, CR, B field, turbulence (DM annih.)

Pop 3.1 (1st generation) massive, high UV

1st HIIR (ion.+comp.) -> IGM reionization

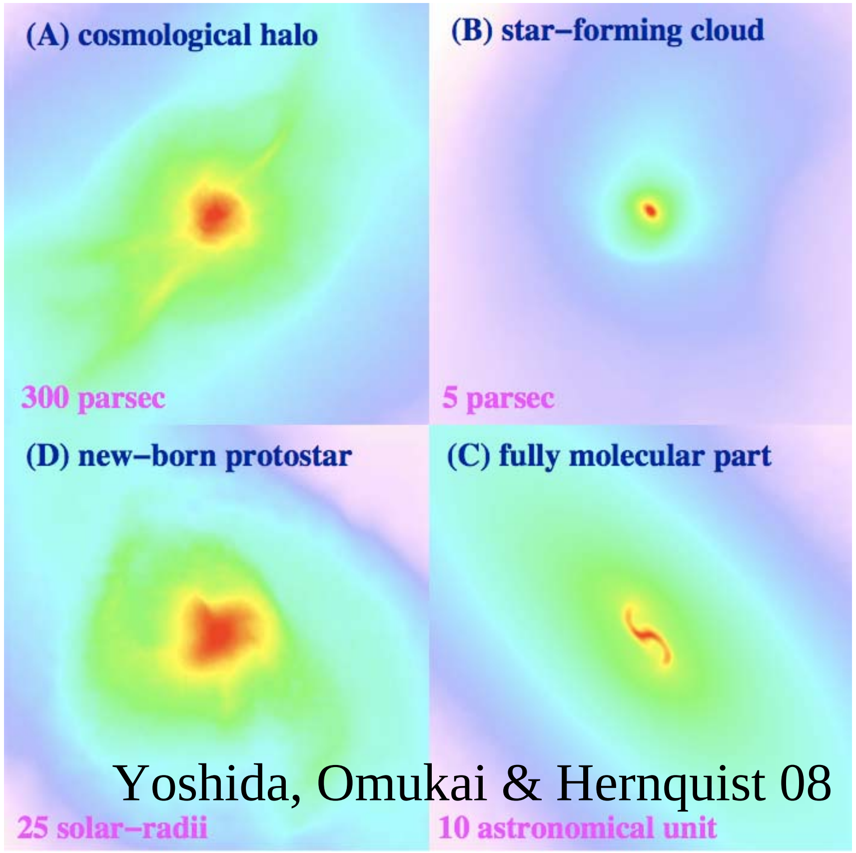
1st SN (ion.+comp.) -> 1st metal/dust (+CR+B)

1st BH -> 1st QSO

Pop 3.2 (2nd generation) not-so-massive?

Pop 2 =metal/dust-cooling

1st sun -> 1st planet, life, human!



Yoshida, Omukai & Hernquist 08

観測ほとんど皆無
=理論屋の天国

1st gen.はわかったつもり
2nd gen.研究に移行

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arXiv:0808.0472

dark stars???

first protostarの中心部でダークマターが対消滅し熱源になり形成・進化の描像がかなり変わるかも

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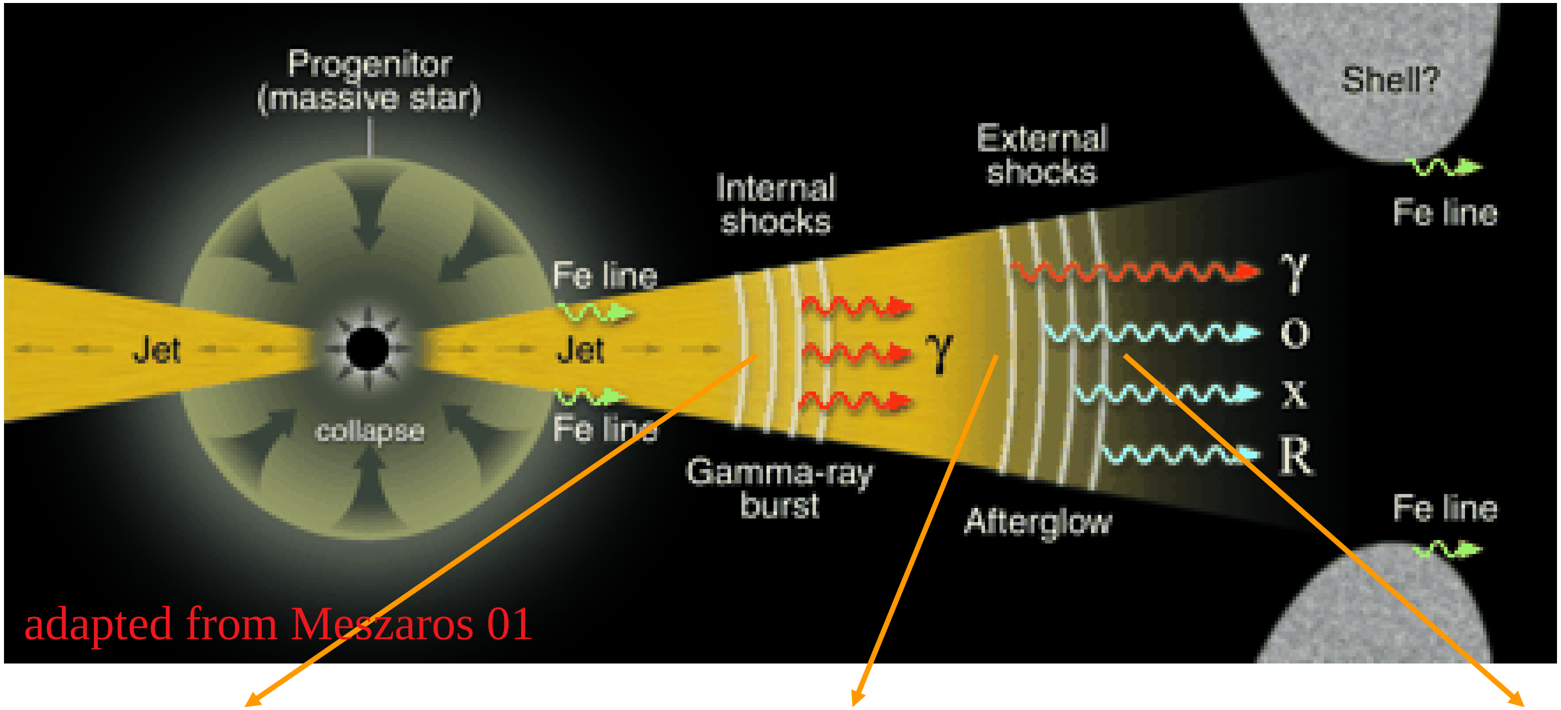
最近多くの人が悪のりして小流行

観測が全くないとこんなこともまかりとおる
GRBを使って鉄槌を下すべし

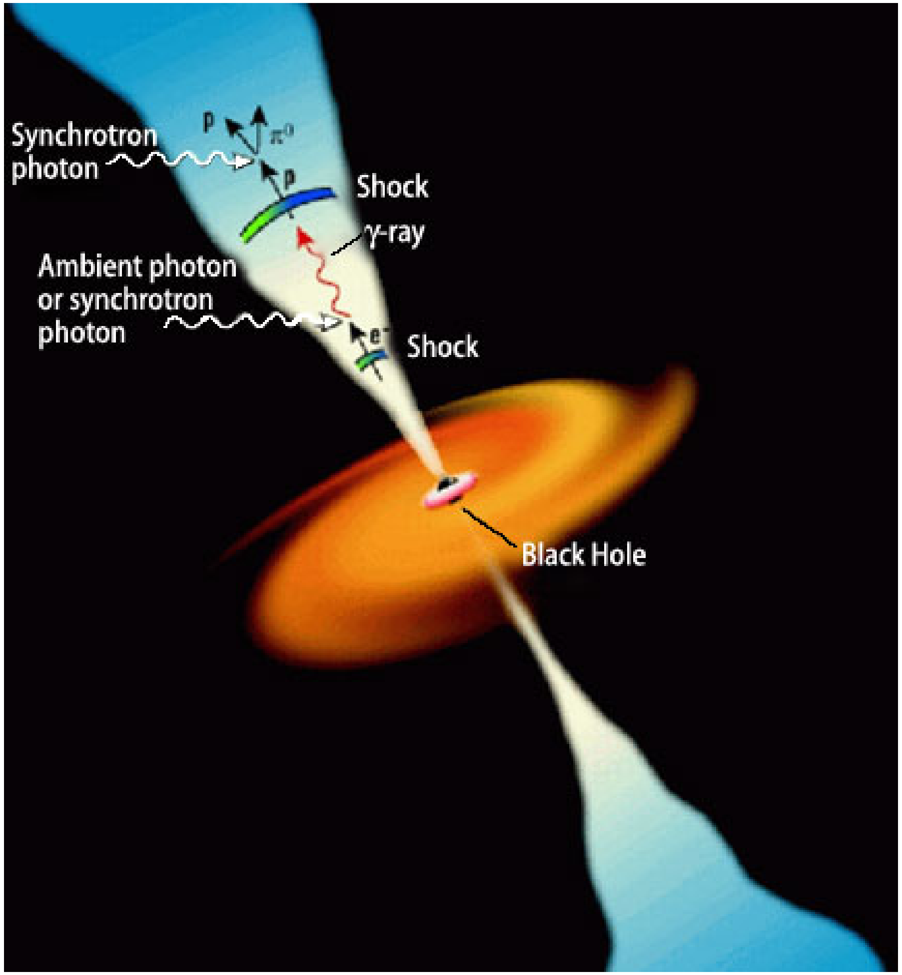
gamma-ray bursts ultrarelativistic outflow+shocks

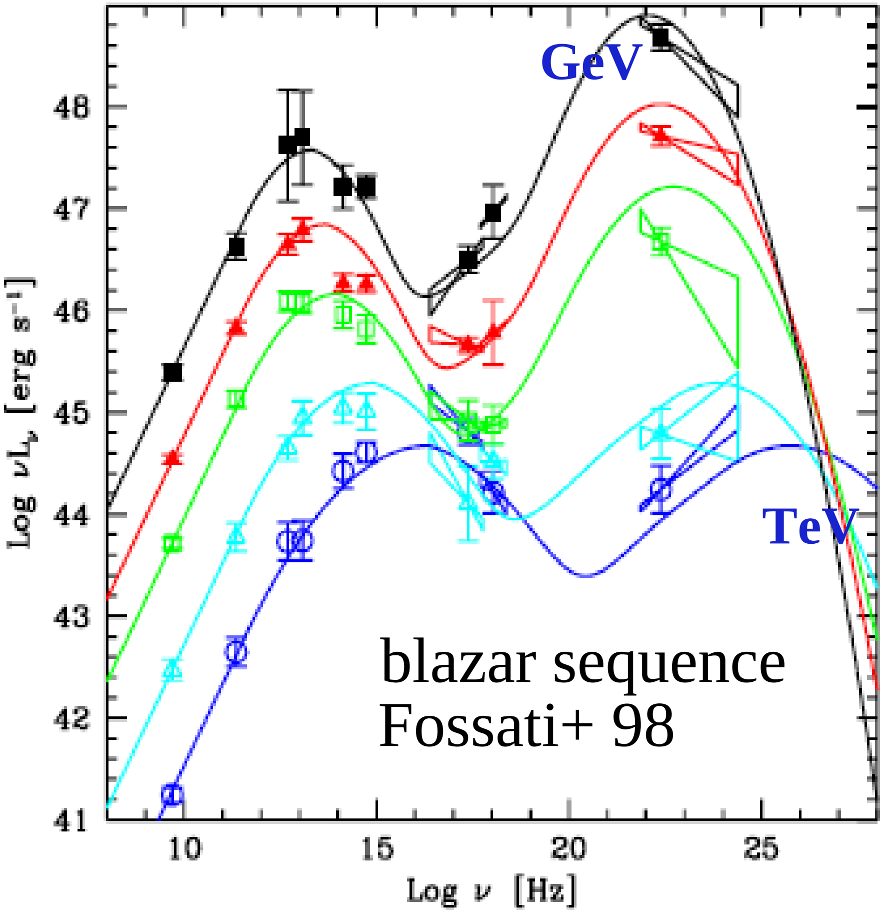


prompt X-γ emission — optical flash, radio flare — radio-IR-opt-X afterglow

internal shocks — **external reverse shock** — **external forward shock**

blazars relativistic jet+internal shocks





1. gamma-ray absorption: probe of diffuse radiation fields

$\gamma + \gamma \rightarrow e^+ + e^-$

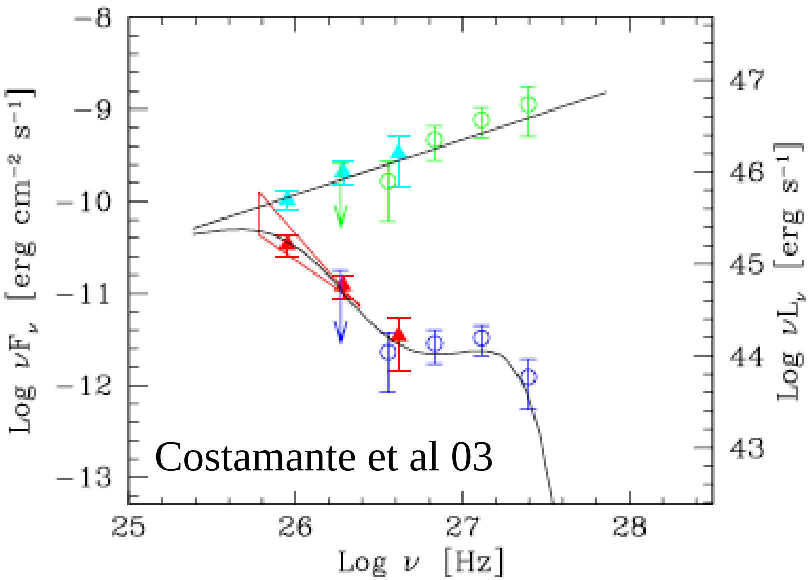
E $\quad \varepsilon$

threshold condition: $E\,\varepsilon\,(1-\cos\theta) > 2\,m_e^2c^4$

σ peak ,, $= 4\,m_e^2c^4$

e.g. TeV + 1eV (IR)

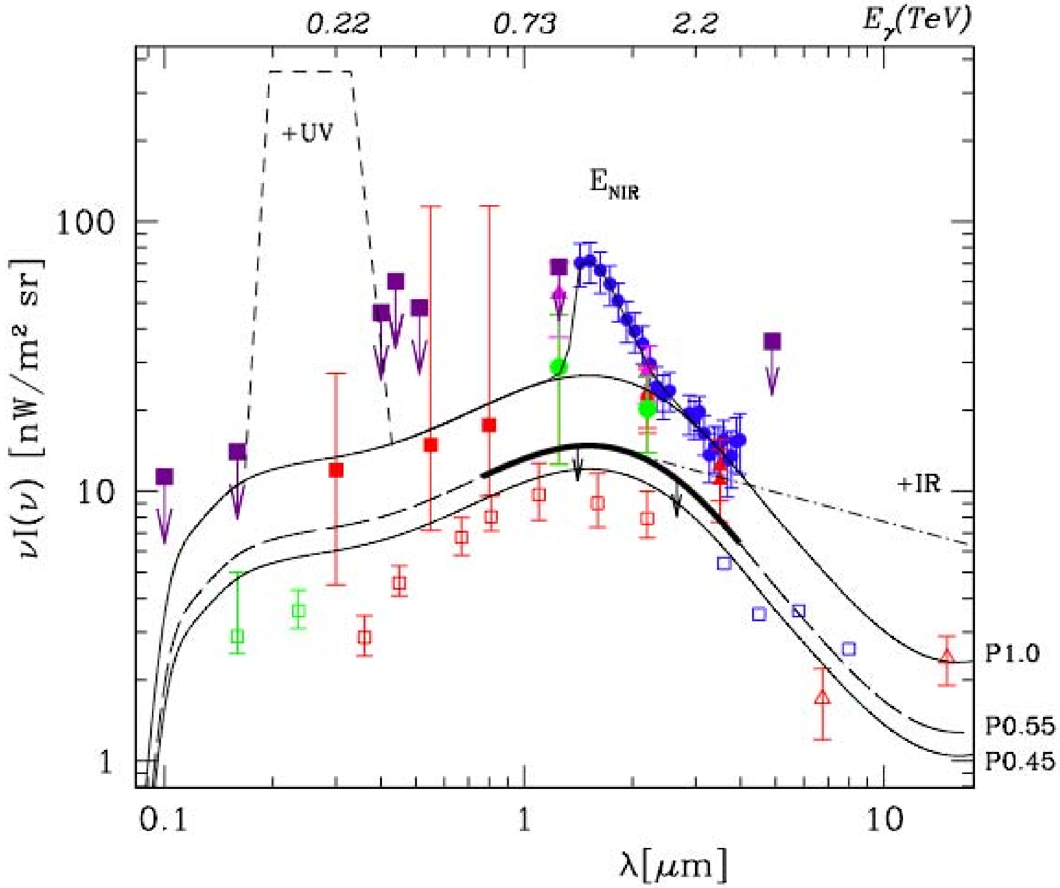
100 GeV + 10 eV (UV)

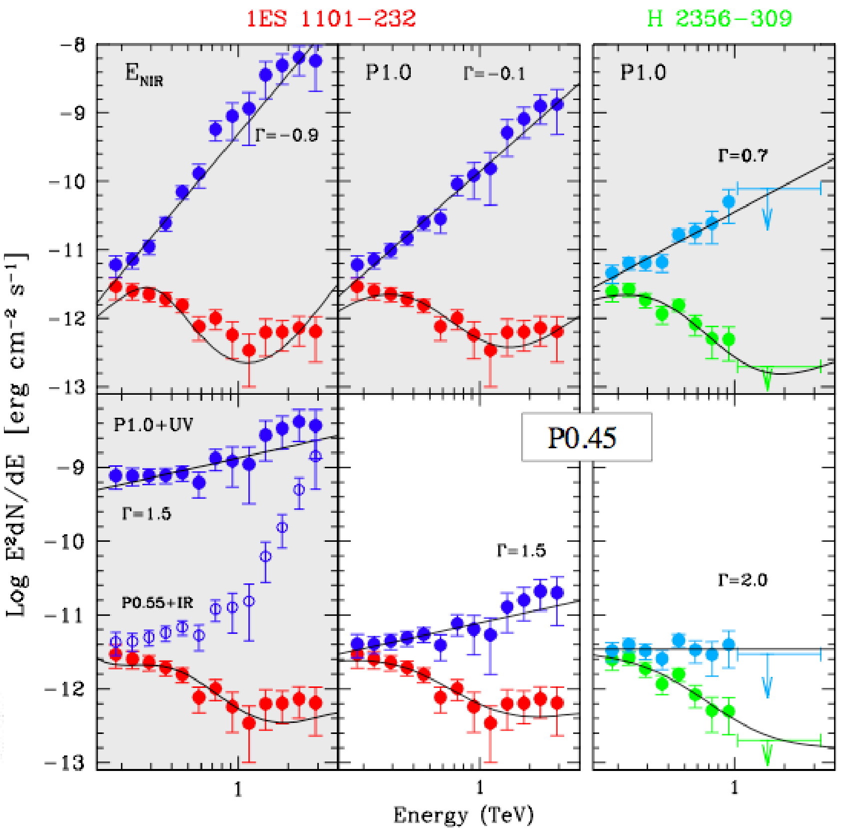


probe of local IRB through gamma absorption in TeV blazars

probing local IR background with gamma-ray absorption

HESS observations of TeV blazars @z=0.165, 0.186
Aharonian+ 06 Nat.





- **strongly rules out NIR peak** no strong Pop III
- **little "missing light"**

gamma-ray absorption at higher z

Albert+ 08 Sci.

MAGIC observation
80-500 GeV
3C279 @z=0.536

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$E_\gamma(\tau=1)$

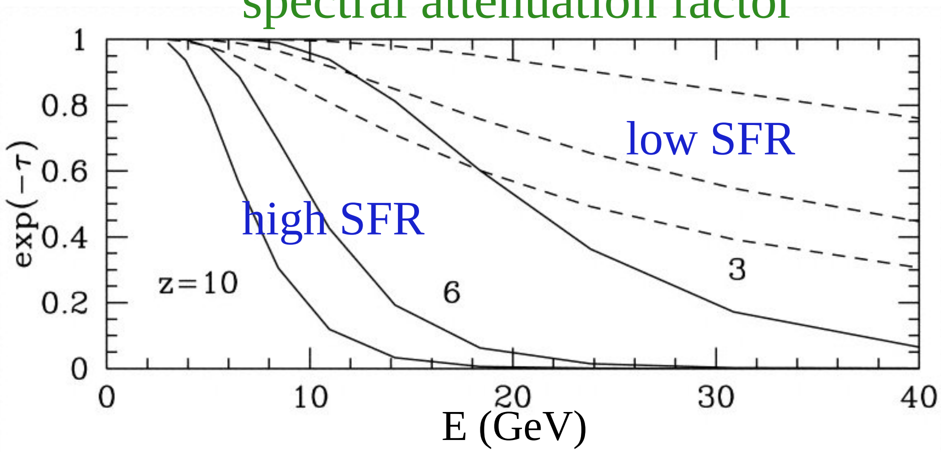
まともなblazarのスペクトル（α>1.5）なら
銀河カウントからの下限値に近い（missing lightは少ない）

gamma absorption at very high-z (reionization epoch)?

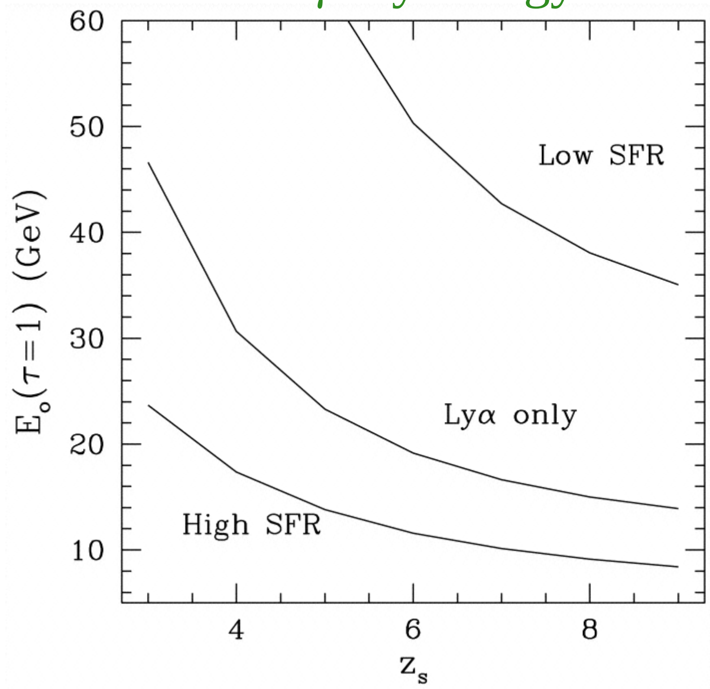
Oh 2001 ApJ 553, 25 (also Madau & Phinney 96)

reionizing radiation fields should induce ~10 GeV absorption

spectral attenuation factor



τ=1 γ-ray energy



pre-WMAP z<10 only, no Pop III

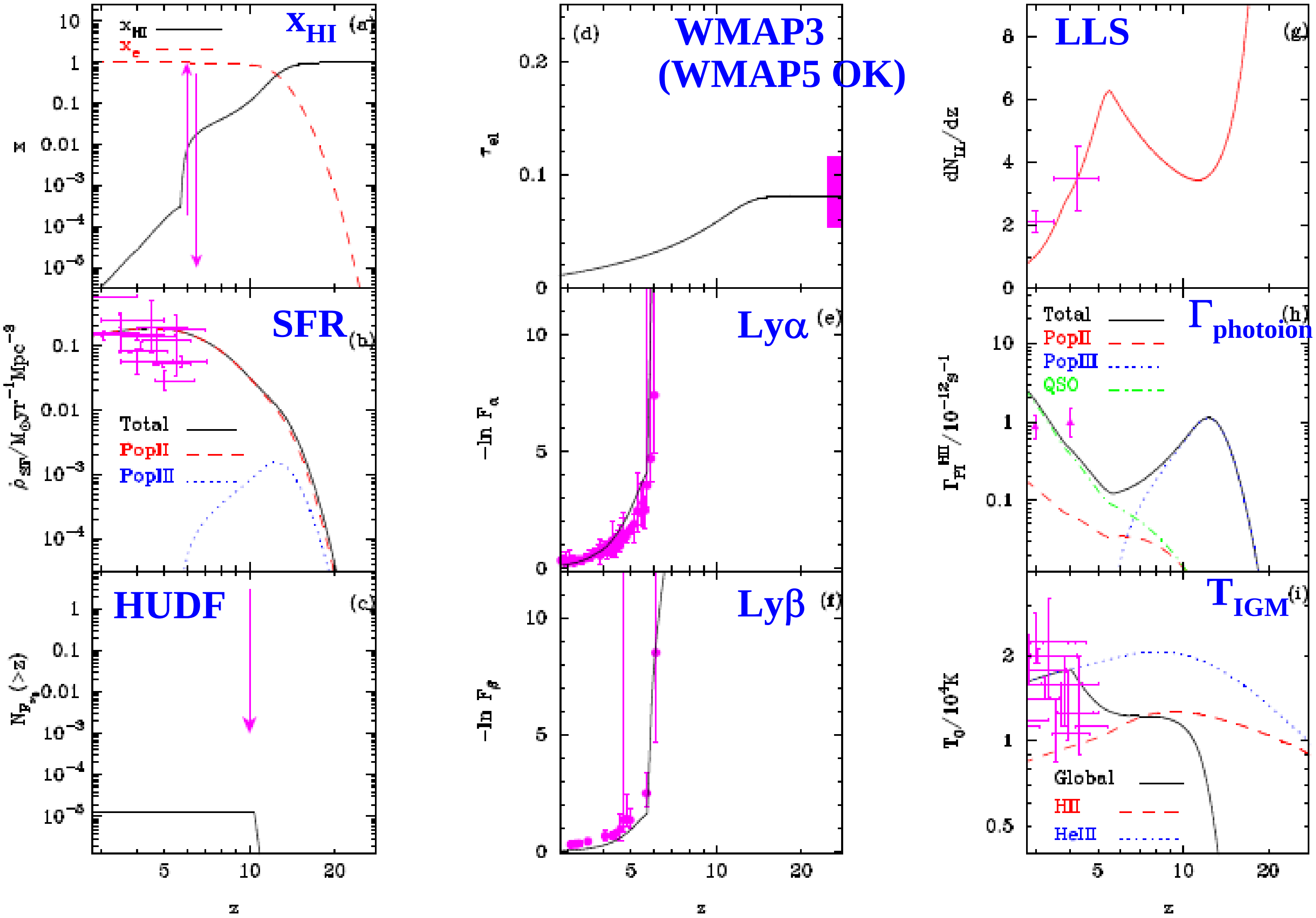
- reionizing radiation much better constrained now
- z>10, effect of Pop III not well explored

high-z UV radiation fields from cosmic reionization model

Choudhury & Ferrara 05, 06

semi-analytic treatment with radiative+chemical feedback   parameters ϵ_{*II}, ϵ_{*III}, η_{esc}, λ_{0IGM}

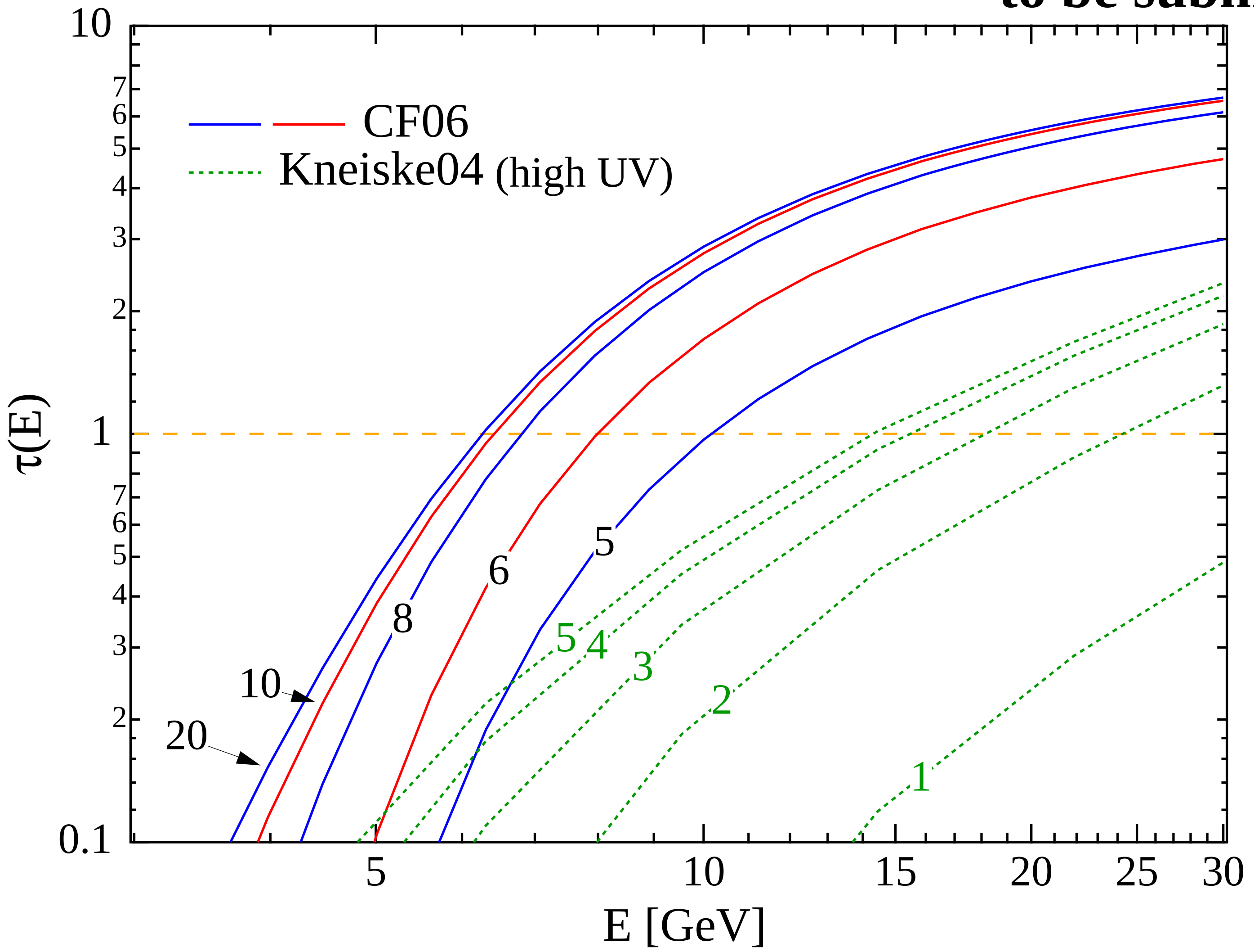
consistent with large set of high-z observations inc. WMAP3, x_{HI}, HUDF NIR counts, etc.



reionization begins z~15
90% z~10
100% z~6

pair absorption optical depth

SI, Salvaterra, Choudhury, Ferrara, Schneider, Ciardi to be submitted

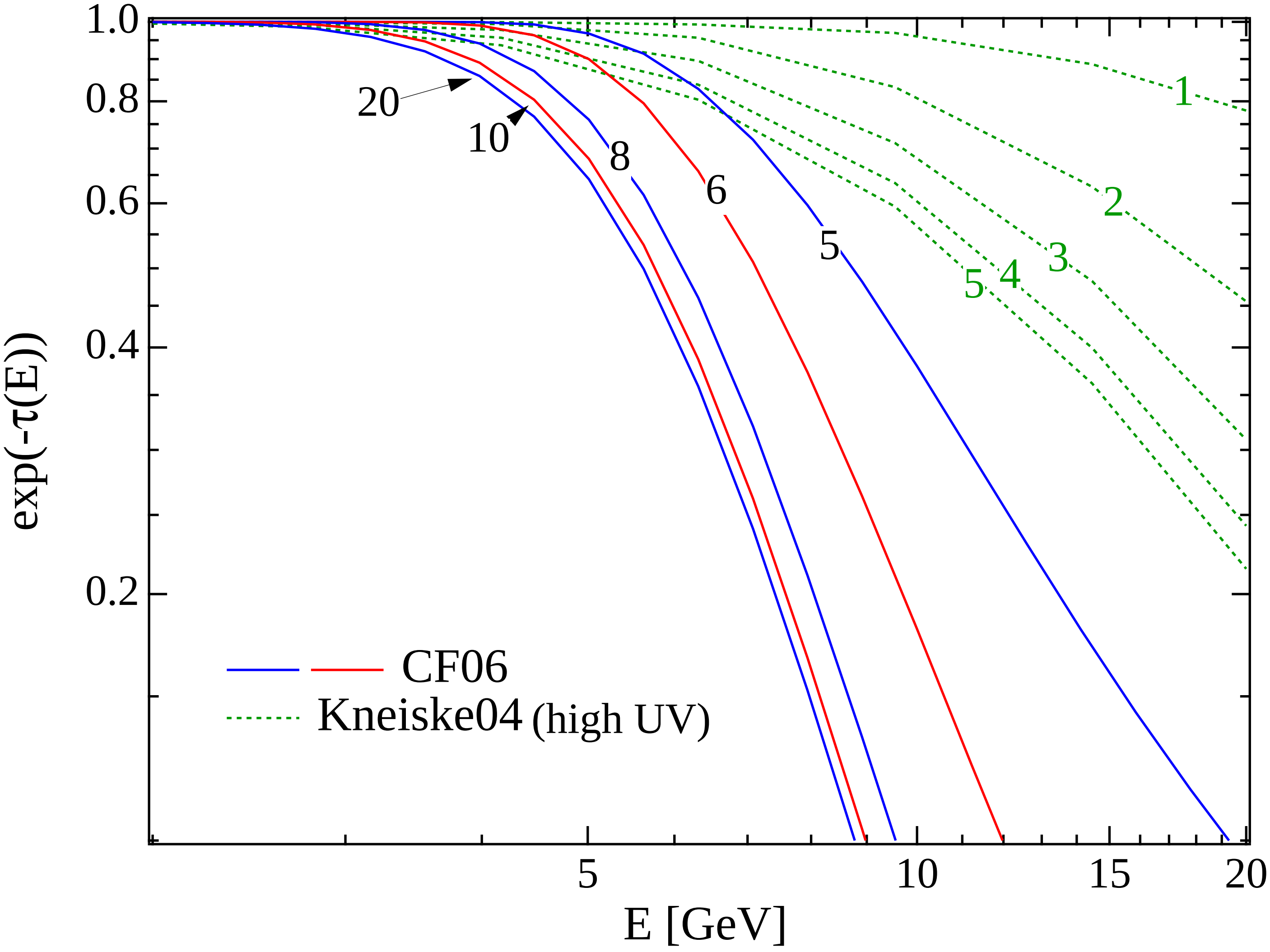


low z (0<z<5) model
Kneiske et al 04
(high stellar UV)

significant optical depth from z~5-8 at several GeV

but not much effect z>~8 due to declining star formation, time interval

pair absorption attenuation factor



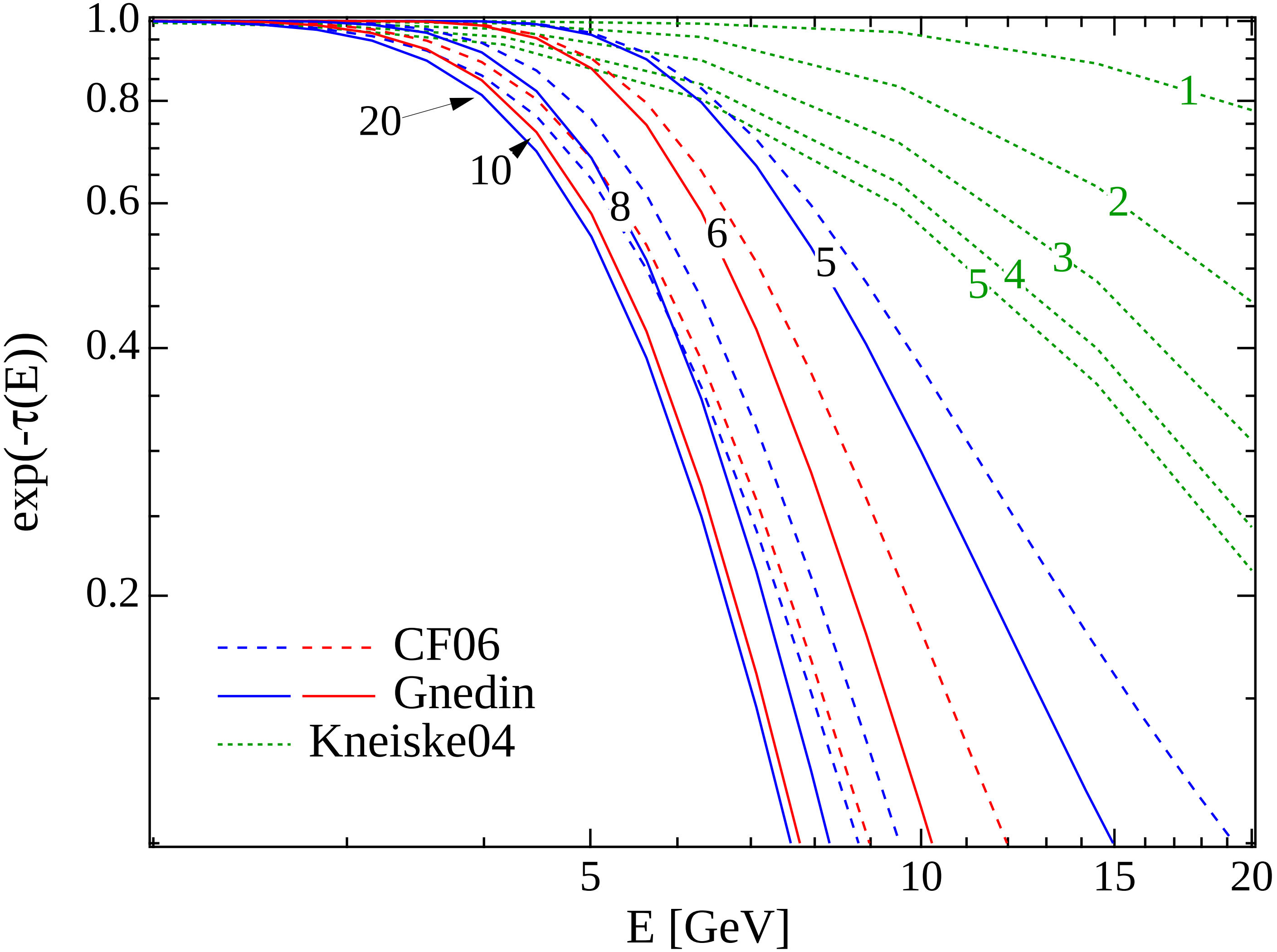
low z (0<z<5) model
Kneiske et al 04
(high stellar UV)

GLAST, 5@5

appreciable differences in cutoffs between z~5-8 at several GeV
→ unique, important info on evolution of UV at reionization epoch

different reionization models

different Pop III efficiency, IMF, escape fraction, etc.



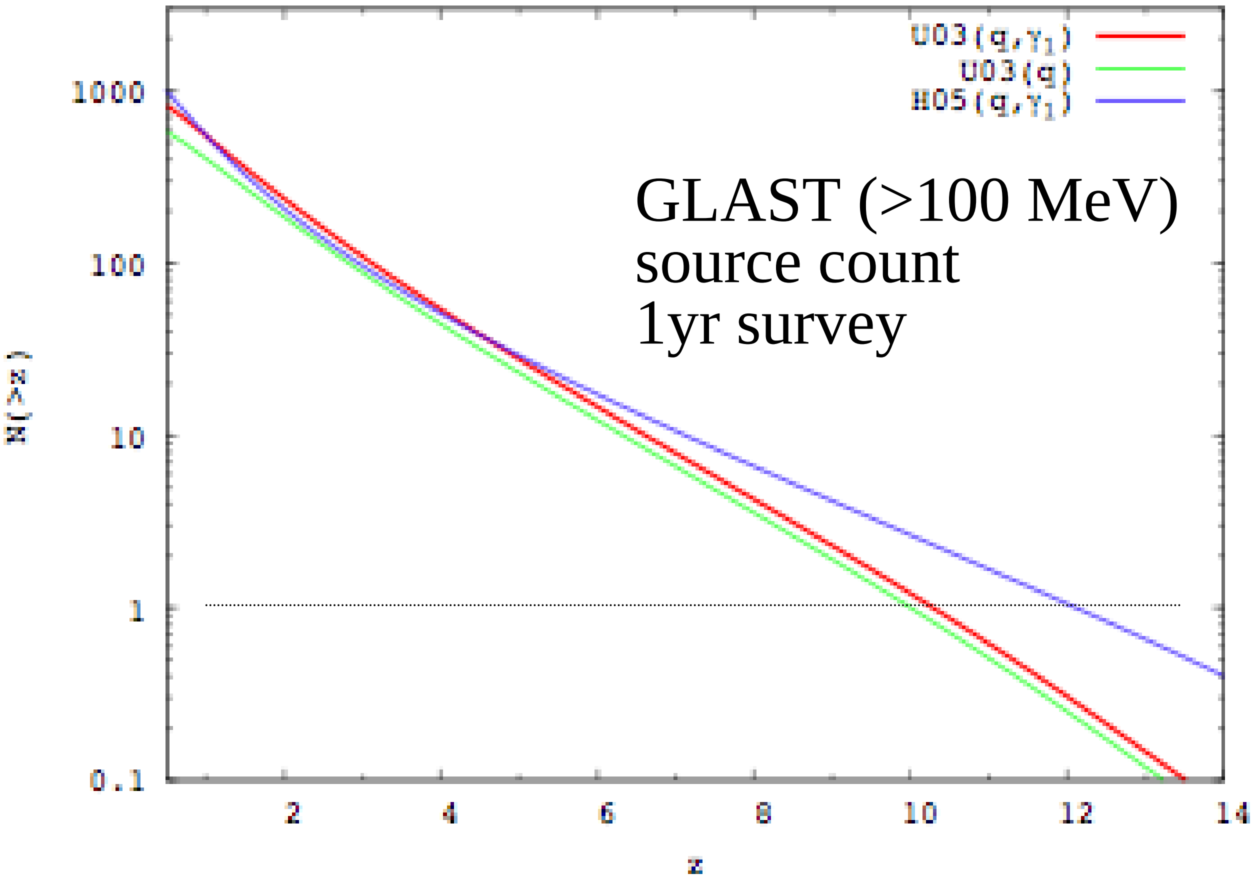
more realistic (Gnedin) model of radiative feedback

only slight differences

→ cutoff predictions robust? → useful as redshift indicators?

very high-z blazars: detectability

Y. Inoue, SI+ (?)

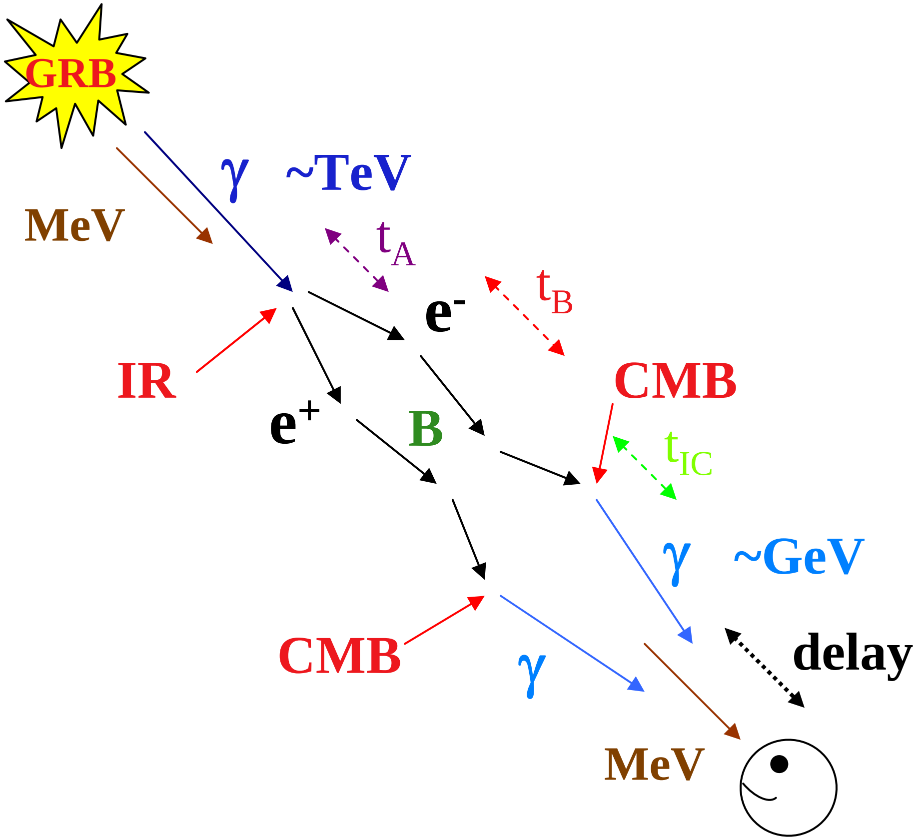


appreciable number at z~6-10!

blazar evolution model (Y. Inoue & Totani, in prep.)
- blazar sequence
- L-dependent density evolution (cosmic downsizing) up to z~5
- EGRET observations

extrapolation to high-z

2. "pair echos" (delayed secondary emission) probe of intergalactic magnetic fields



Plaga 95

sensitive to very weak intergalactic magnetic fields

Ichiki, SI, Takahashi
ApJ 682, 127

new formulation

distinguish coherent or random B

dependence on coherence length

intergalactic magnetic fields in voids

very weak primordial or high-z B fields could have survived
"intergalactic archaeology"

n_{HI} **B**

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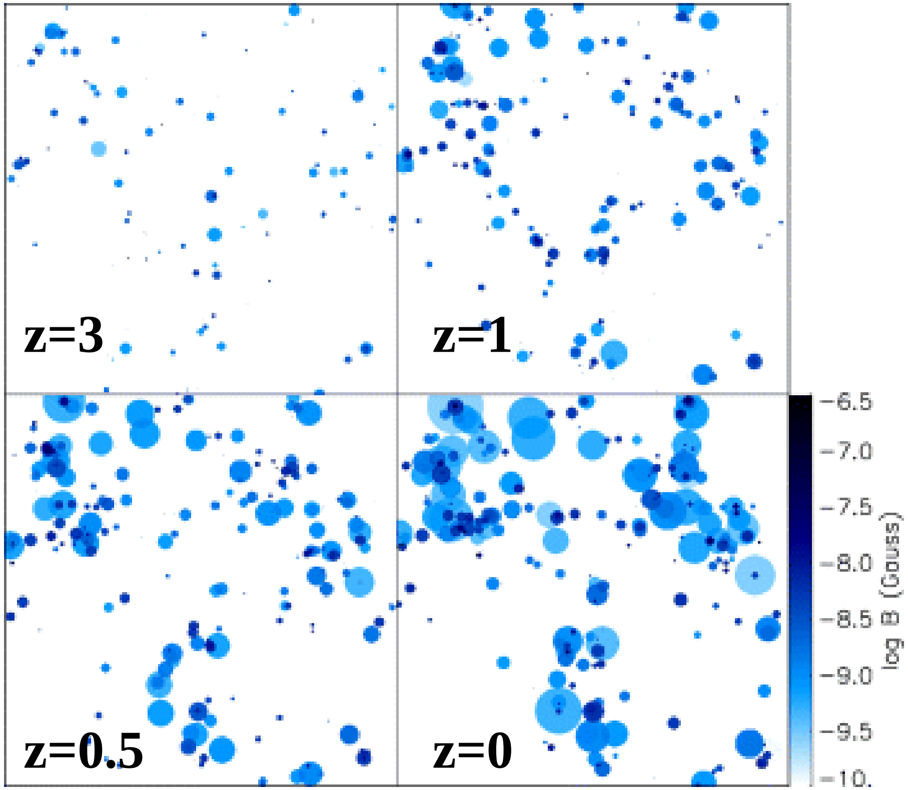
n_{gas} **T**



Gnedin+ 00

Bertone+ 06

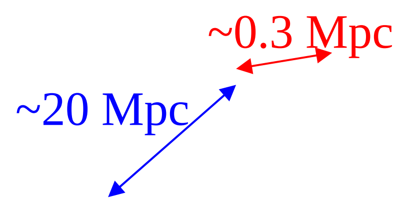
B generation by Biermann battery
at high z reionization fronts
$B \sim 10^{-20}$-10^{-18} G

B seeding by Galactic winds
quasar outflows
Furlanetto & Loeb 01

probing intergalactic magnetic fields with “pair echos”

Ichiki, SI, Takahashi

ApJ 682, 127



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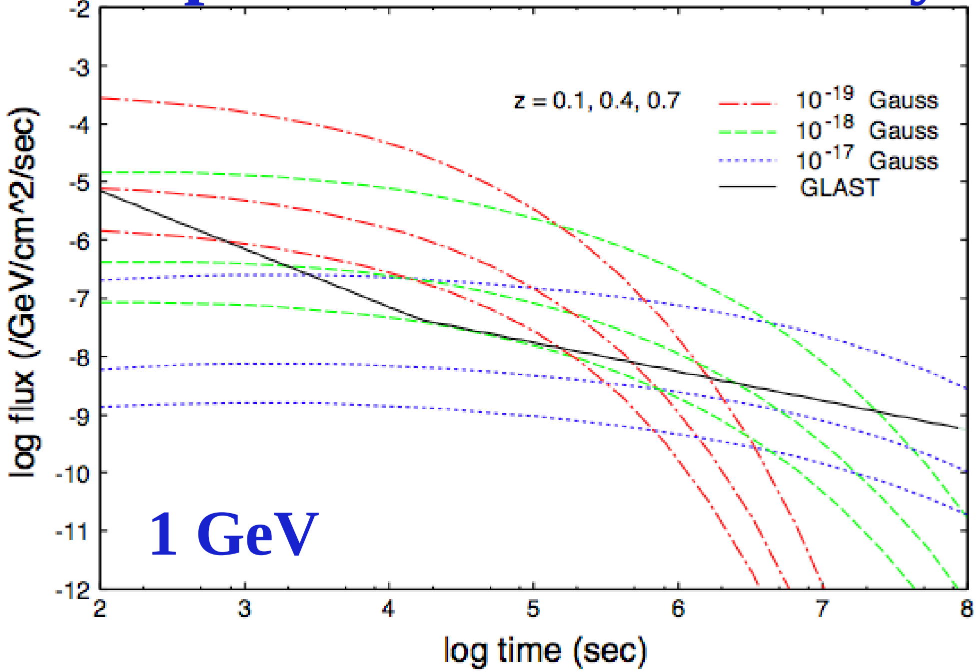
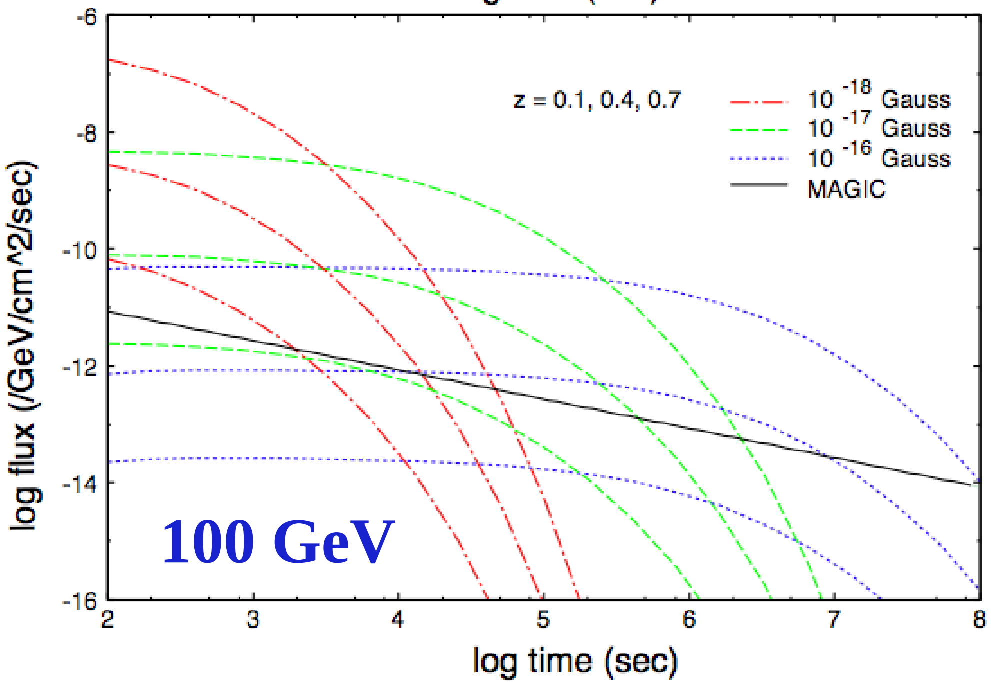
$B=10^{-18}$ G, l_c=100pc
E_{max}=10 TeV

important difference
for coherent/random fields

GRB pair echos: detectability





Takahashi, Murase, Ichiki, SI+
arXiv:0806.2825

detectable out to z~<0.7

pair echos from TeV blazar flares

Murase, Takahashi, SI, Ichiki+

ApJL in press (arXiv:0806.2829)

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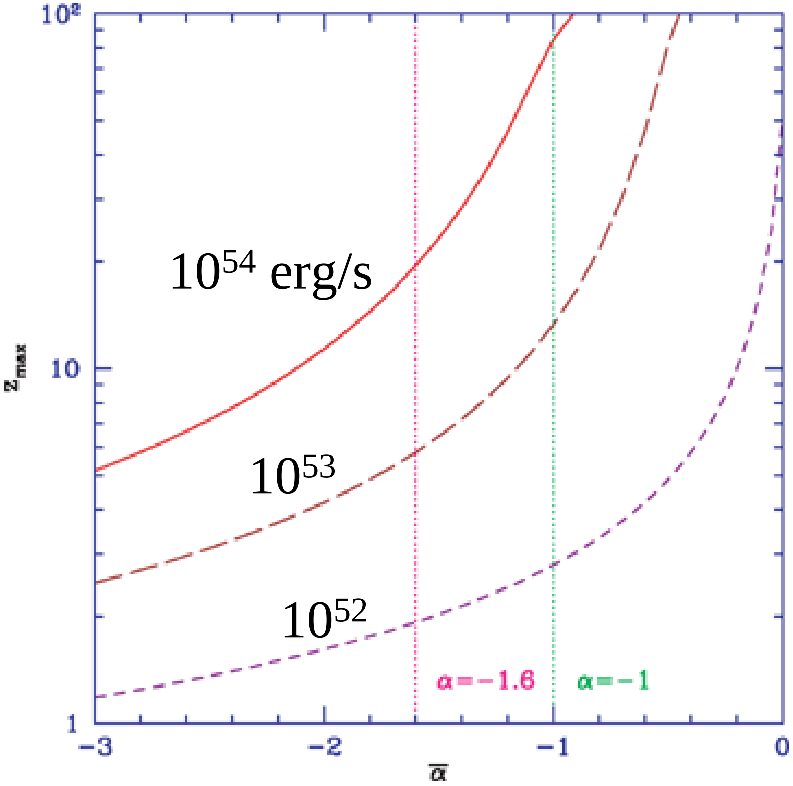
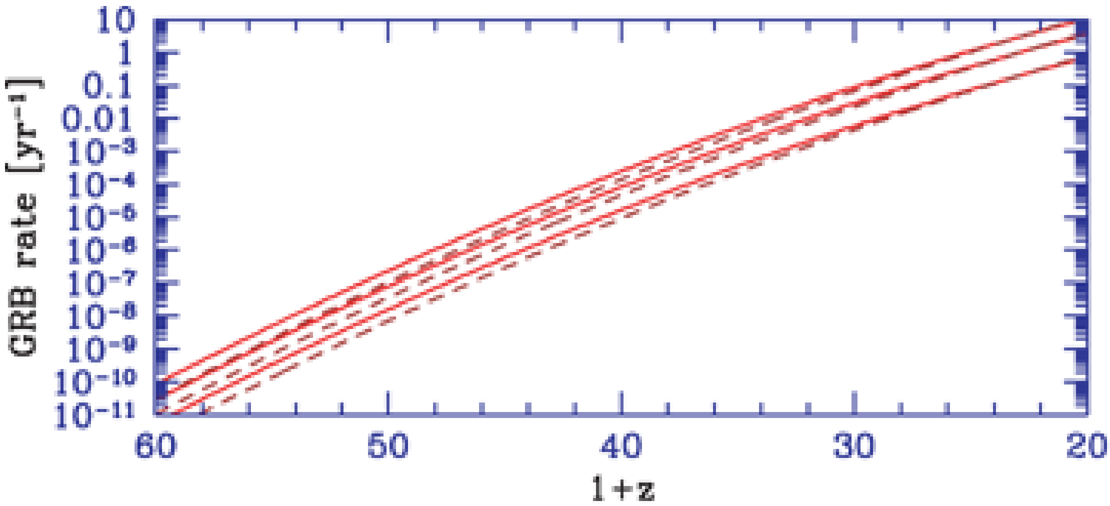
Mrk 501 flare

3. The very first "GRB": characteristic signatures at z~30-60?





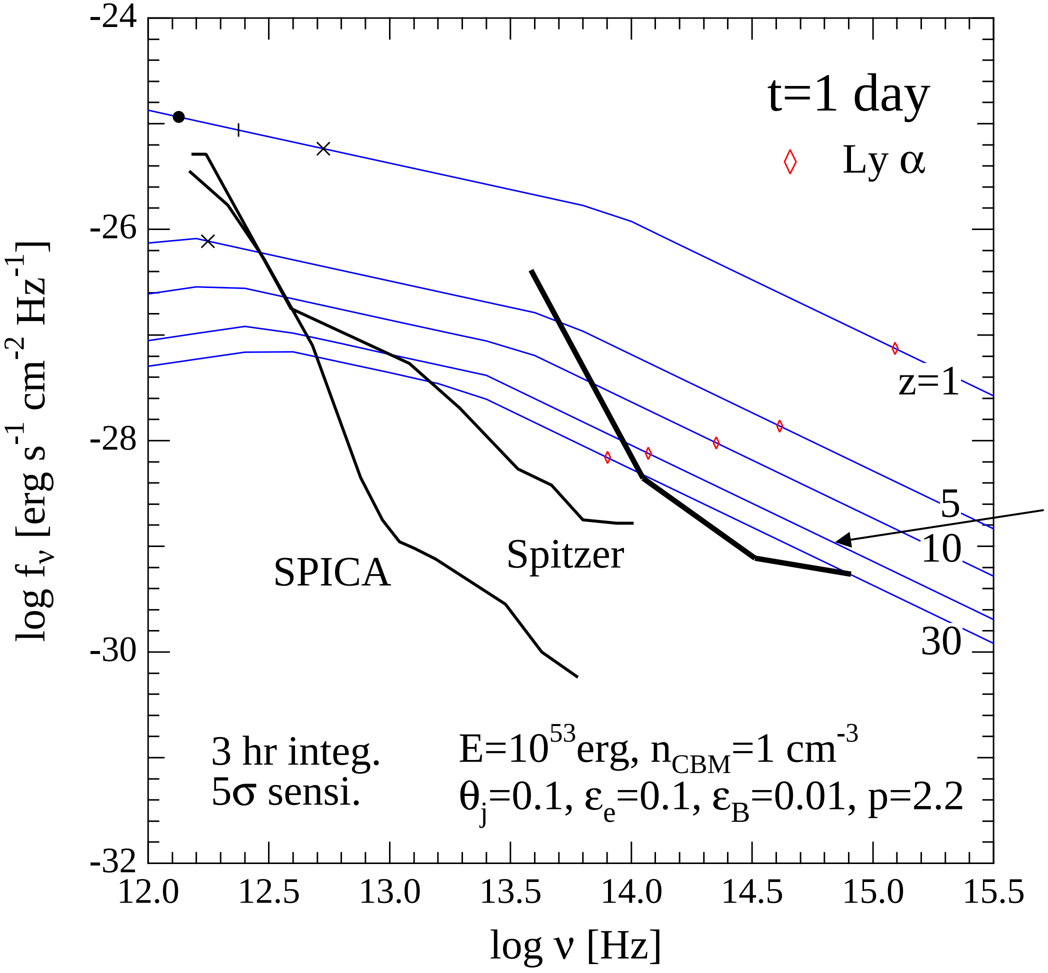
Naoz & Bromberg 07

peak energy ~10 keV (XRF)
long duration ~1000s

宇宙の一番星を見つけるには？

high-z GRB afterglows in IR

c.f. SI, Omukai & Ciardi 2007 MNRAS 380, 1715

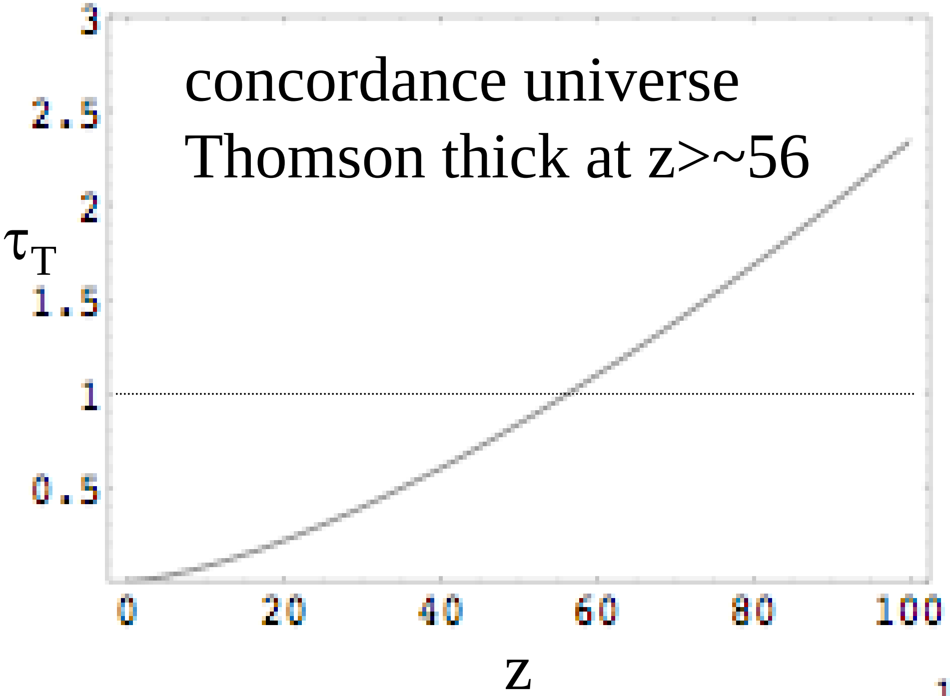


Subaru (ground) only up to z~17

Ly break >3-7 μm SPICA, JWST

Compton attenuation

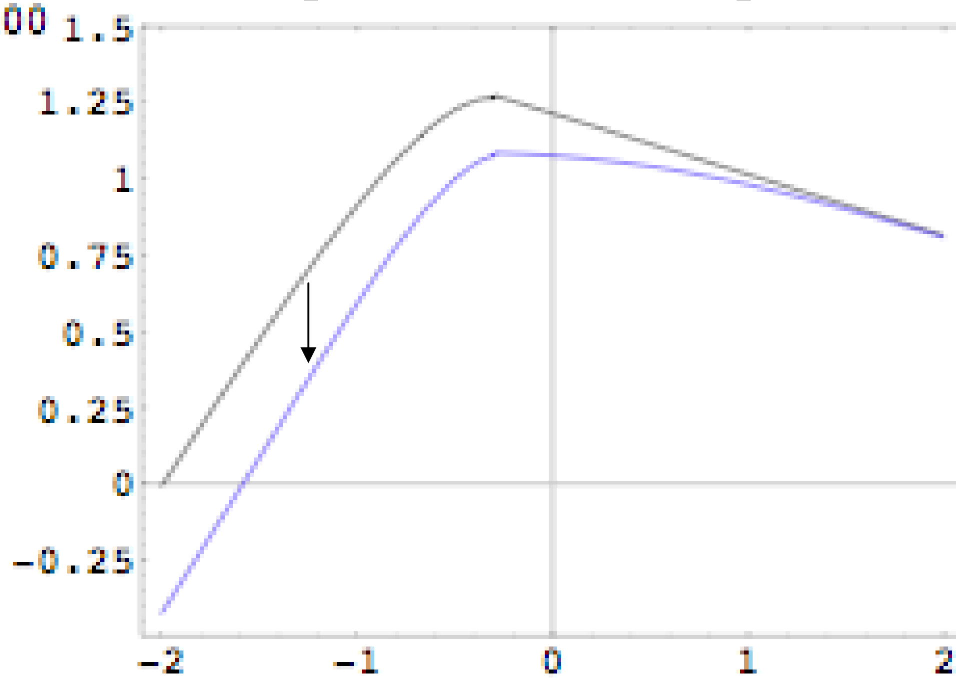
SI, Nakamura+ (?)



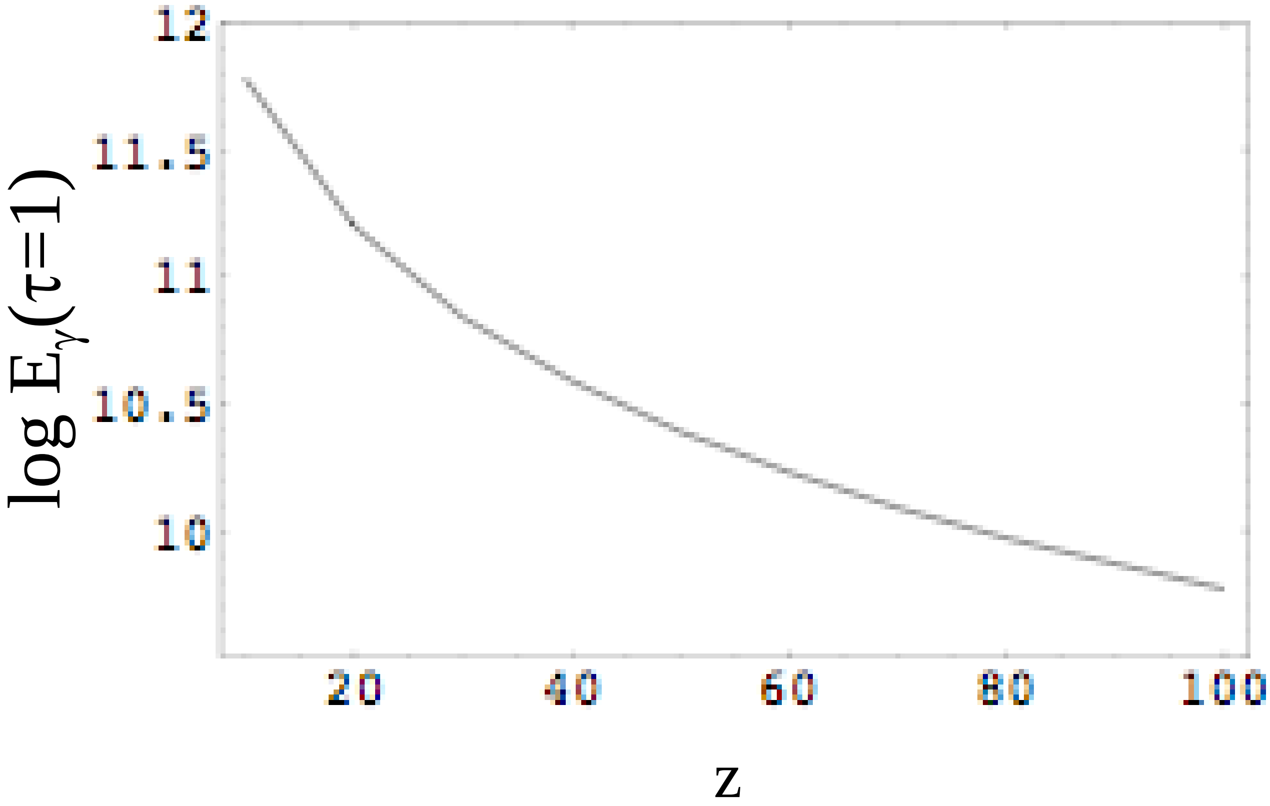
E>~keV indep. of ionization

E>~MeV Klein-Nishina decline

Compton attenuated spectrum



gamma absorption by high-z CMB?

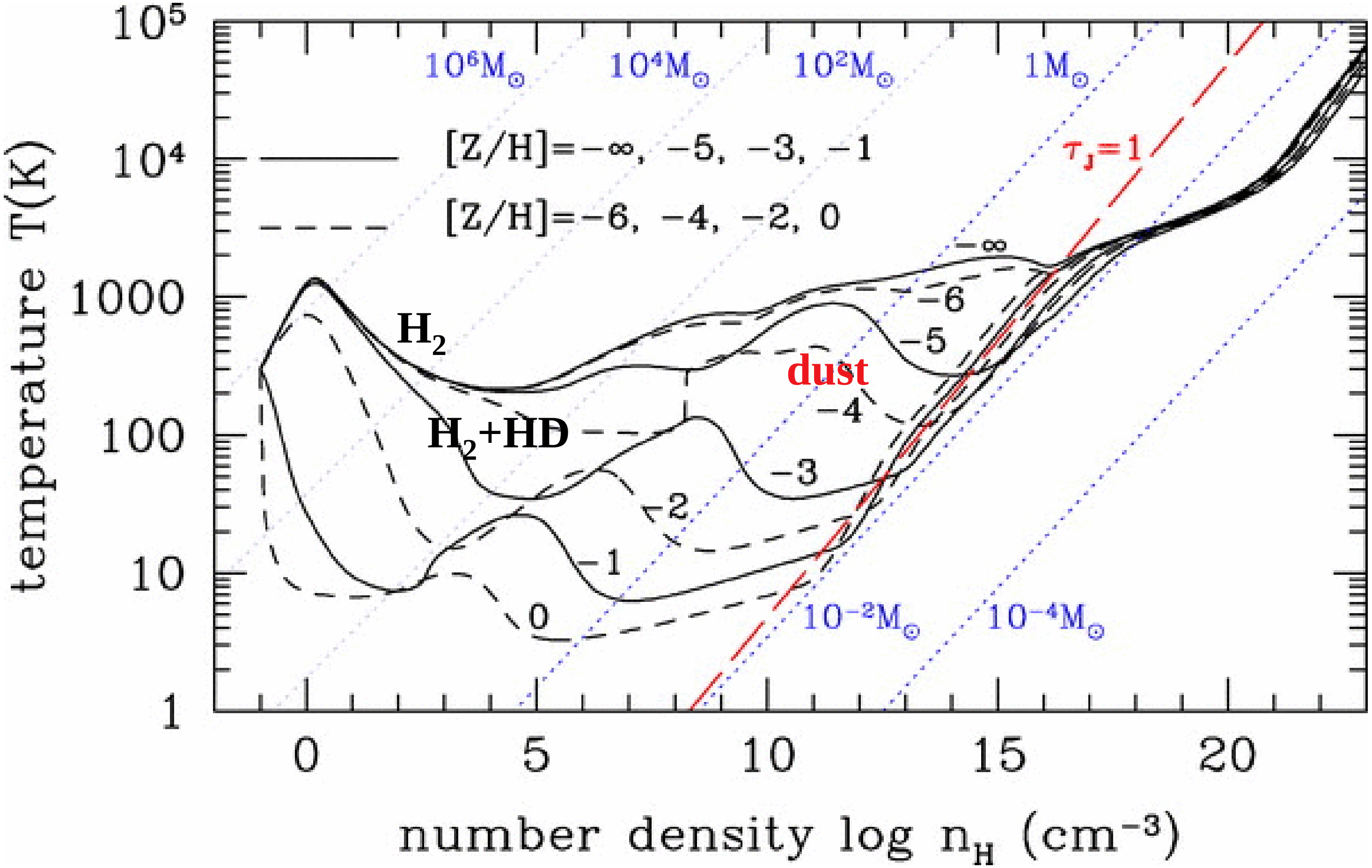


4. first dust   Pop 3 → Pop 2 transition

Omukai+ 05 model

collapsing zero/low-metal clouds
- 1-zone, simplified dynamics
- detailed chemistry inc. HD+metals+dust

T minimum -> fragmentation

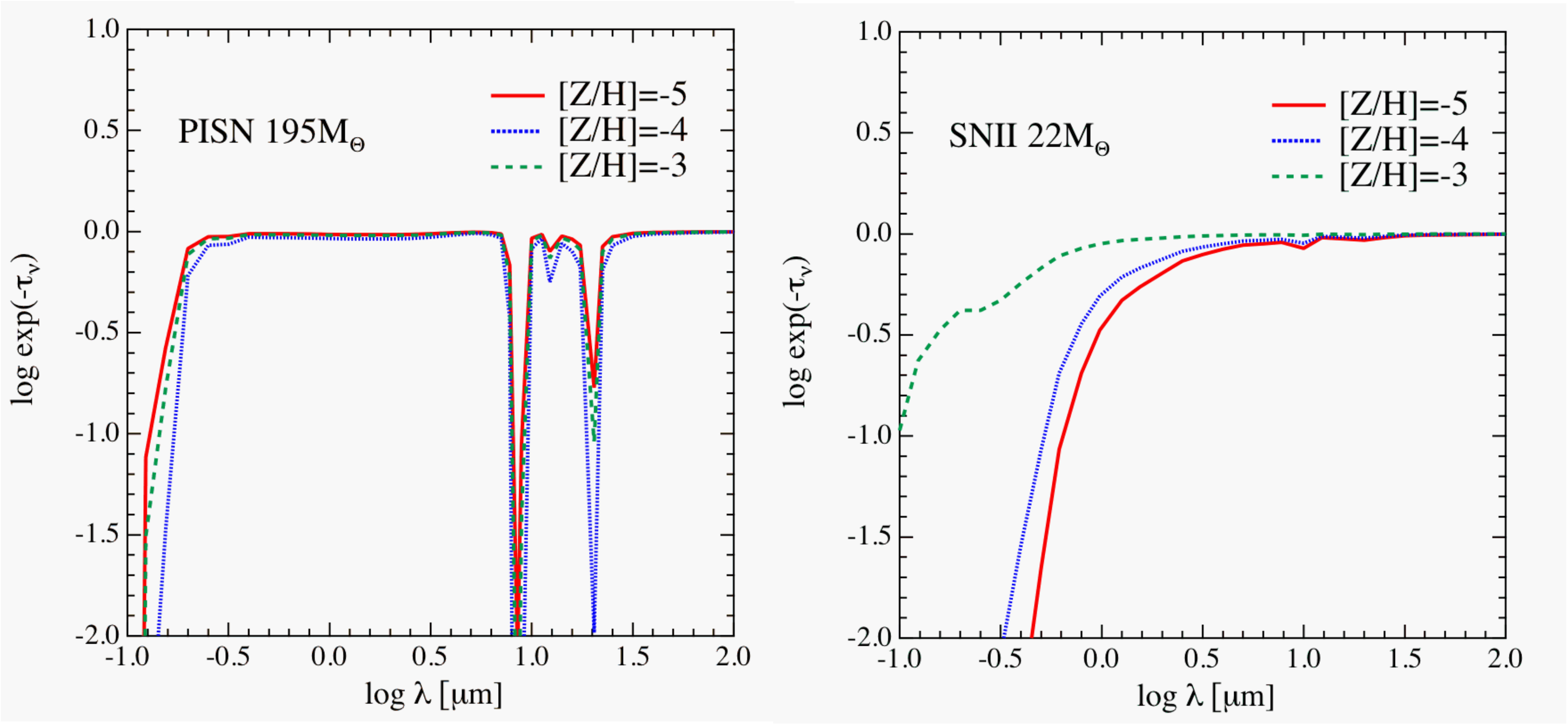


[Z/H]<-6: M_{frag}~$10^3 M_\odot$ **Pop 3**

-3<[Z/H]<-5: M_{frag}~0.1-100$M_\odot$ **Pop 2!**

$[Z/H]_{crit}$=-5+-1

absorption by first dust (optical depth at fragmentation)



implications if observable

- probe of Pop 3 → Pop 2 epoch (formation of first sun)!
- absence=Pop 3 signature?
- probe of first dust properties

すばるで何かできるかも？

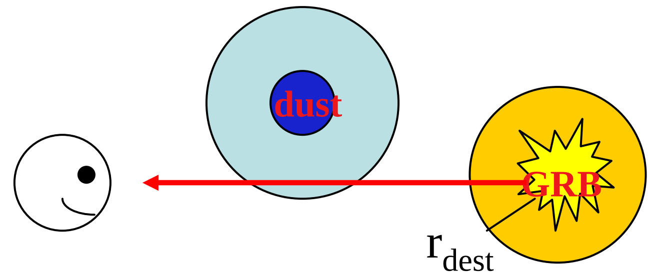
caveats: dust distribution in GRB environment

dust-cooled fragments -> not GRB progenitors?

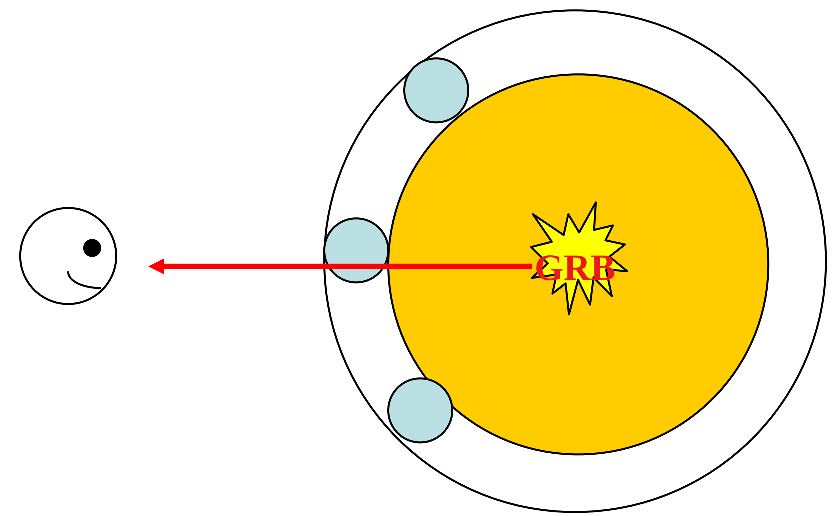
effect of progenitor evolution: UV, HII region, wind …

destruction by GRB UV+X

foreground star forming cores



star forming cores triggered by photodiss. region driven shock



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Tsuribe & Omukai 06

まとめ

ガンマ線吸収で再電離UVを探る
z~5-8では数GeV帯域　blazar+GLASTでできる

２次ガンマ線(pair echo)で銀河間磁場を探る
z~<0.7 GRB or blazar + GLAST, MAGICでできるかも

宇宙の一番星を探す方法　コンプトン減衰？
もっと検討必要

赤外吸収でダスト（生命、人間の元）を探る
GRB＋SPICAで（すばるでも）できるかも

z>10 first star epochは観測未開拓

現在蛮族（理論屋）の支配下

GRB, blazarで切り開く！