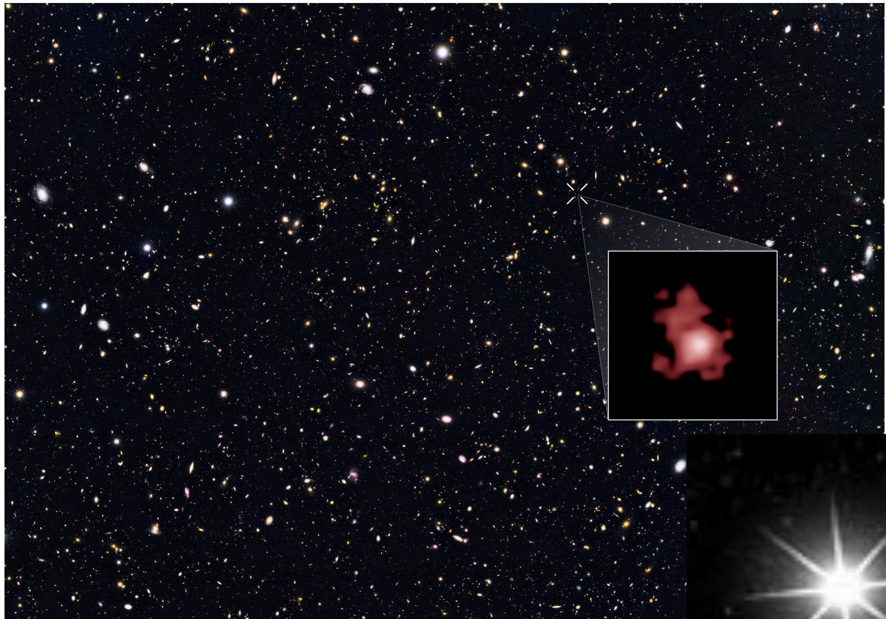
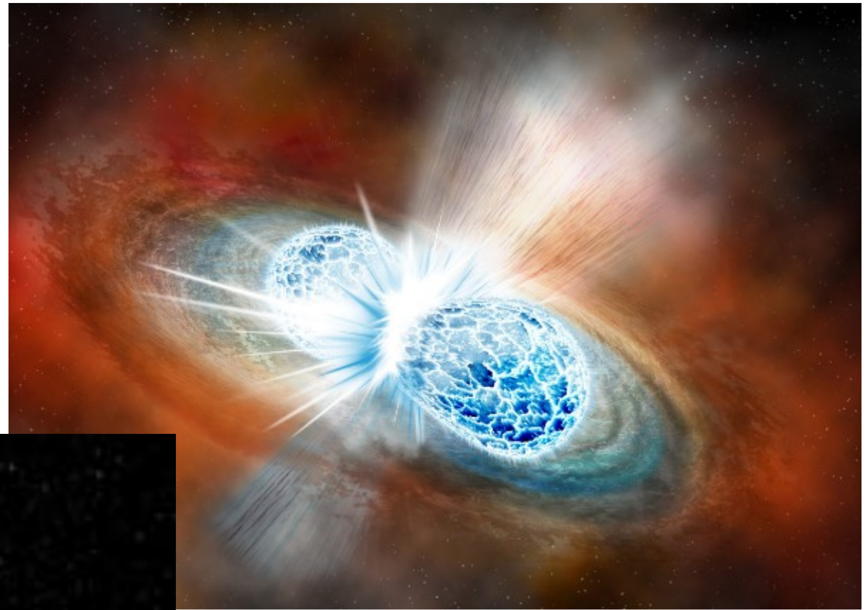
ガンマ線バーストと遠方宇宙・元素の起源

井上 進（理研）　　+共同研究者の皆様





outline

I. GRBs and the high-z Universe

- overview: early excitement vs recent calming down
- quasar contribution to reionization
- gamma-ray probe of UV background

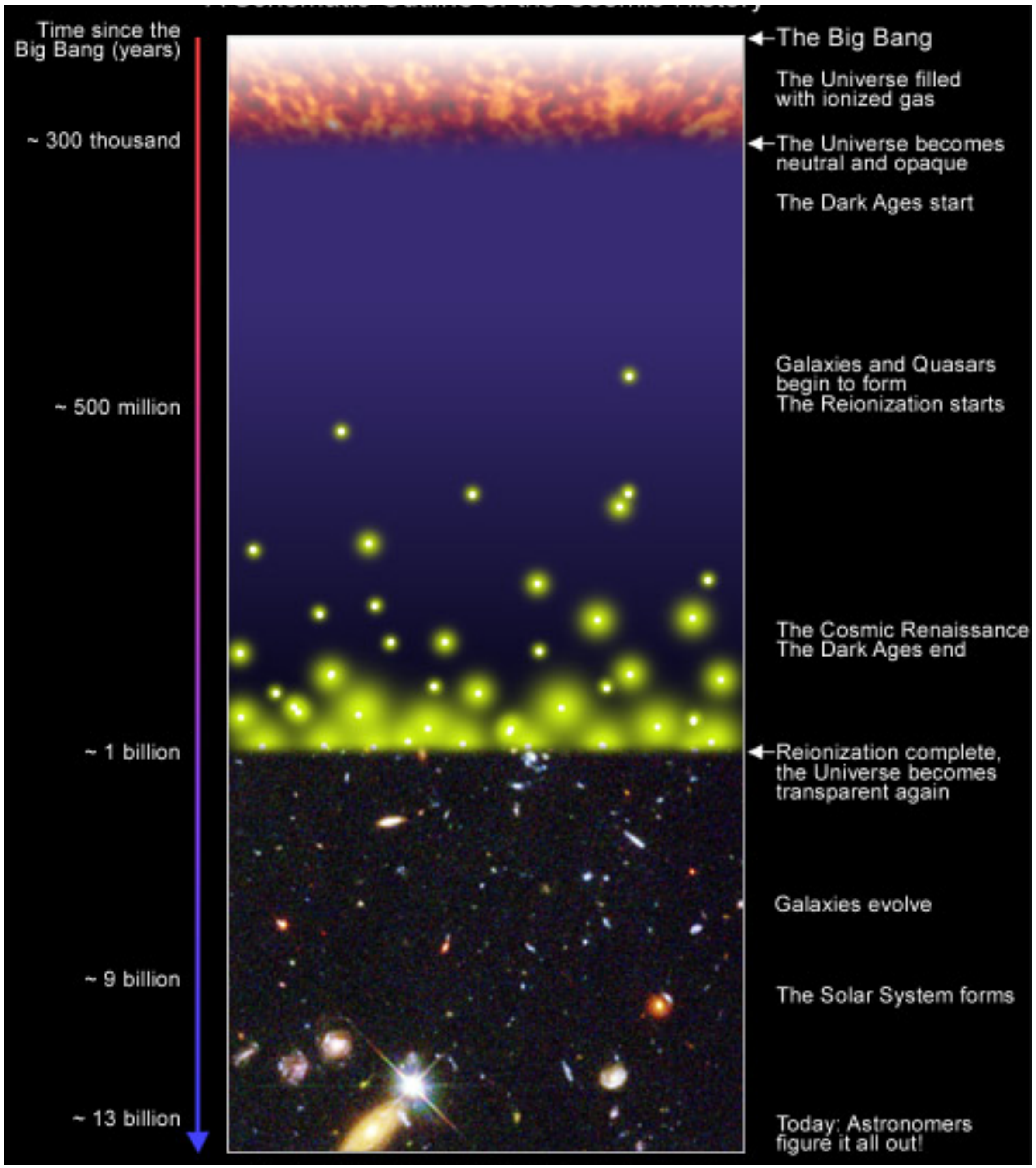
*star formation rate, metal evolution, damping wings…
-> later talks
recent reviews: Space Sci. Rev. (2016) 202

II. neutron star mergers and r-process nucleosynthesis

- potential of X-ray diagnostics

cosmic dark ages -> cosmic dawn

z~3600
z~1000
z>~30
z~8-10
z~6
z~1-3
z~0



- big bang
- matter-rad. eq.
- recombination
- first stars, galaxies, black holes…
  -> reionization
- reion. ends
- star formation peak

adapted from Djorgovski

GRBs and high-z Universe

2000's: excitement, hope

GRBs

1967 discovery (670702)

…

1997 afterglow, cosmological z (970508)

2000 potential recognition
 Lamb & Reichart 00
 Bromm & Loeb 01…

2003 massive star (030329)

2005 z=6.3 (050904)

2009 z=8.2 (090423)

high-z

~2000 first star simulations

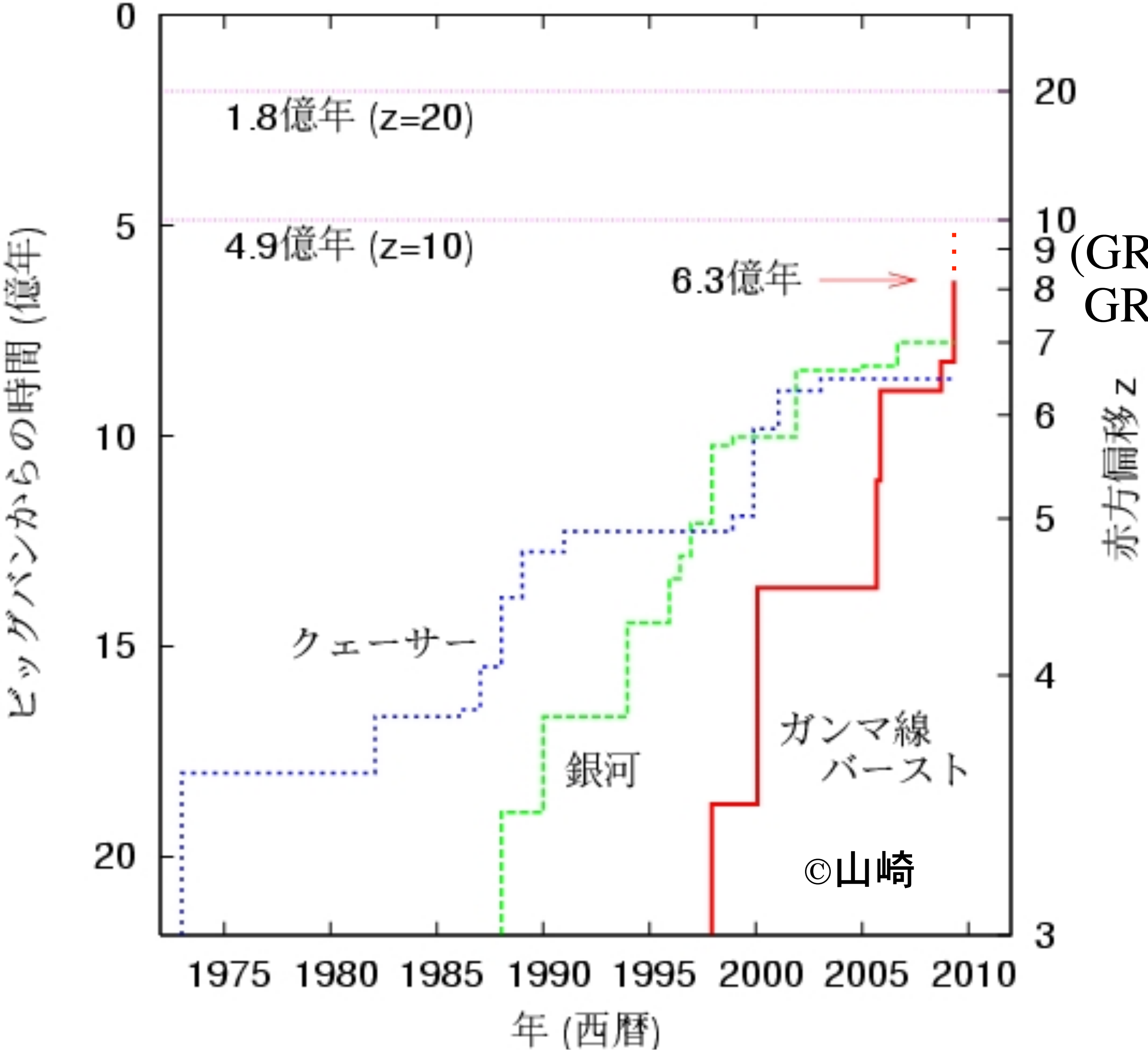
2001 quasar GP troughs

2003 CMB optical depth

z_{reion}~17??

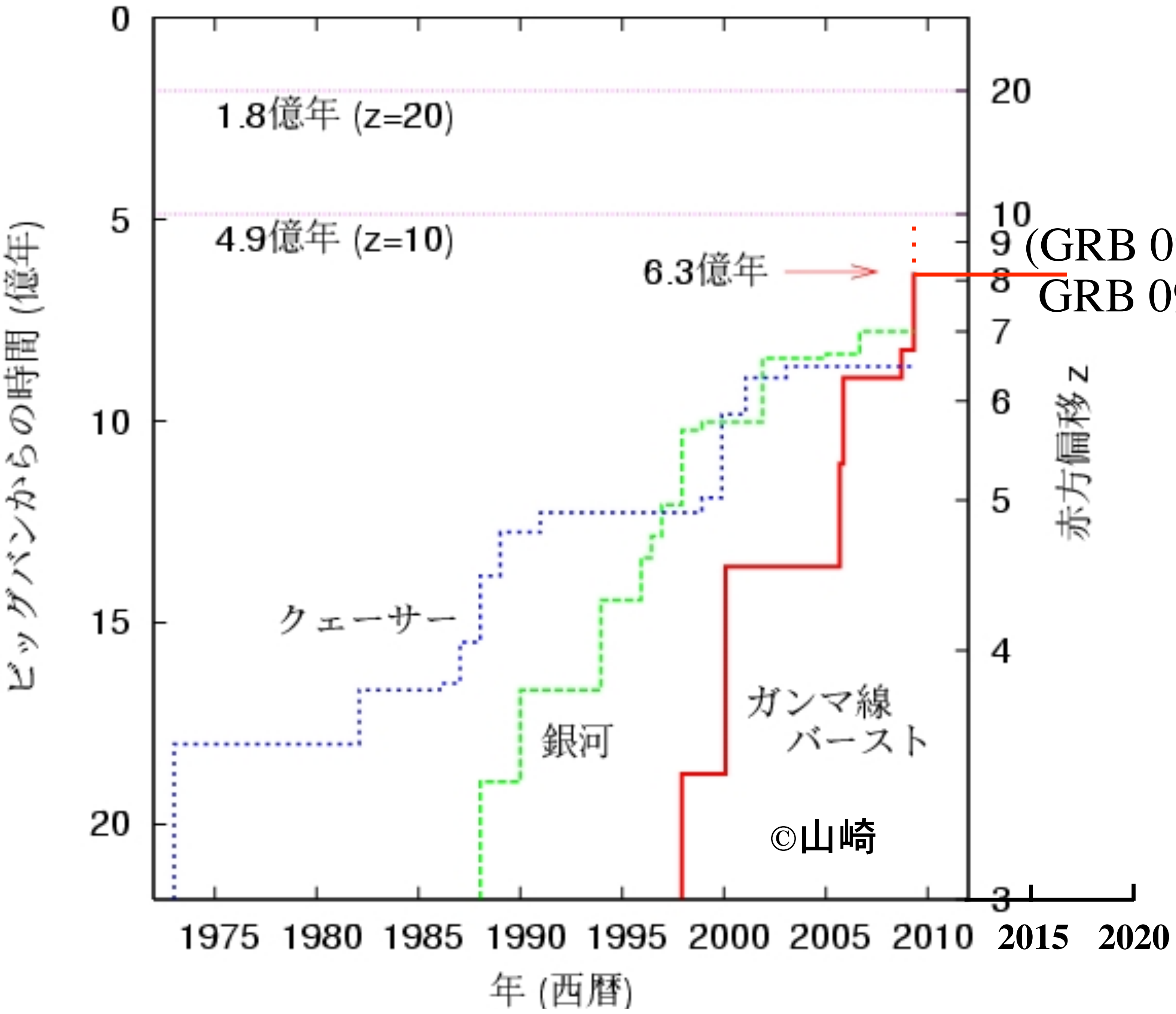
high-z GRB mania!

record redshifts (spectroscopic): -2009

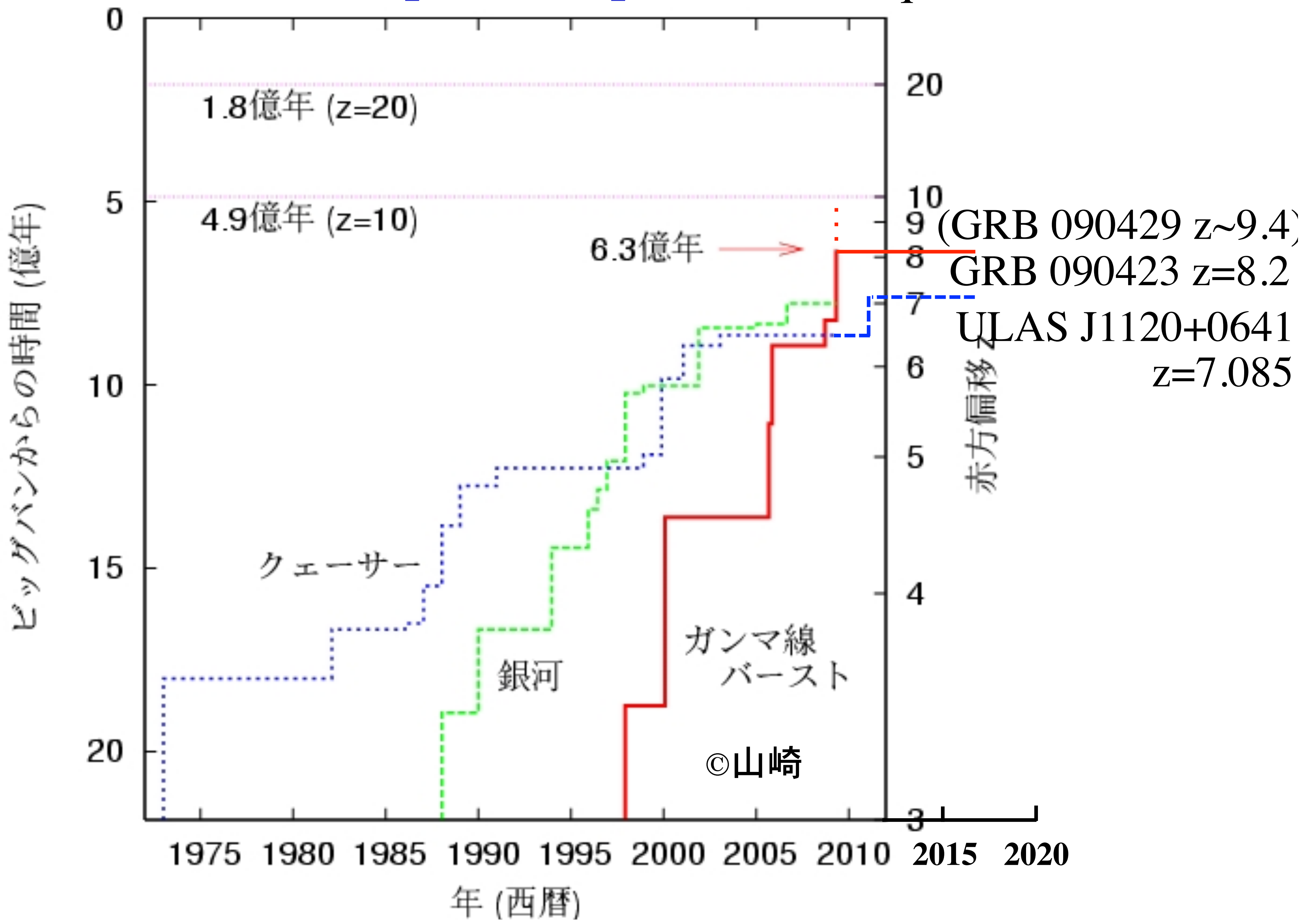


(GRB 090429 z~9.4)
GRB 090423 z=8.2

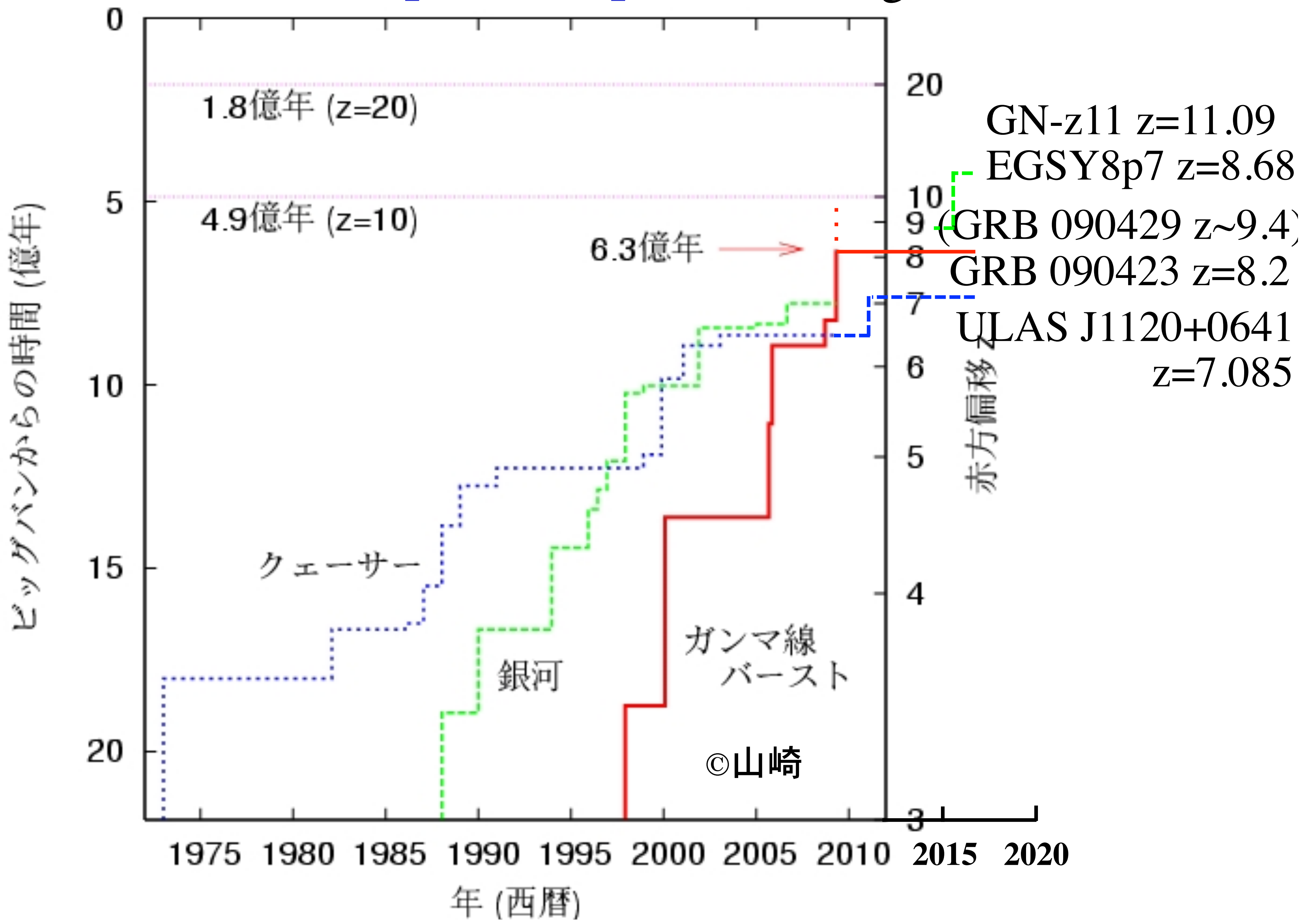
record redshifts (spectroscopic): -2017



record redshifts (spectroscopic): -2017 quasars strike back?

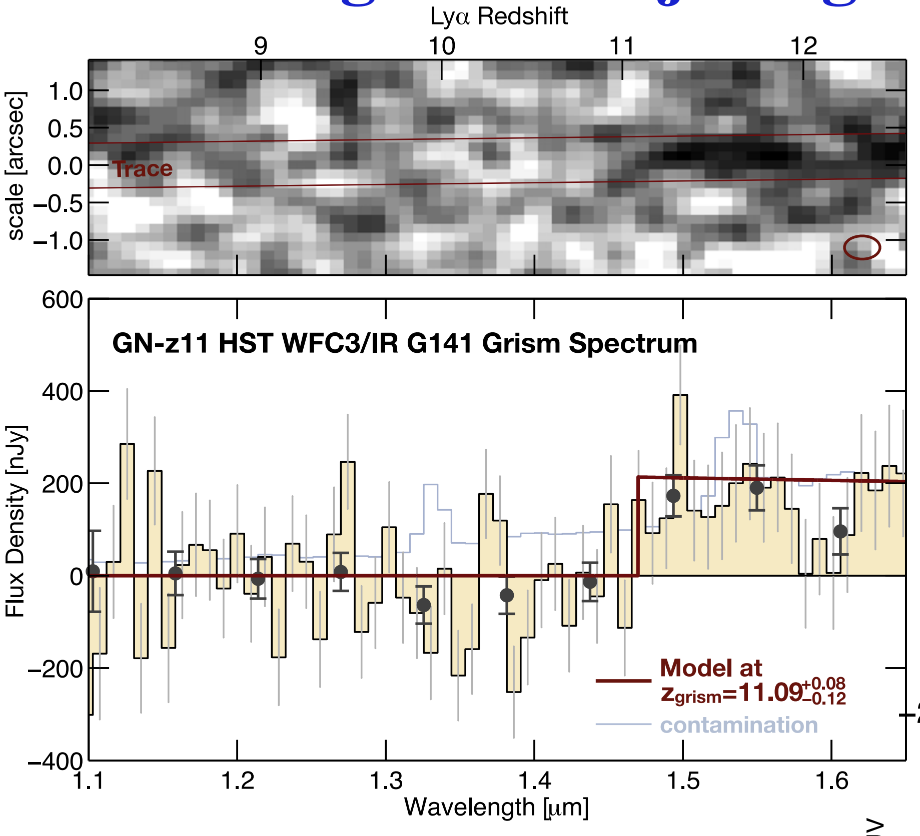


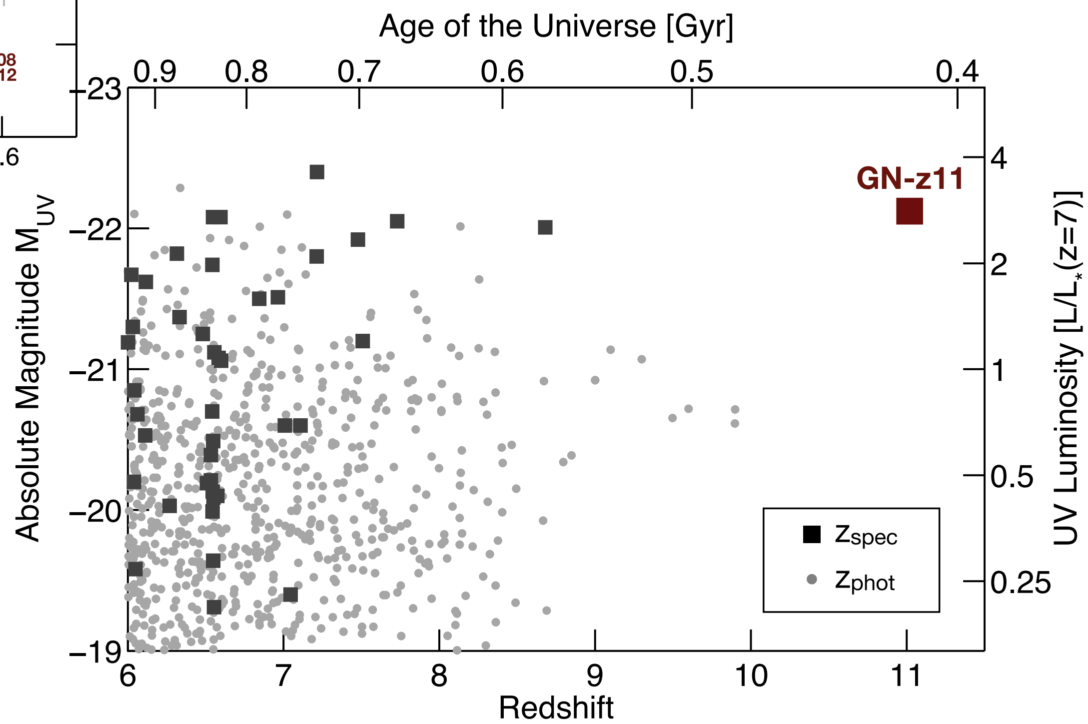
record redshifts (spectroscopic): -2017 galaxies strike back!



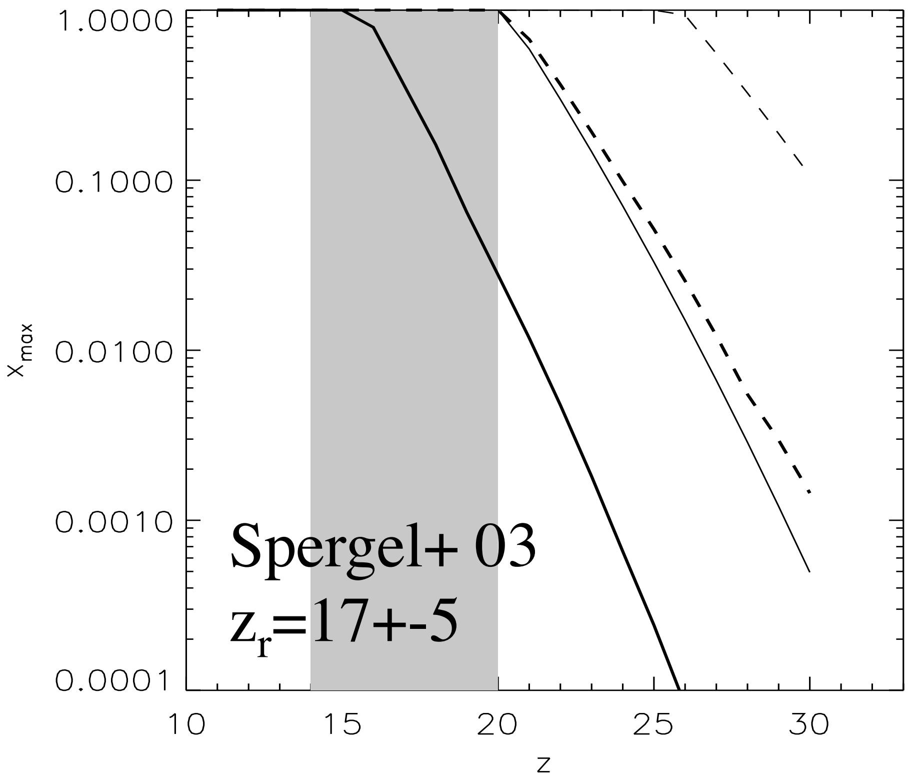
current highest-z object: galaxy at z=11.09

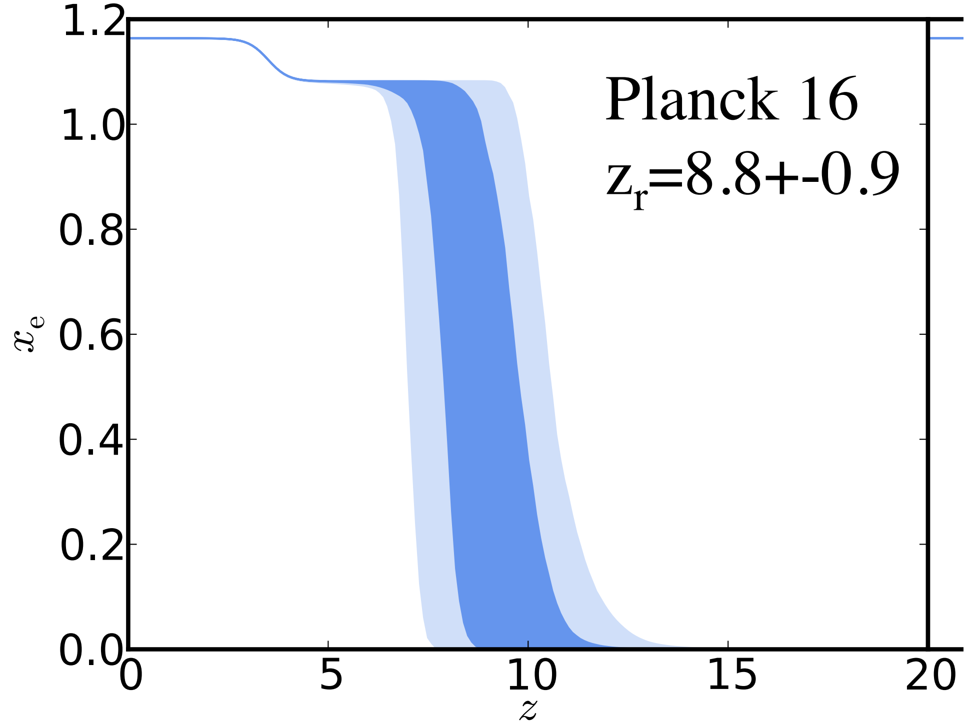
Oesch+ 16





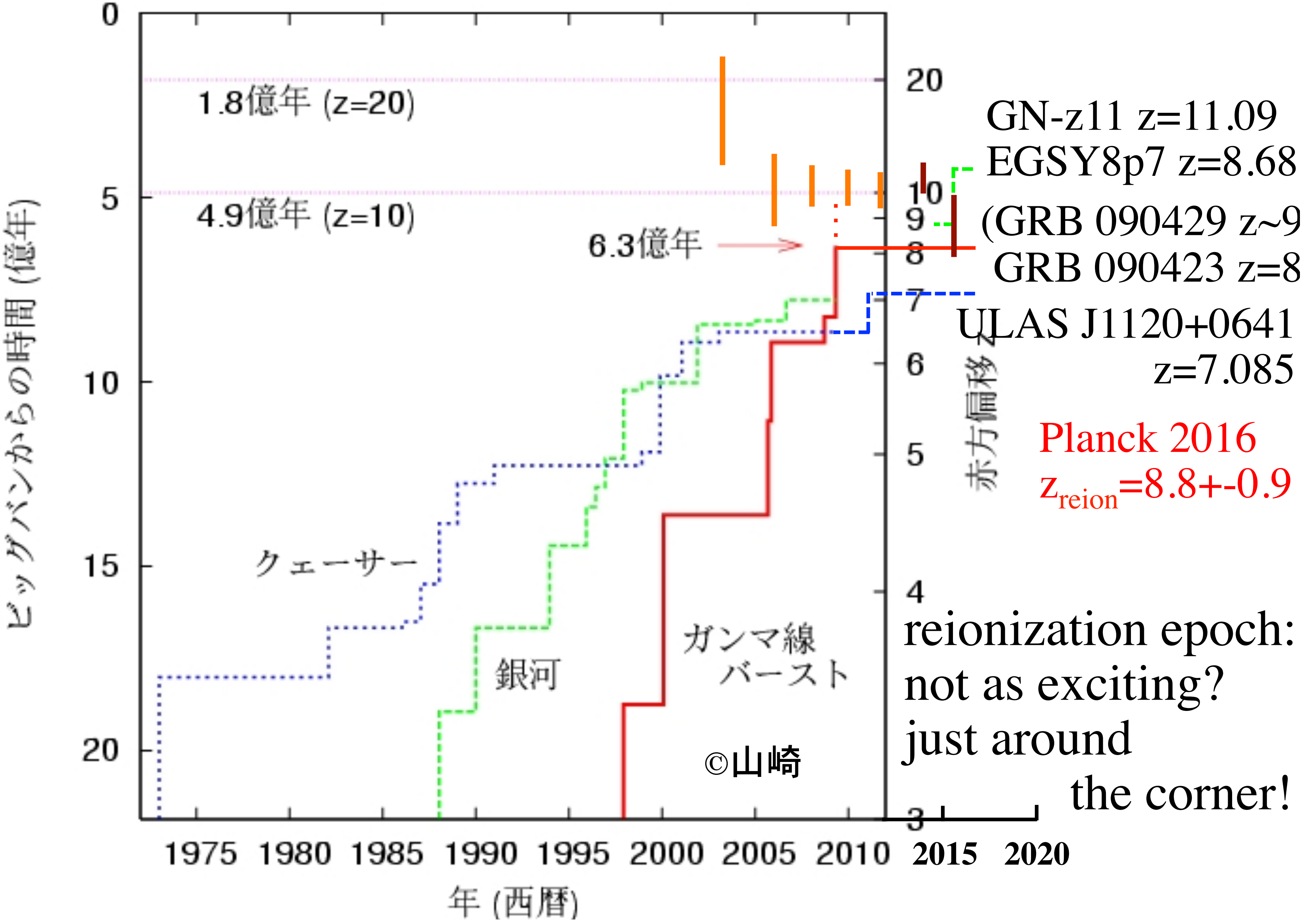
reionization z from CMB polarization anisotropy



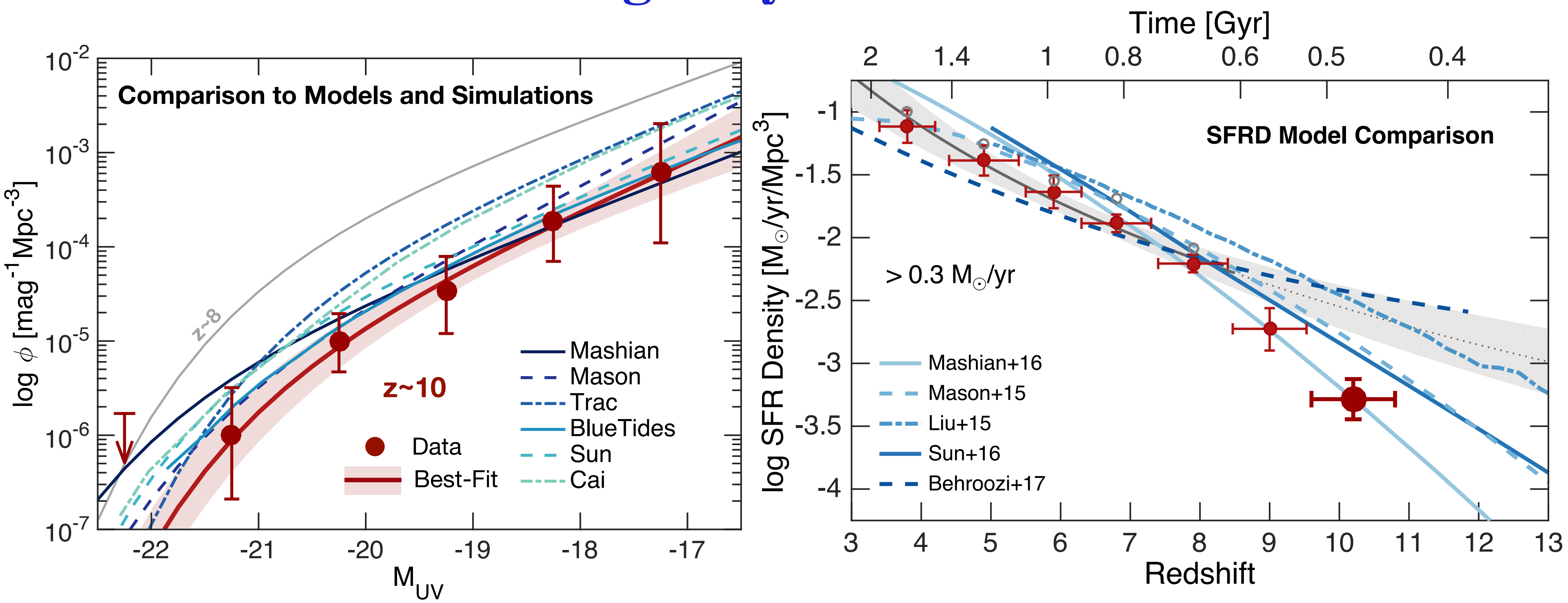


2003	z_r=17+-5	WMAP1 Spergel+ 03
2006	z_r=10.9+2.7-2.3	WMAP3 Page+ 07
2008	z_r=11.0+-1.4	WMAP5 Dunkley+ 09
2010	z_r=10.6+-1.2	WMAP7 Komatsu+ 11
2012	z_r=10.3+-1.1	WMAP9 Hinshaw+ 13
2014	z_r=11.1+-1.1	Planck 14
2016	z_r=8.8+-0.9	Planck 16

record redshifts (spectroscopic): -2017 + CMB z_{reion}



low abundance of z~10 galaxy candidates? Oesch+ 1710.1113



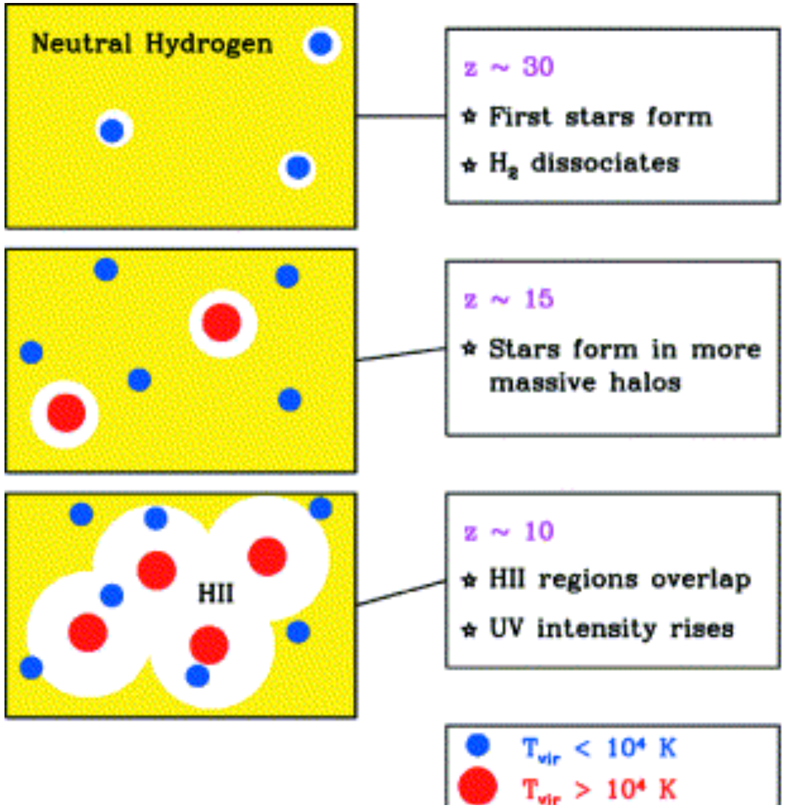
cosmic reionization epoch

status circa 2003

When? early? late? two-epoch?

How? topology?

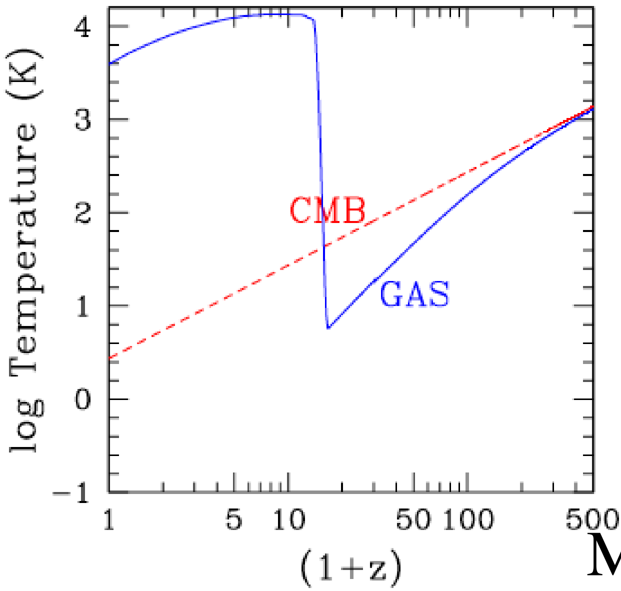
What? Pop III? Pop II?
mini-QSOs?
dark matter decay?



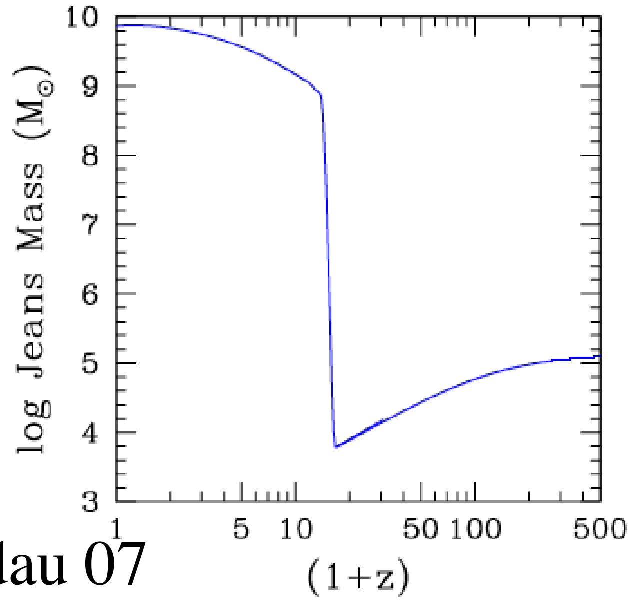
So what?

regulation of
dwarf galaxy
formation

…



Madau 07



cosmic reionization epoch

status circa 2017

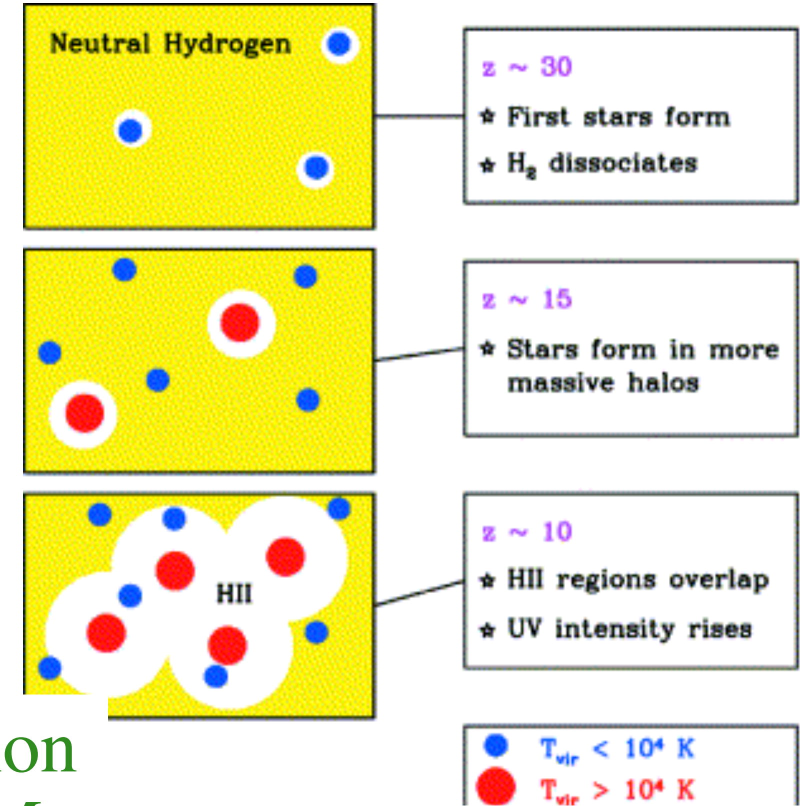
When? relatively late

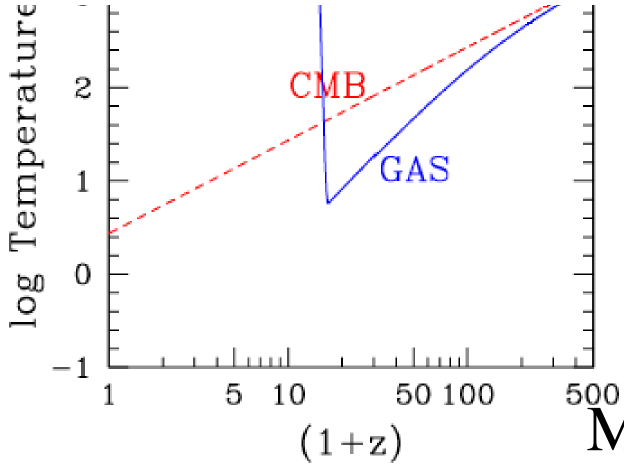
How? topology?

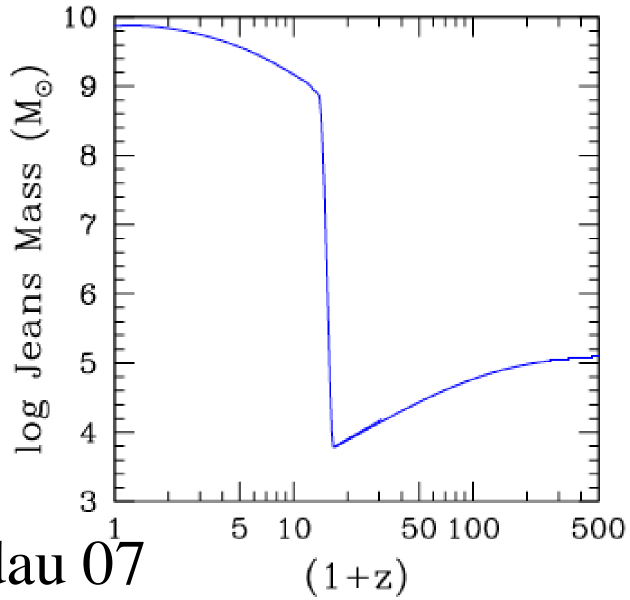
What? Pop II? quasars?

So what?

regulation of dwarf galaxy formation
baryon distribution in halos vs IGM
CDM small-scale power spectrum

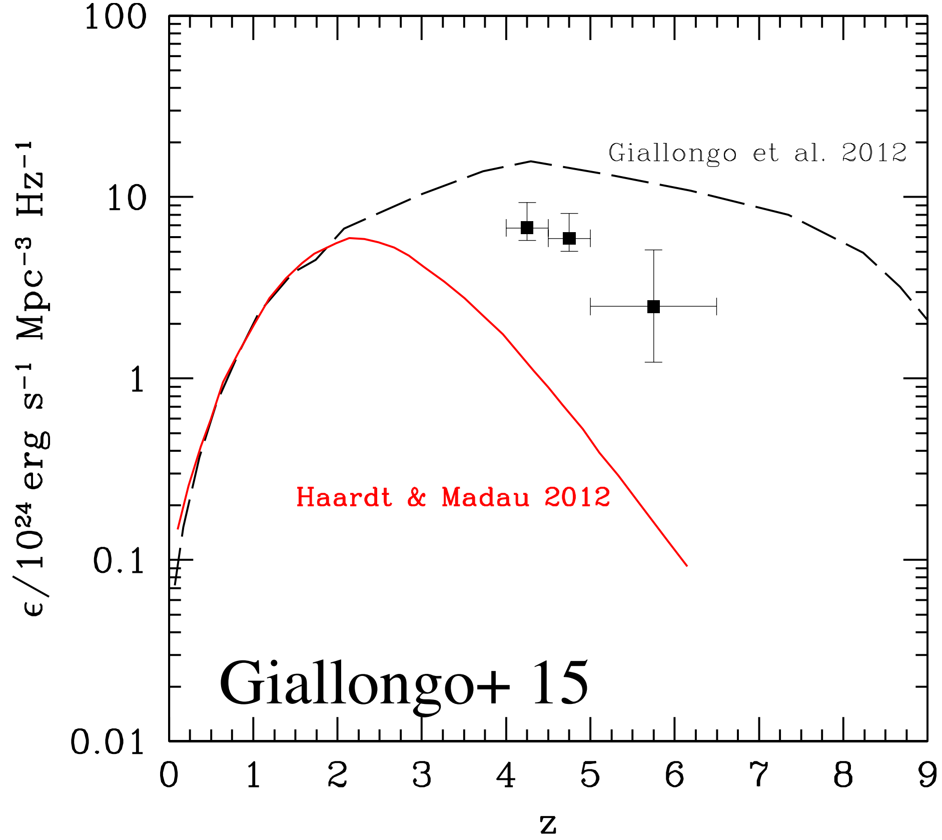


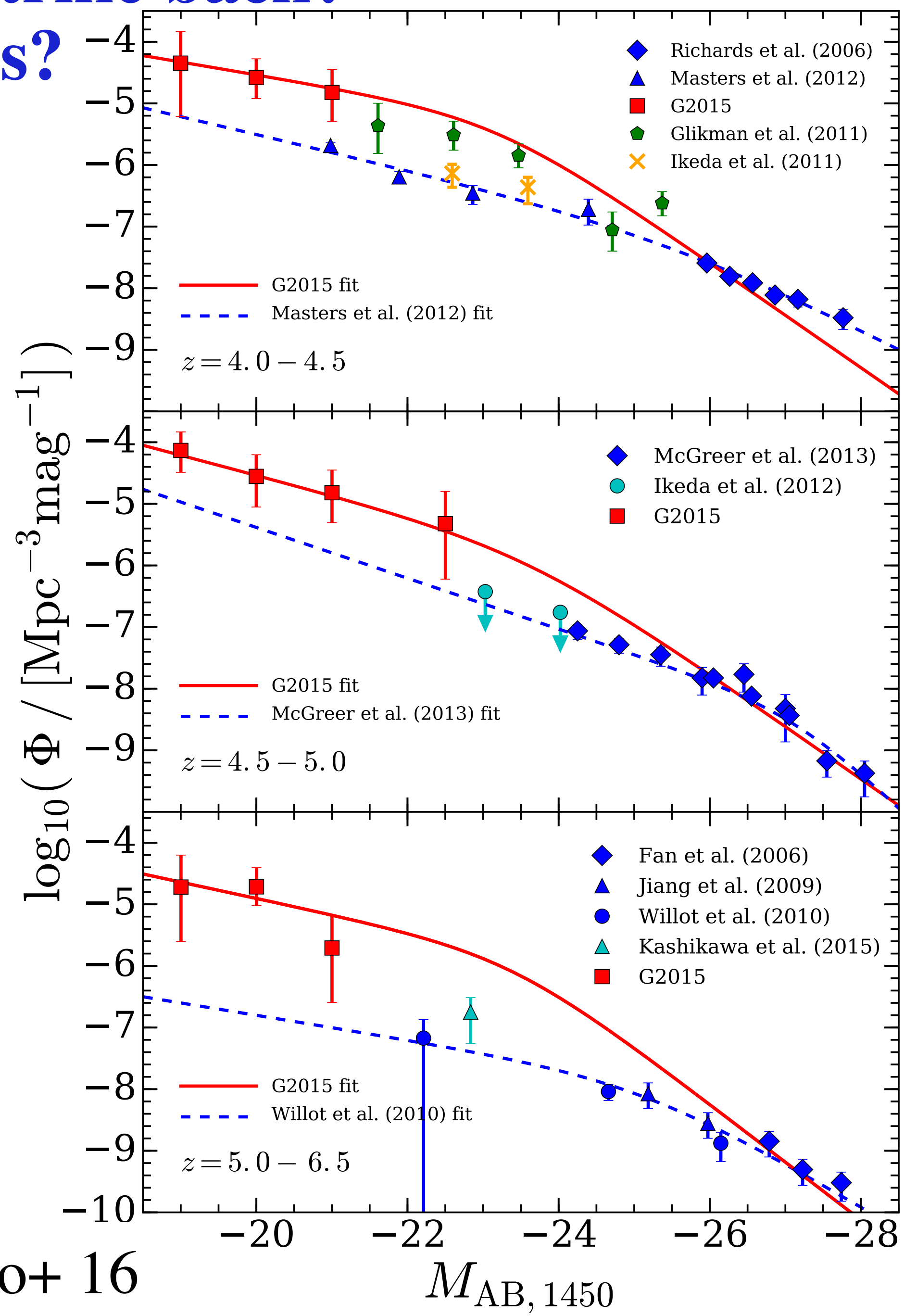




Madau 07

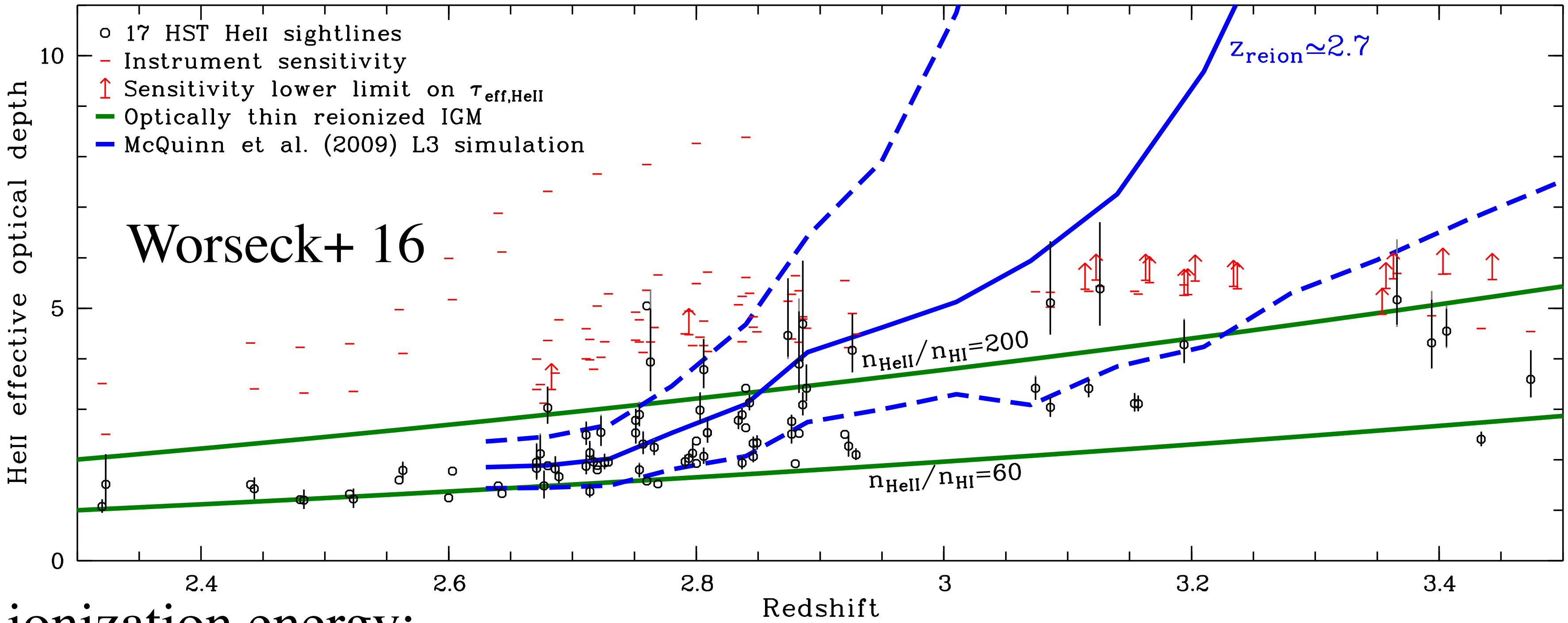
cosmic reionization: quasars strike back?
large number of low-L quasars?





D'Aloisio+ 16

cosmic reionization: quasars strike back?
HeII Ly α opacity -> He reionization more extended?



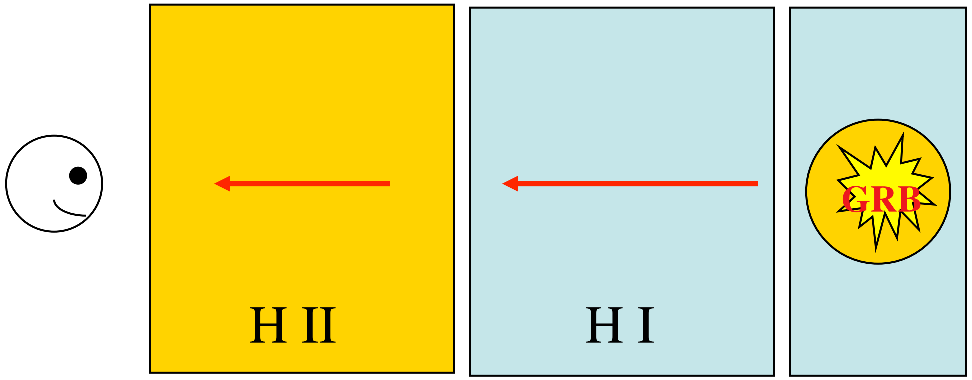
ionization energy:
HeI – 24.6 eV: near-simultaneous with H reionization (massive stars?)
HeII – 54.4 eV: quasars only

large fluctuations in HI Ly α opacity — Becker+ 15
-> more patchy reionization by rare, bright sources?

GRB damping wing observations
probe of SMBH evolution

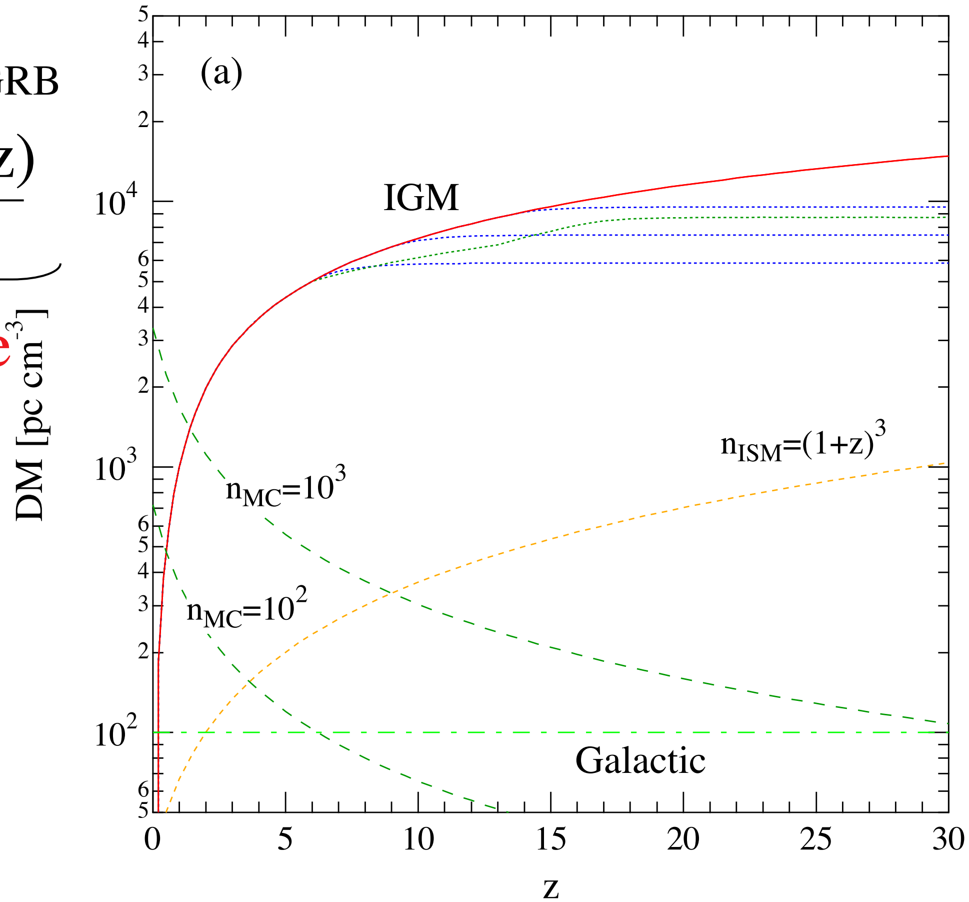
probing ionized IGM with radio dispersion

SI 04
also Ioka 03



$z = 0$ $\quad z_{\mathrm{reion}}$ $\quad z_{\mathrm{GRB}}$

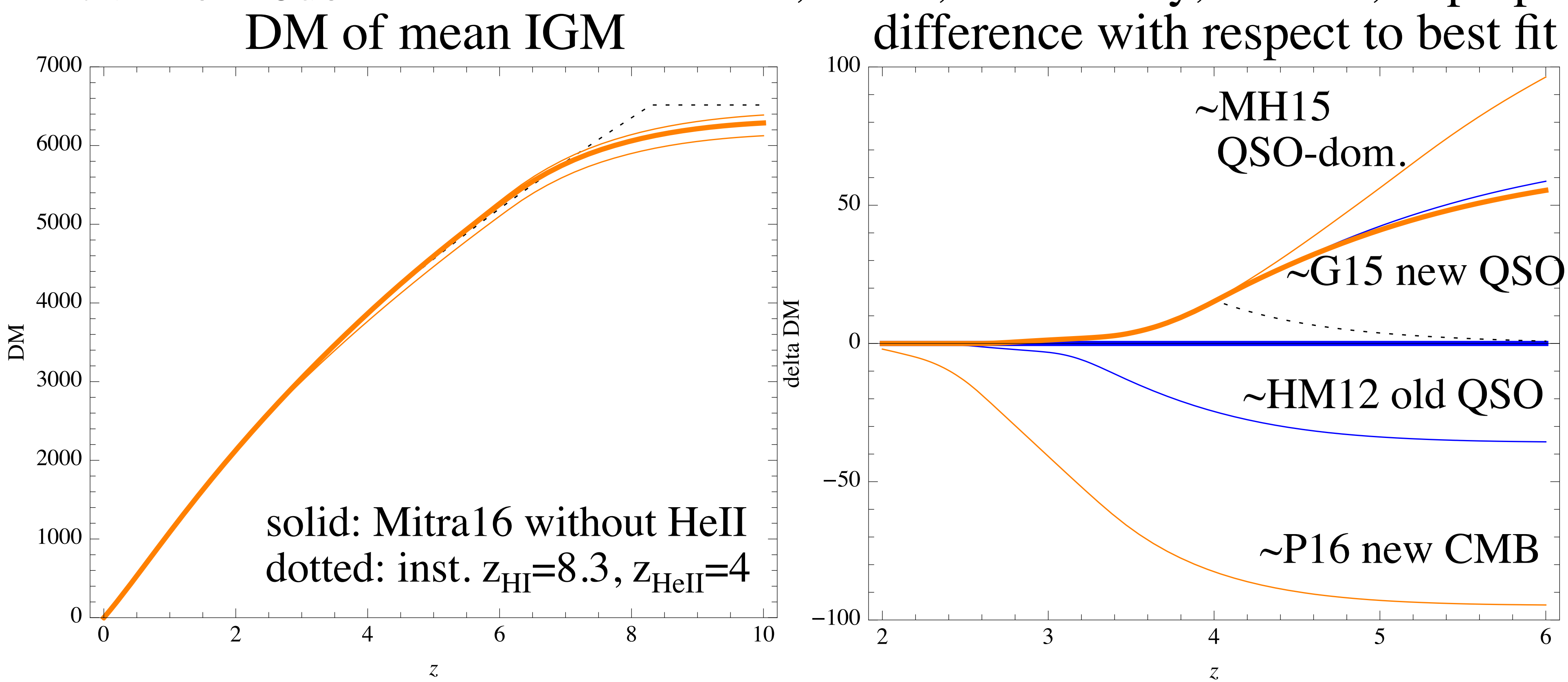
$$\Delta t = \frac{e^2}{2\pi m_e c\,\nu^2} \underbrace{\int dz\, \frac{c\,dt}{dz} \frac{x_e(z)\, n_{\mathrm{IGM}}(z)}{1+z}}_{\text{dispersion measure}}$$



IGM dispersion measure with reionization by stars+quasars

Mitra+16 model

SI, Mitra, Choudhury, Ferrara, in prep.



- model differences not large but relevant for obs. (δDM~+-100 at z~2-6)
  unique info on H+He reionization, evolution of low-L quasars
- variance due to LSS averaged out with large enough sample
- local DM main uncertainty -> can it be sufficiently constrained?
- uncertainties in reionization important for interpreting DM at z>~3

gamma-ray absorption: probe of diffuse background radiation (integrated starlight)

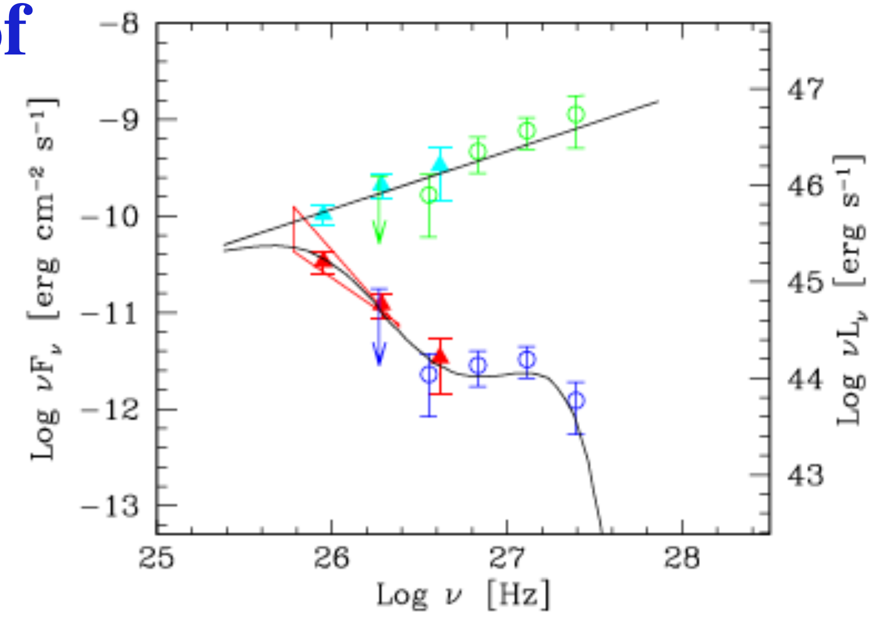
$\gamma + \gamma \rightarrow e^+ + e^-$

E ε

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

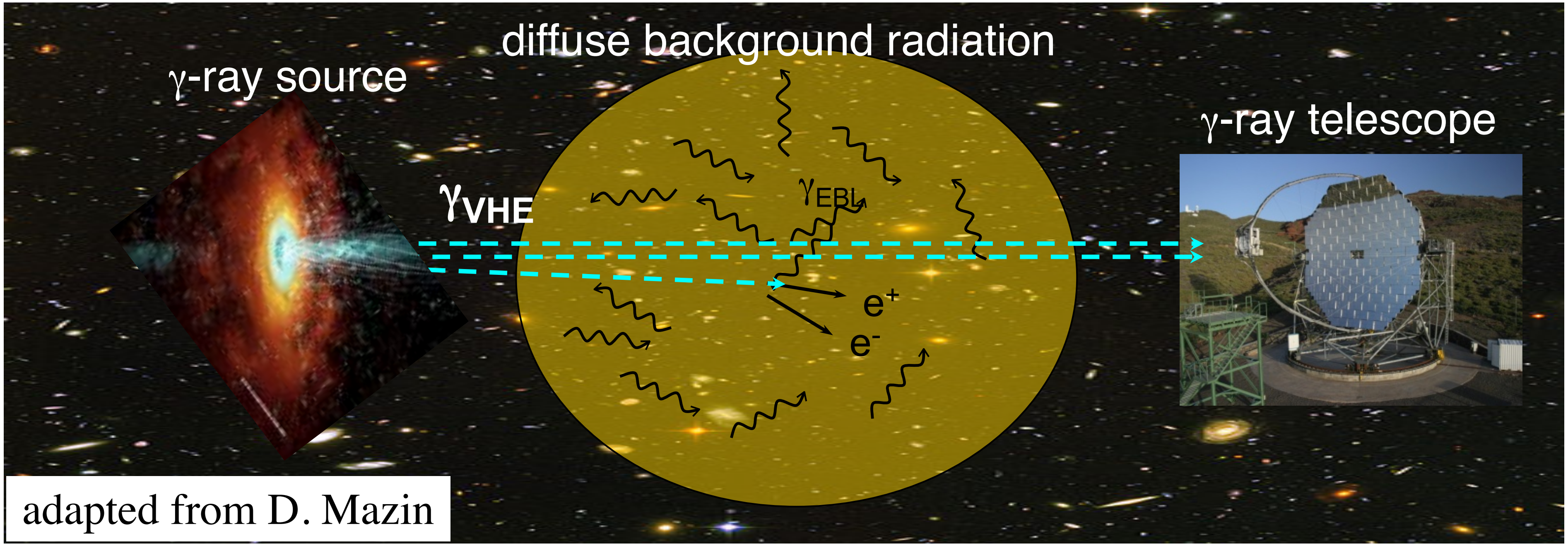
e.g. 100 GeV + 10 eV (UV)

TeV + 1eV (IR)



γ absorption in blazars (z~<1)

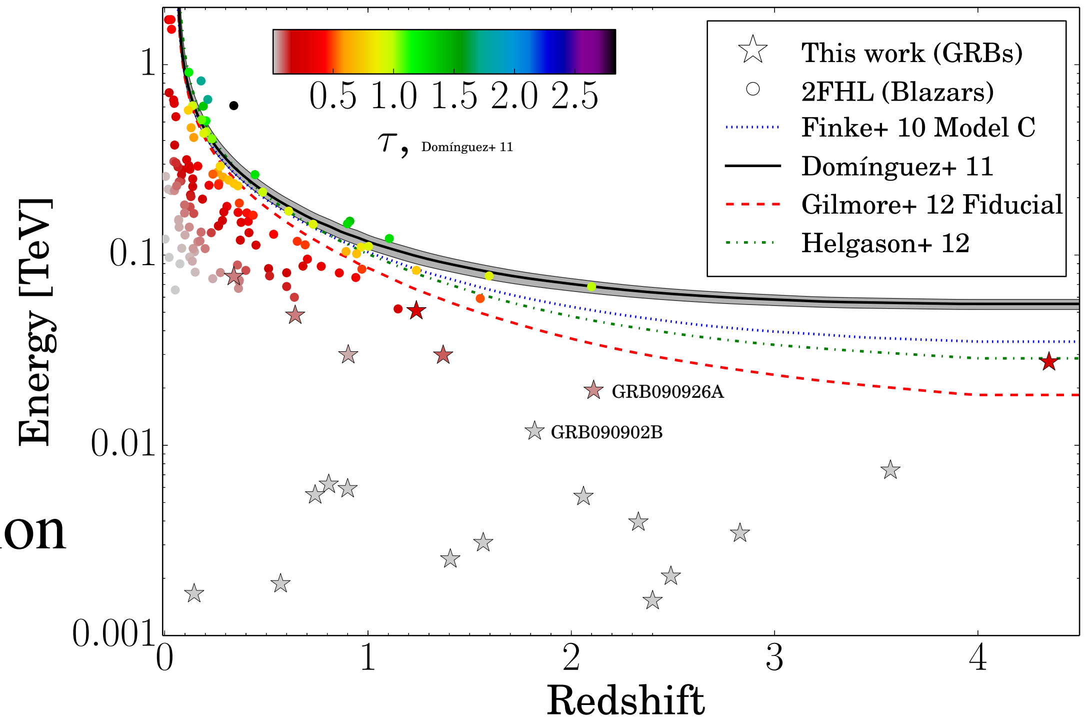
-> probe of IR/opt. background

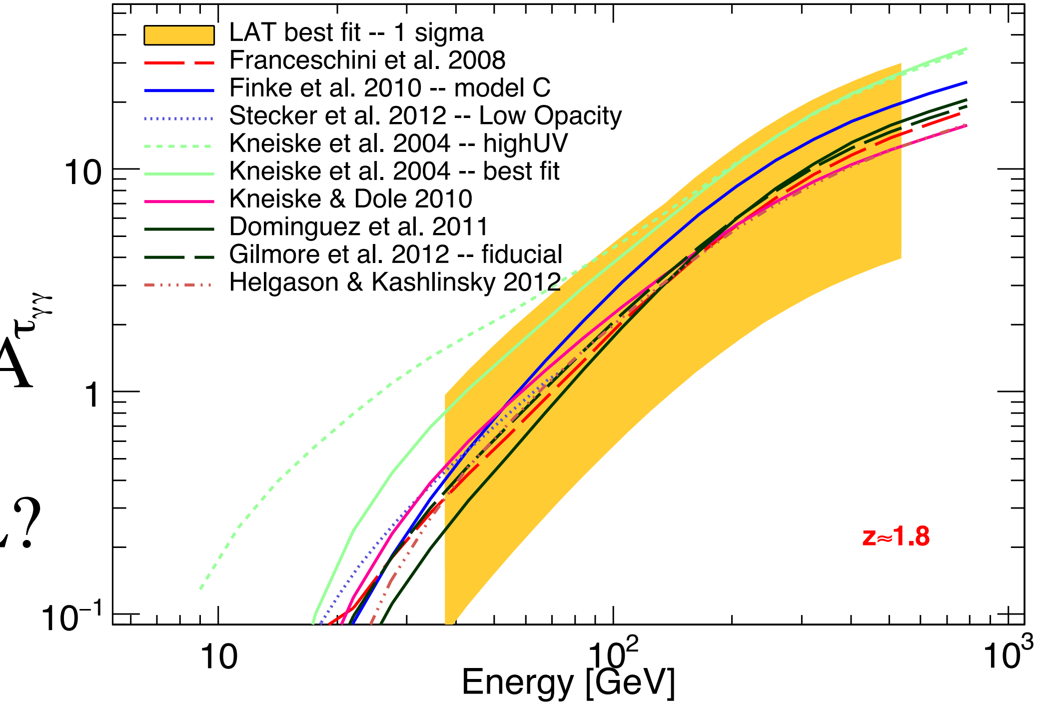


probe of high-z UV background via GRB gamma-rays

Desai+ 1710.02535

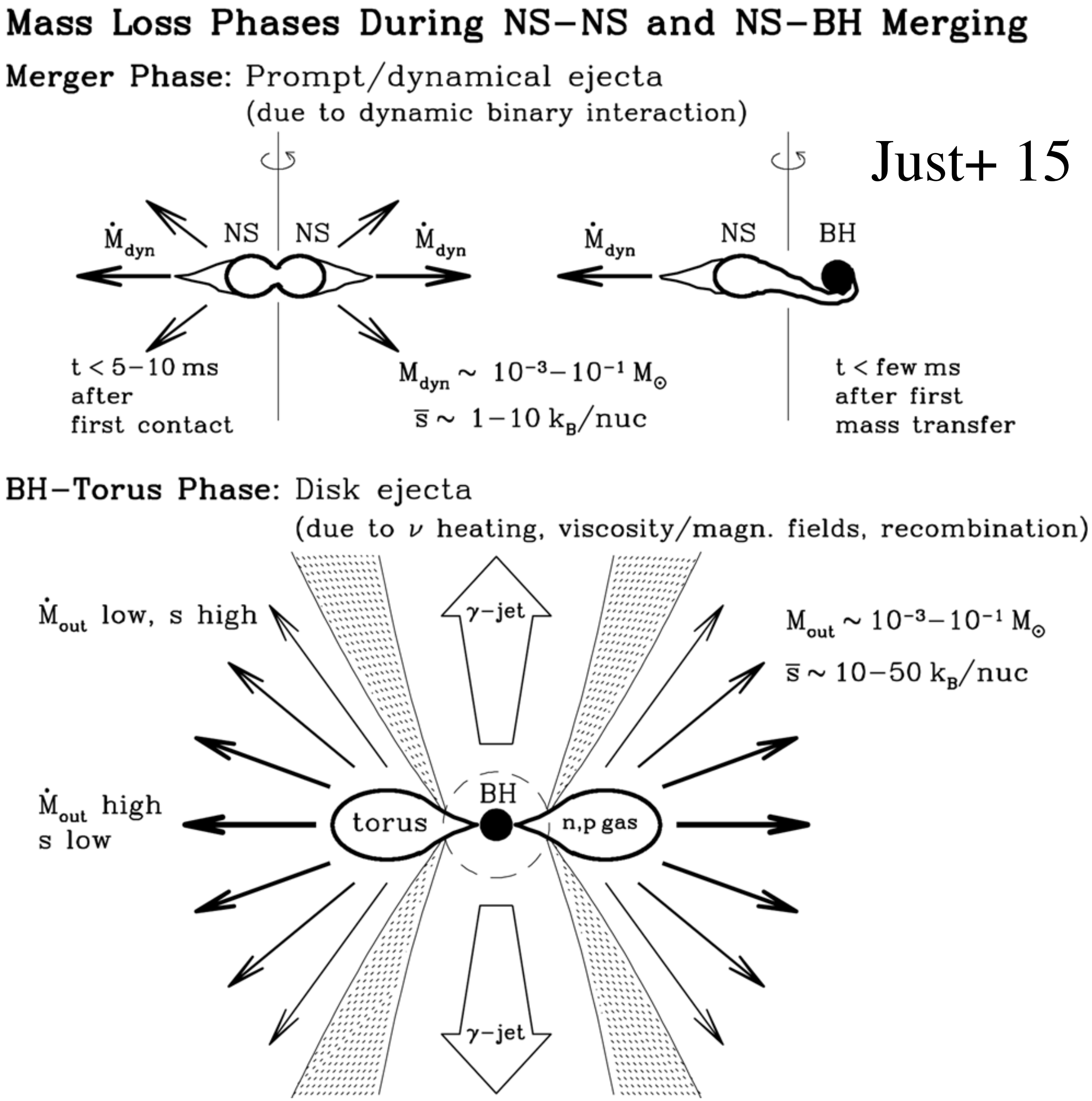
22 Fermi-LAT GRBs with z
2.8σ evidence of EBL attenuation at z~1.8



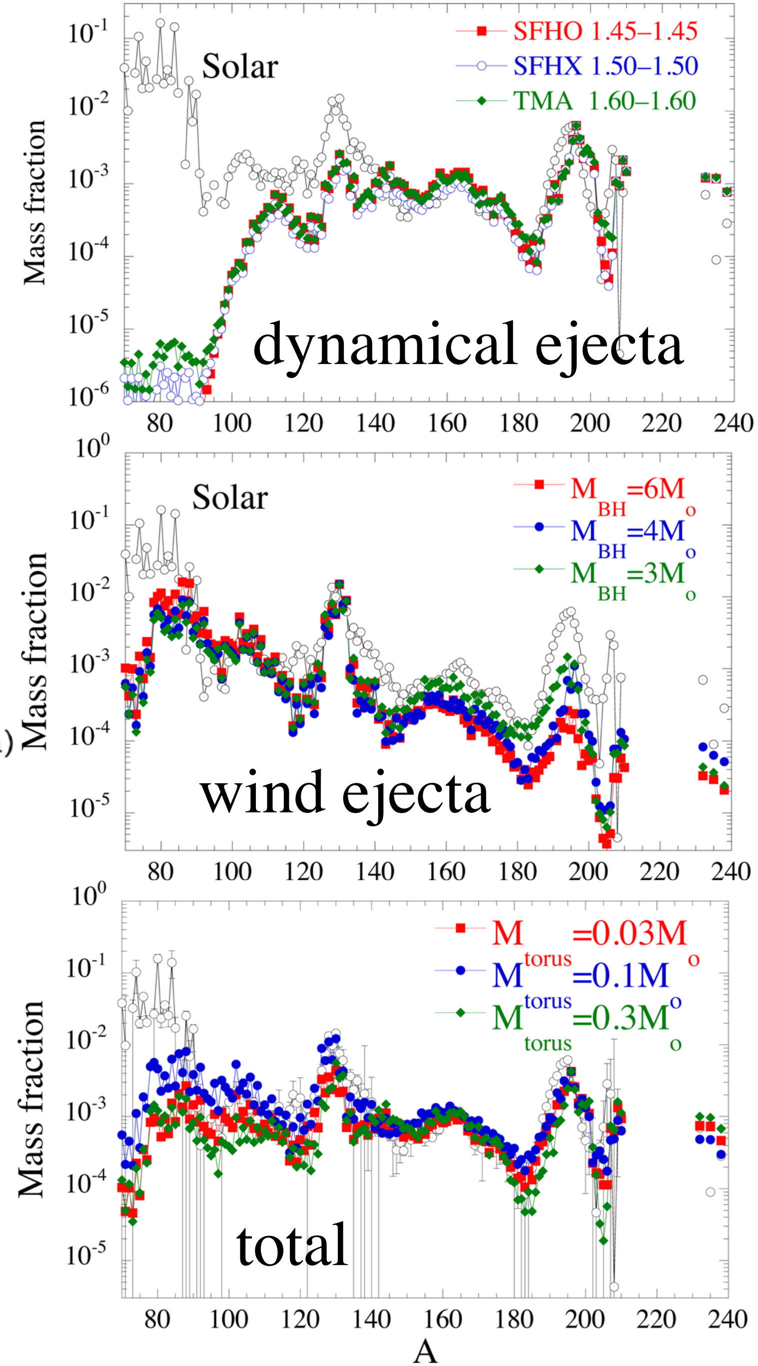


interesting prospects for CTA
- more robust constraints
- quasar contribution to EBL?
- probe H+He reionization?

r-process nucleosynthesis in NS mergers



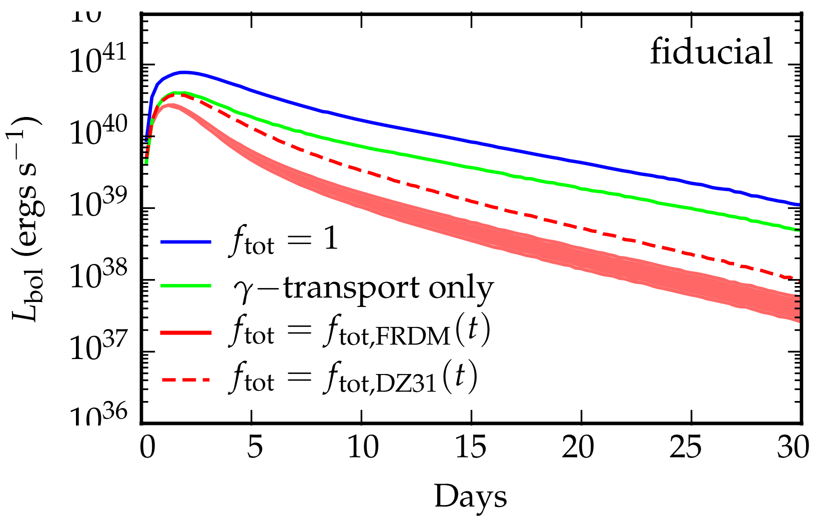
Just+ 15

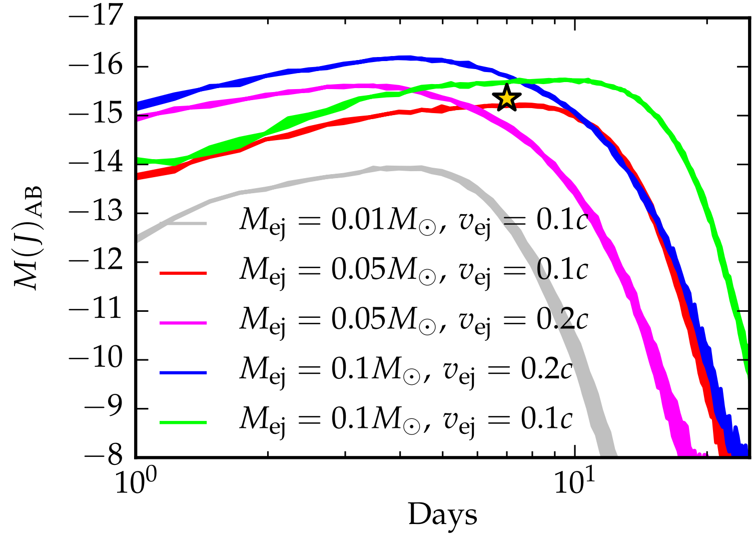


other scenarios: all from dynamical ejecta, 1st peak from other sources…

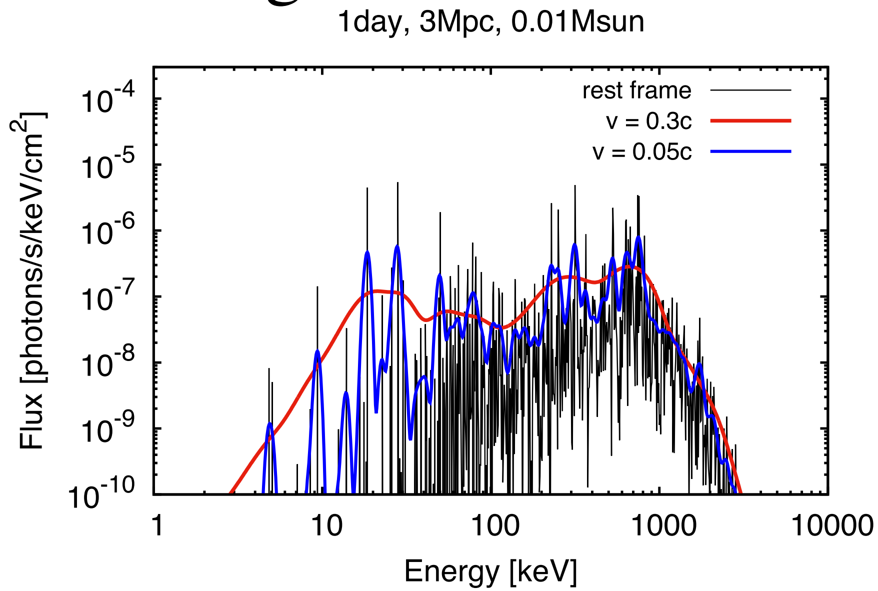
r-process nucleosynthesis in NS mergers: in-situ probe?

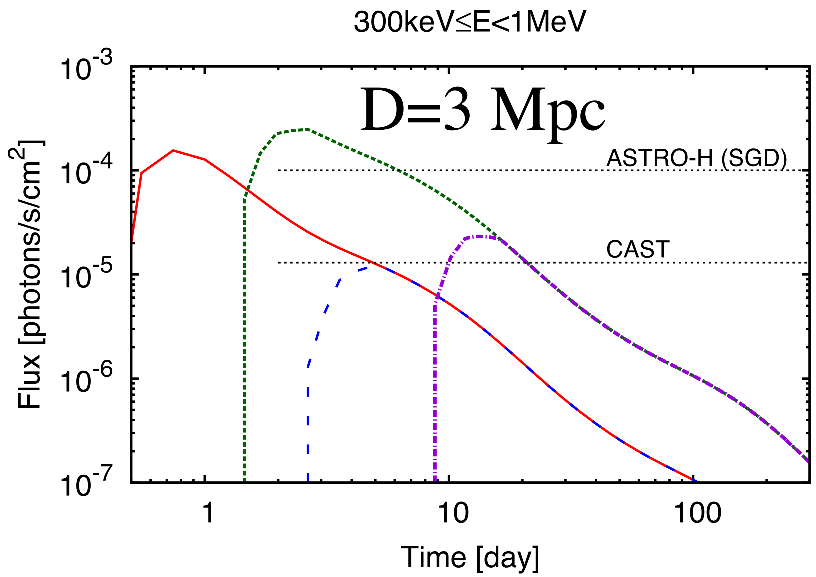
macro/kilonova Barnes+ 16 difficult to obtain detailed info





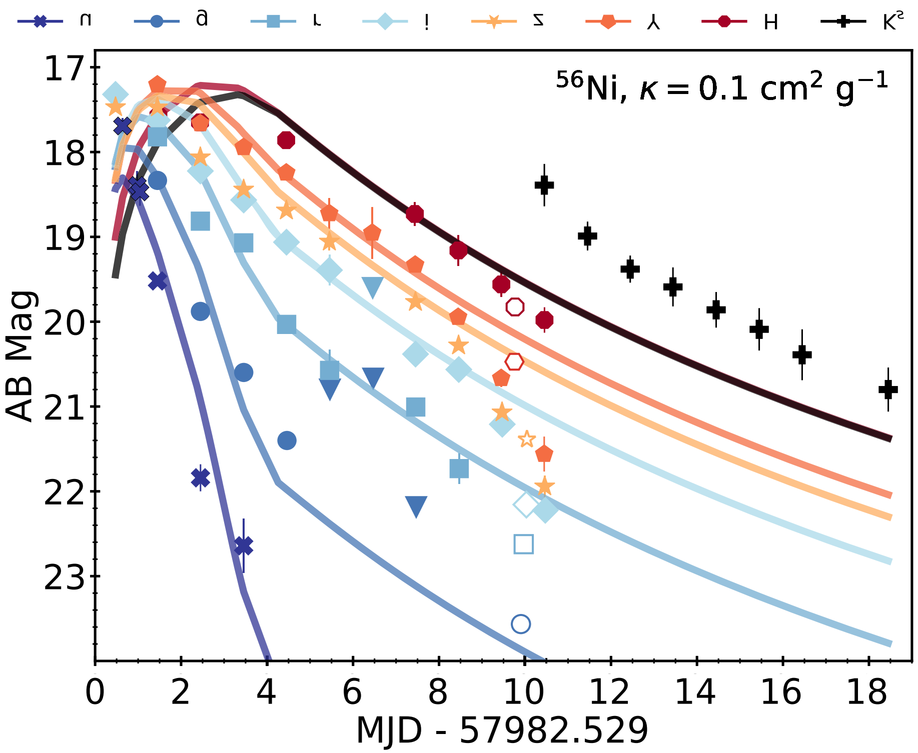
nuclear gamma lines Hotokezaka+ 16 very difficult to detect





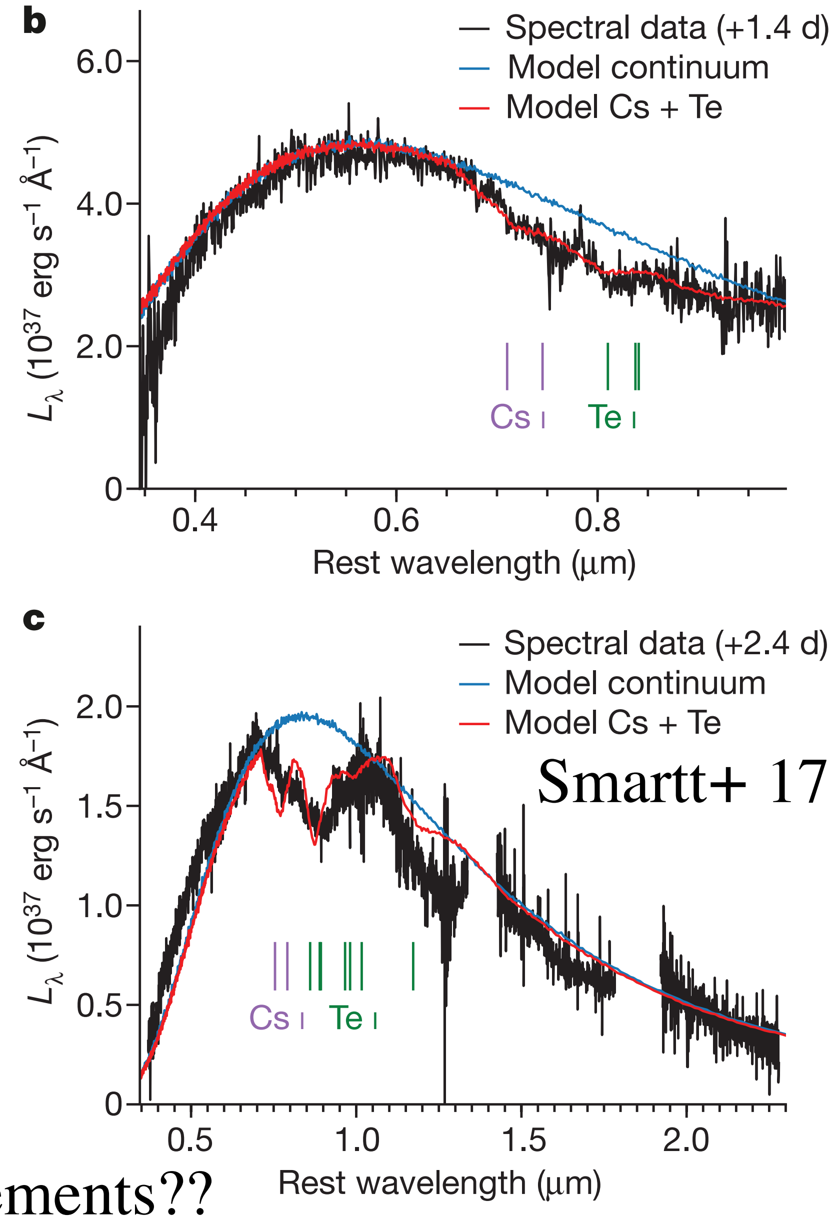
macro/kilonova in GW170817

good indication but not definitive proof of r-process



Cowperthwaite+ 17

blue kilonova
indistinguishable from ^{56}Ni

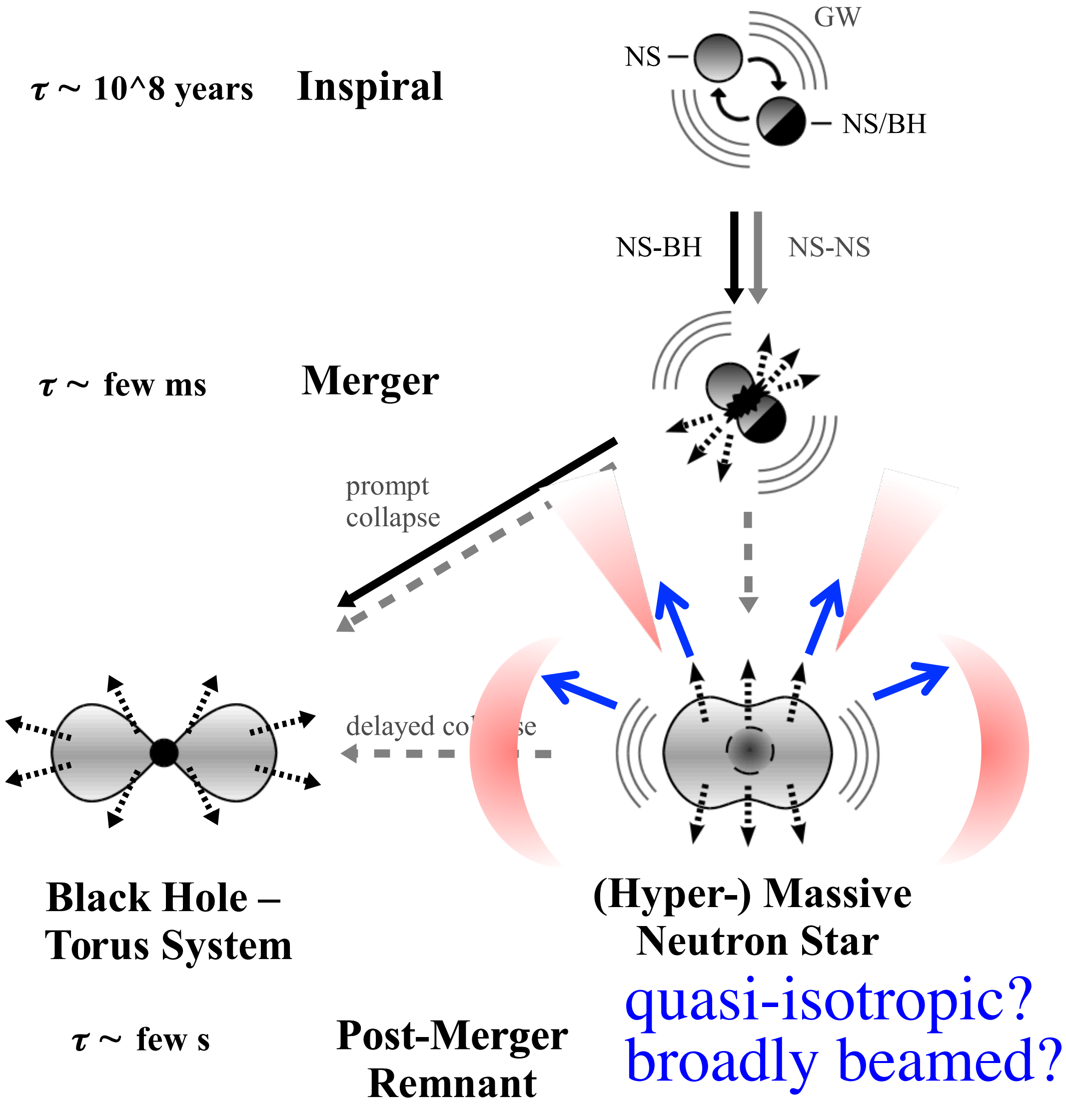


Smartt+ 17

features from
individual elements??

short GRBs: X-rays from extended engine activity

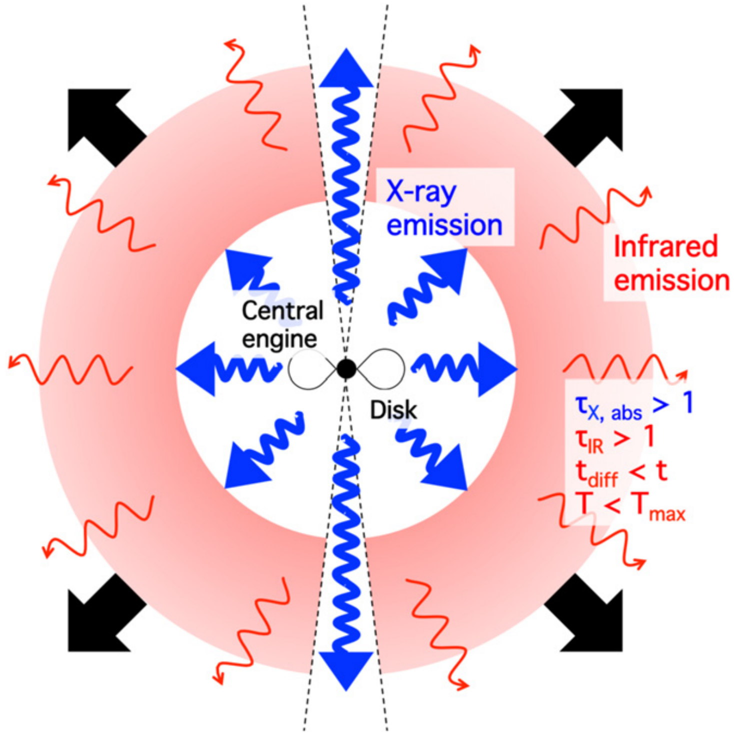
X-rays from
transient magnetar spindown



quasi-isotropic?
broadly beamed?

adapted from Just

X-ray powered
macronova model

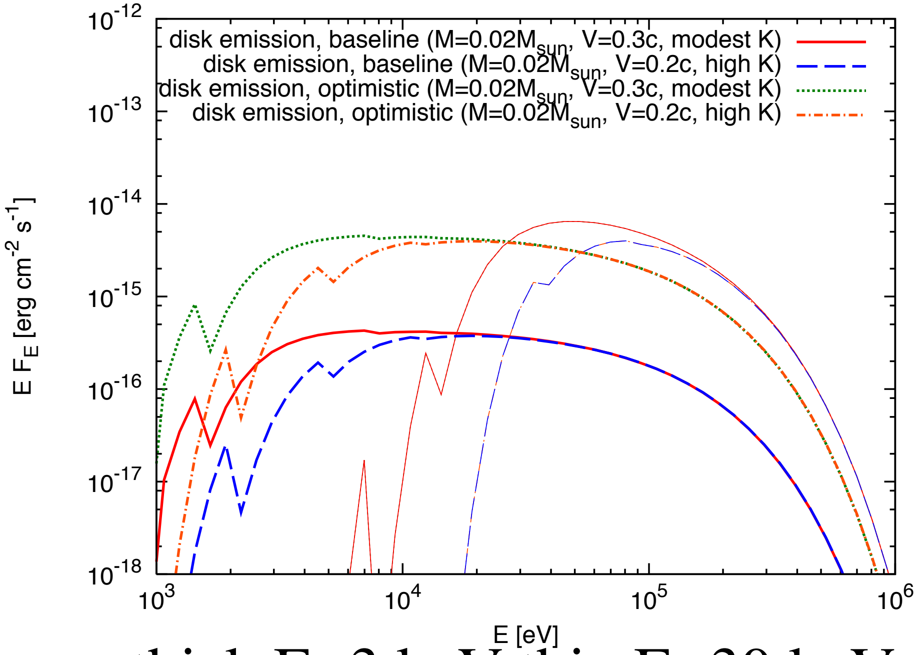


Kisaka+ 16

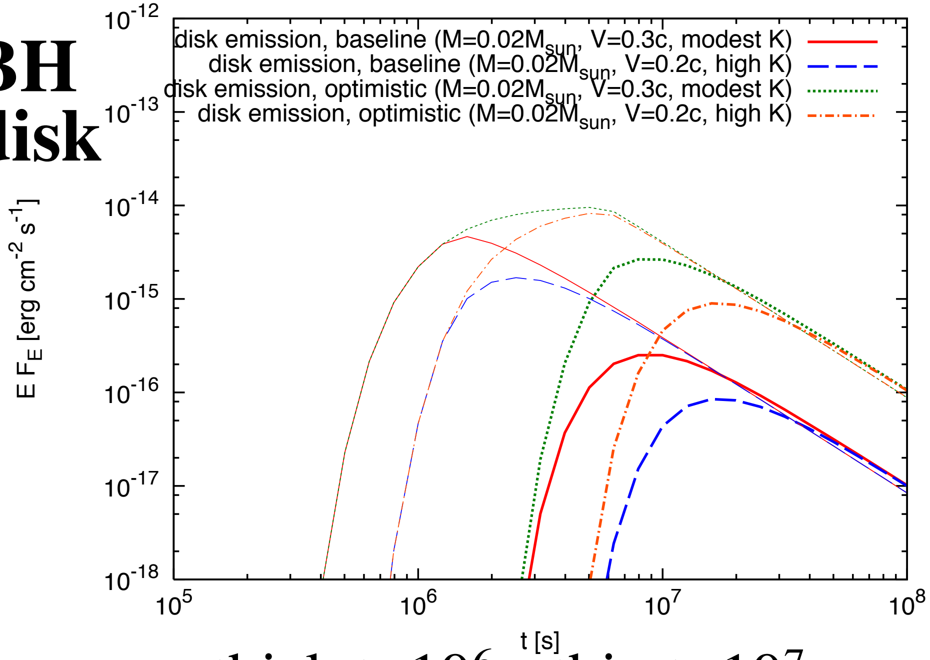
- some lines of sight must have τ~1
- Doppler broadening less severe

X-rays from remnant engine

Murase+ 1710.10757

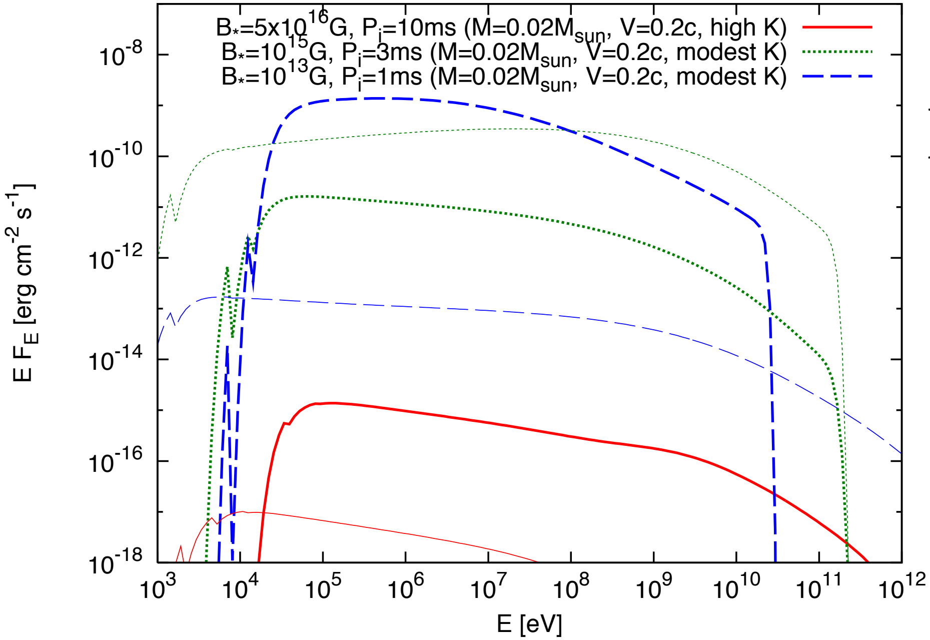


BH disk

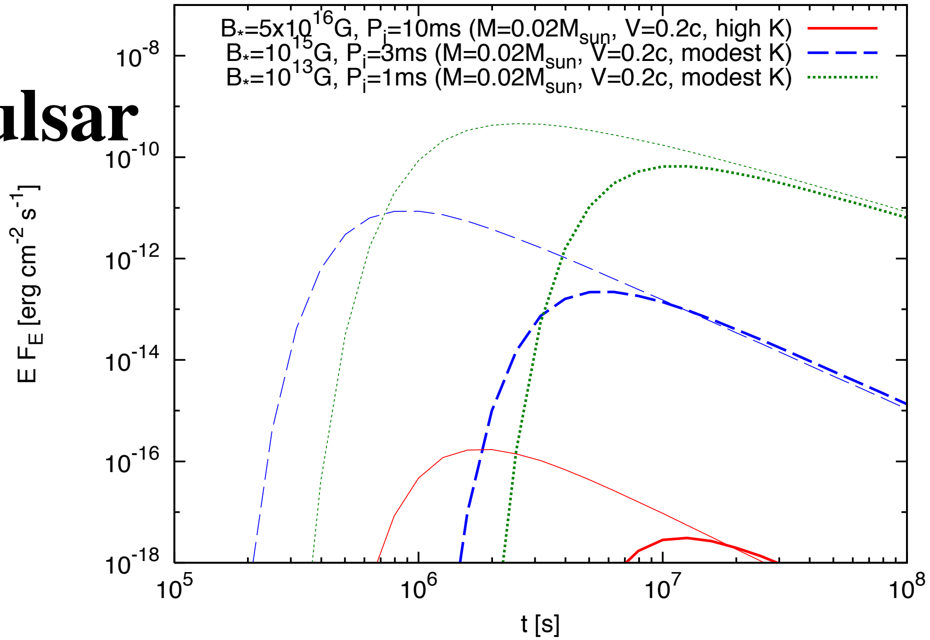


thick E=3 keV thin E=30 keV

thick t=10^6 s thin t=10^7 s

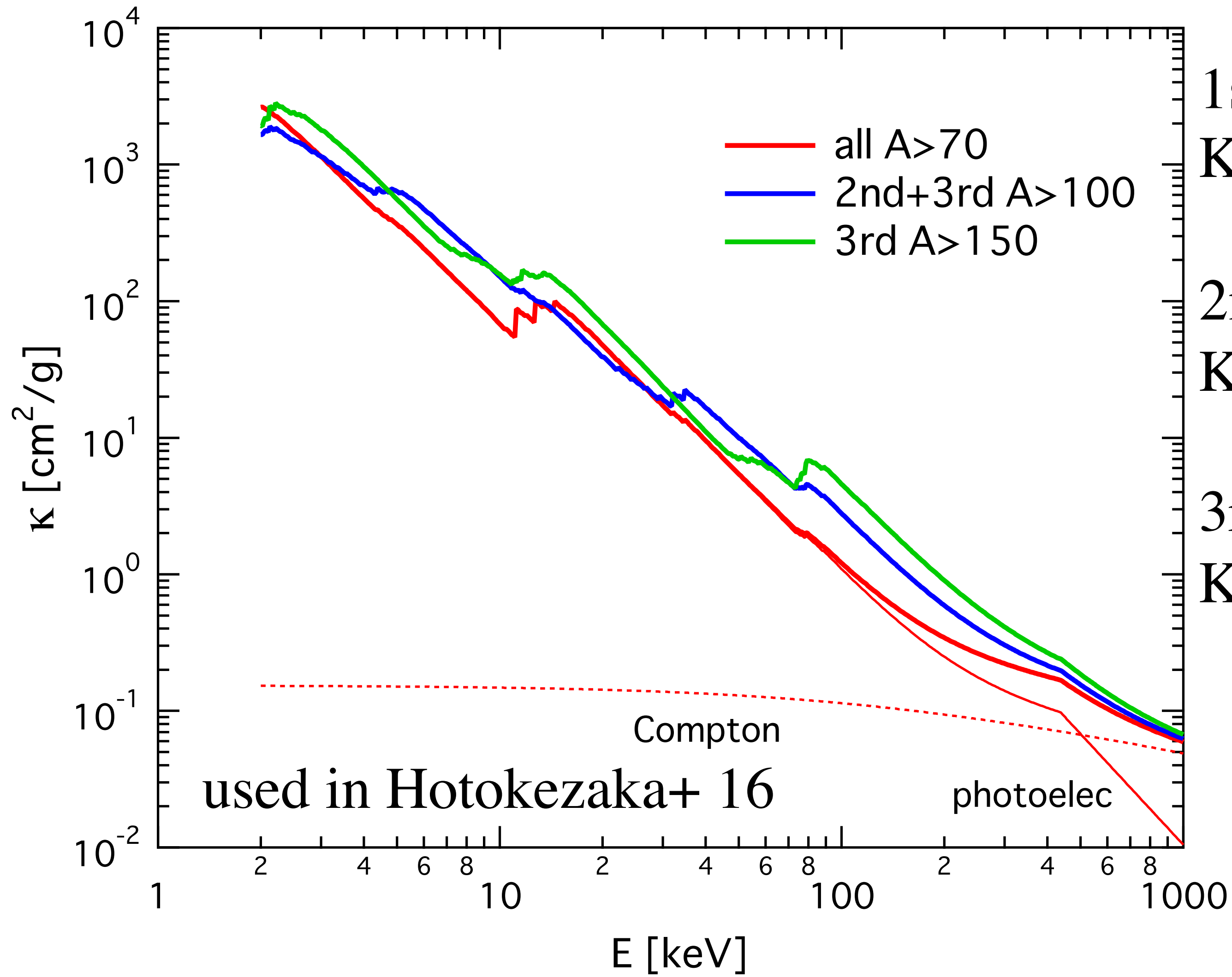


pulsar



X-ray opacity of NS merger ejecta

SI, Hotokezaka, Murase, Bamba+



1st peak e.g. ^{80}Se^{34}
K: 12.7keV, L: 1.66keV

2nd peak e.g. ^{130}Te^{52}
K: 31.8keV, L: 4.94keV

3rd peak e.g. ^{195}Pt^{78}
K: 78.4keV, L: 13.9keV

hard X-ray range
-> FORCE

homologous expansion

$$R_{ej} = v_{ej} t \qquad \tau_{\rm avg} = \frac{\kappa M_{ej}}{4\pi R_{ej}^2} = 2\times 10^3 \frac{\kappa}{10{\rm cm}^2/{\rm g}} \frac{M_{ej}}{0.01 M_\odot} \left(\frac{v_{ej}}{0.3c}\frac{t}{10^4 s}\right)^{-2}$$

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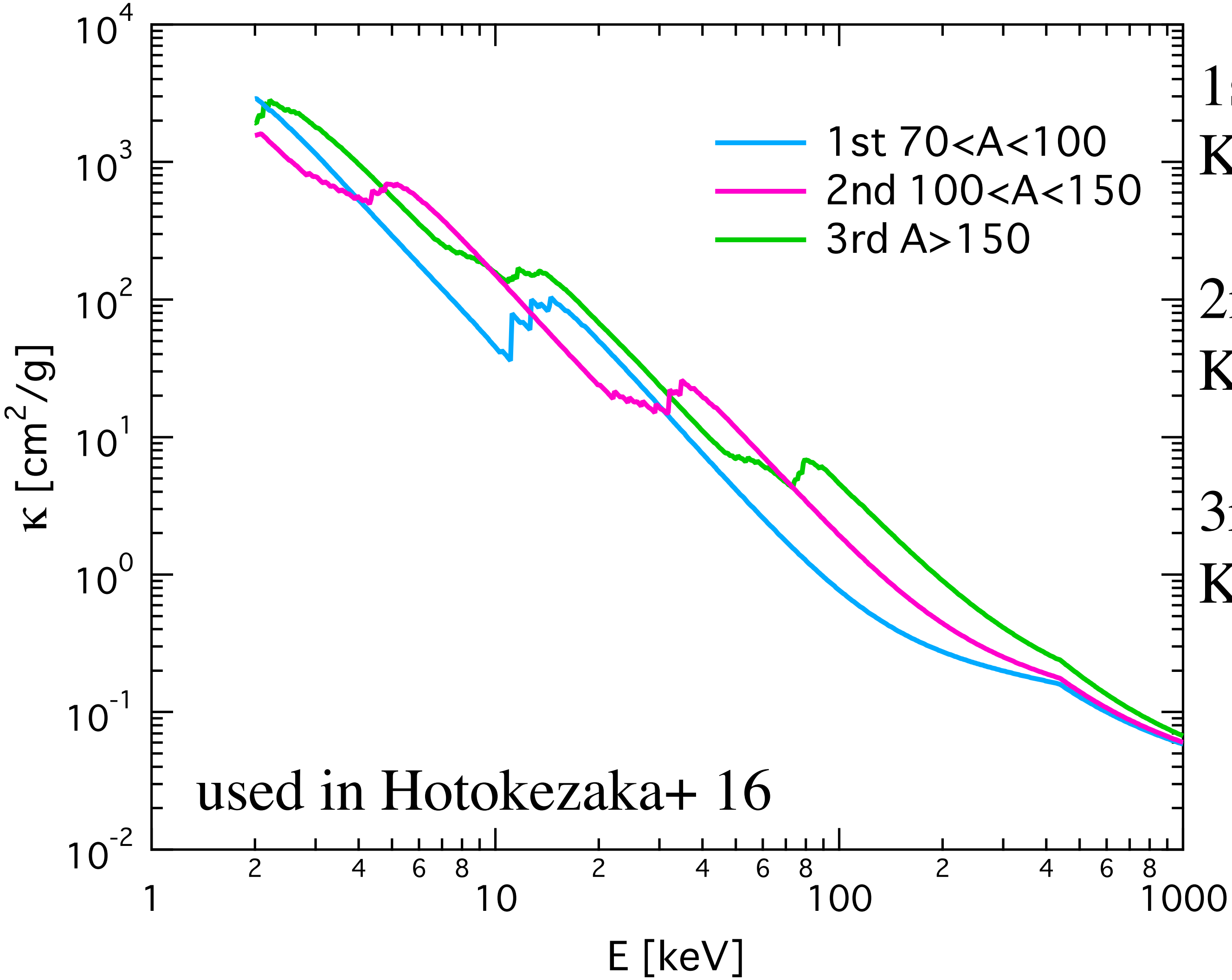

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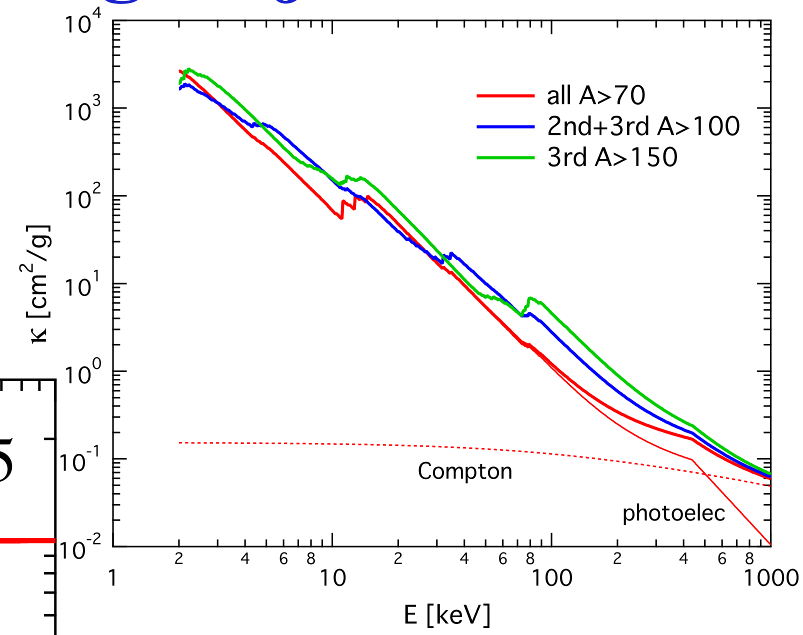
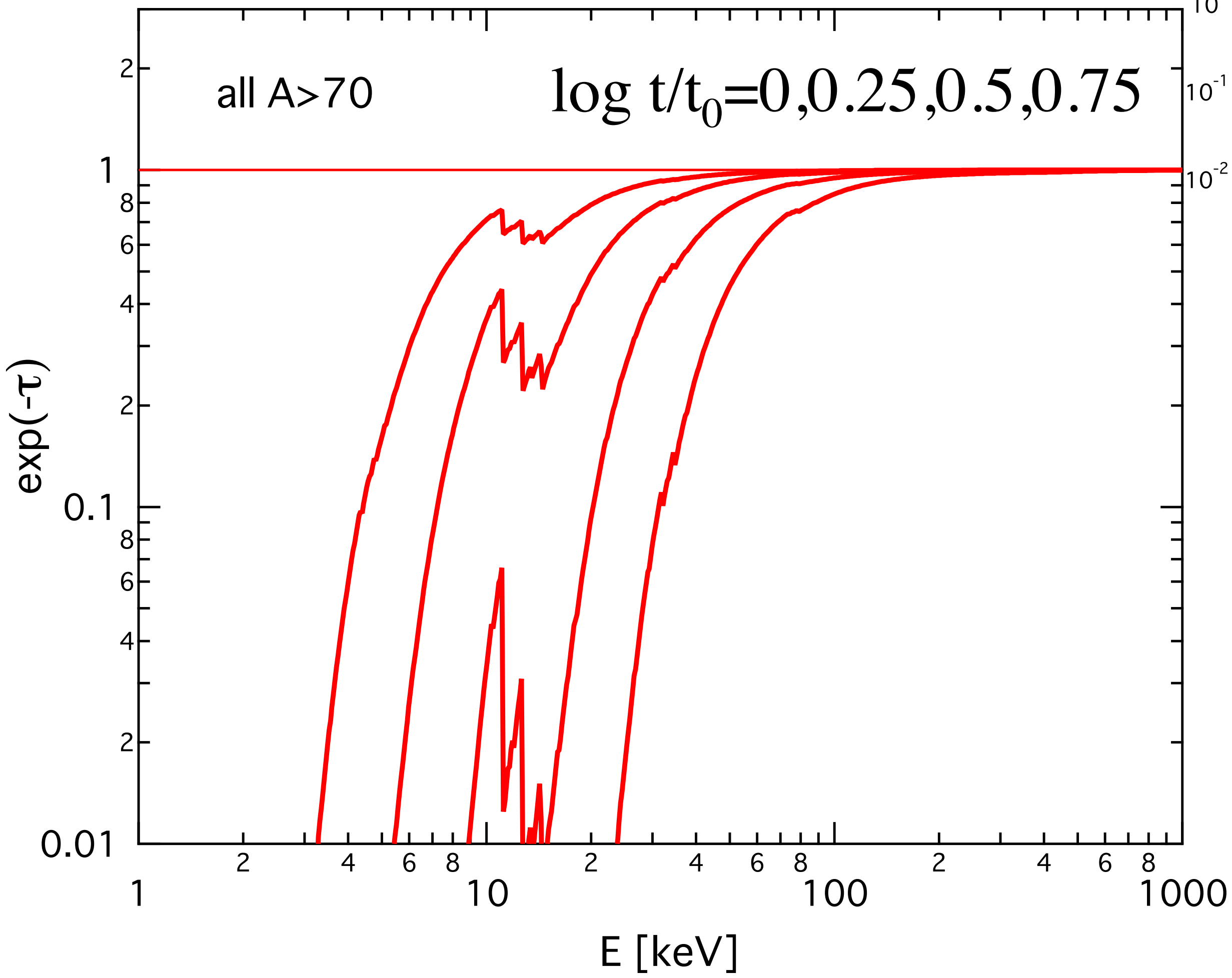
X-ray “spectra” through NS merger ejecta

assume $\tau \sim 1$ for 3rd peak K edge

for line of sight at $t=t_0$

$\tau \propto t^{-2}$





X-ray "spectra" through NS merger ejecta

assume $\tau \sim 1$ for 3rd peak K edge
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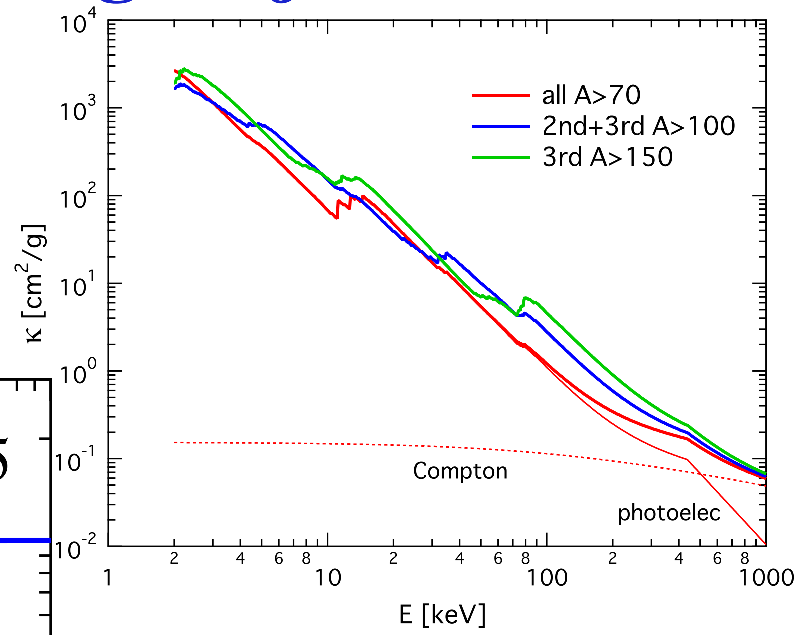
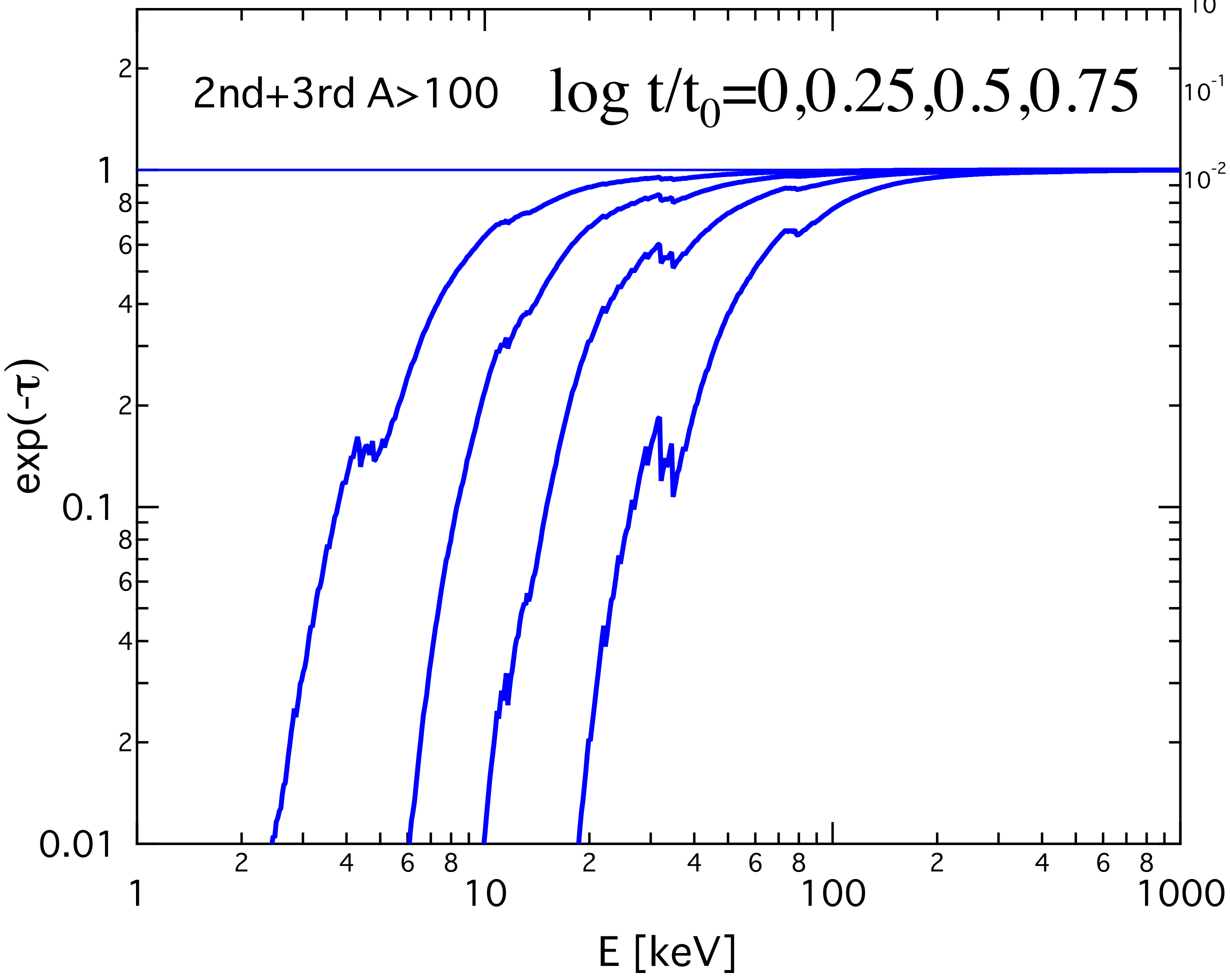
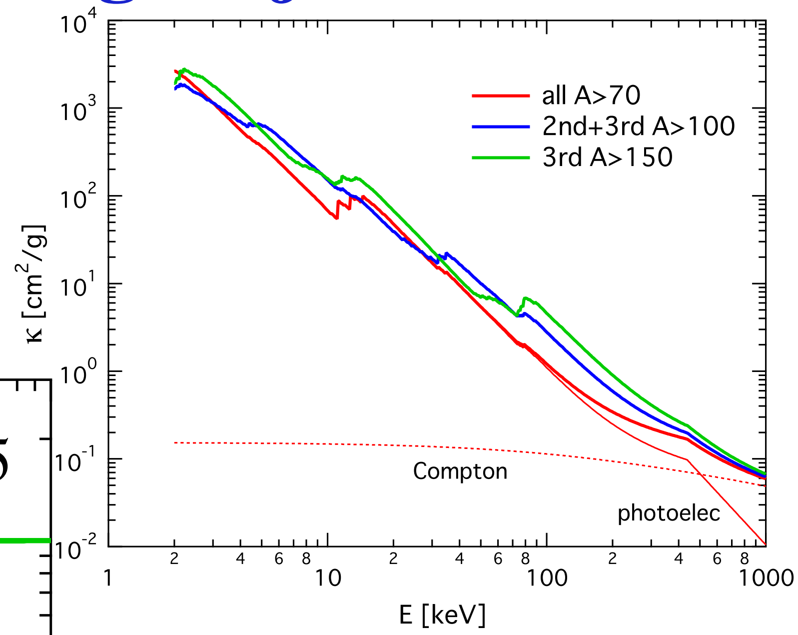
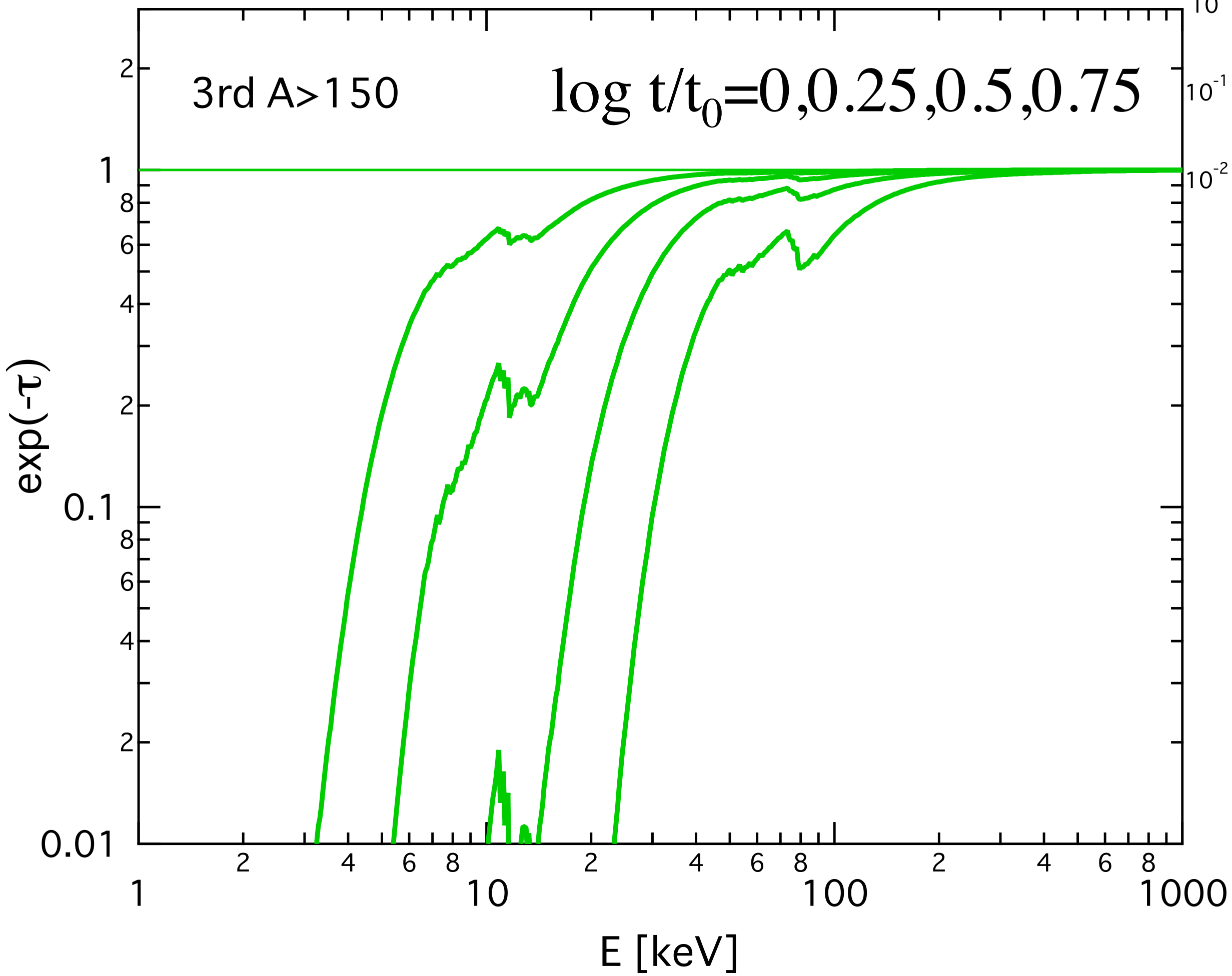




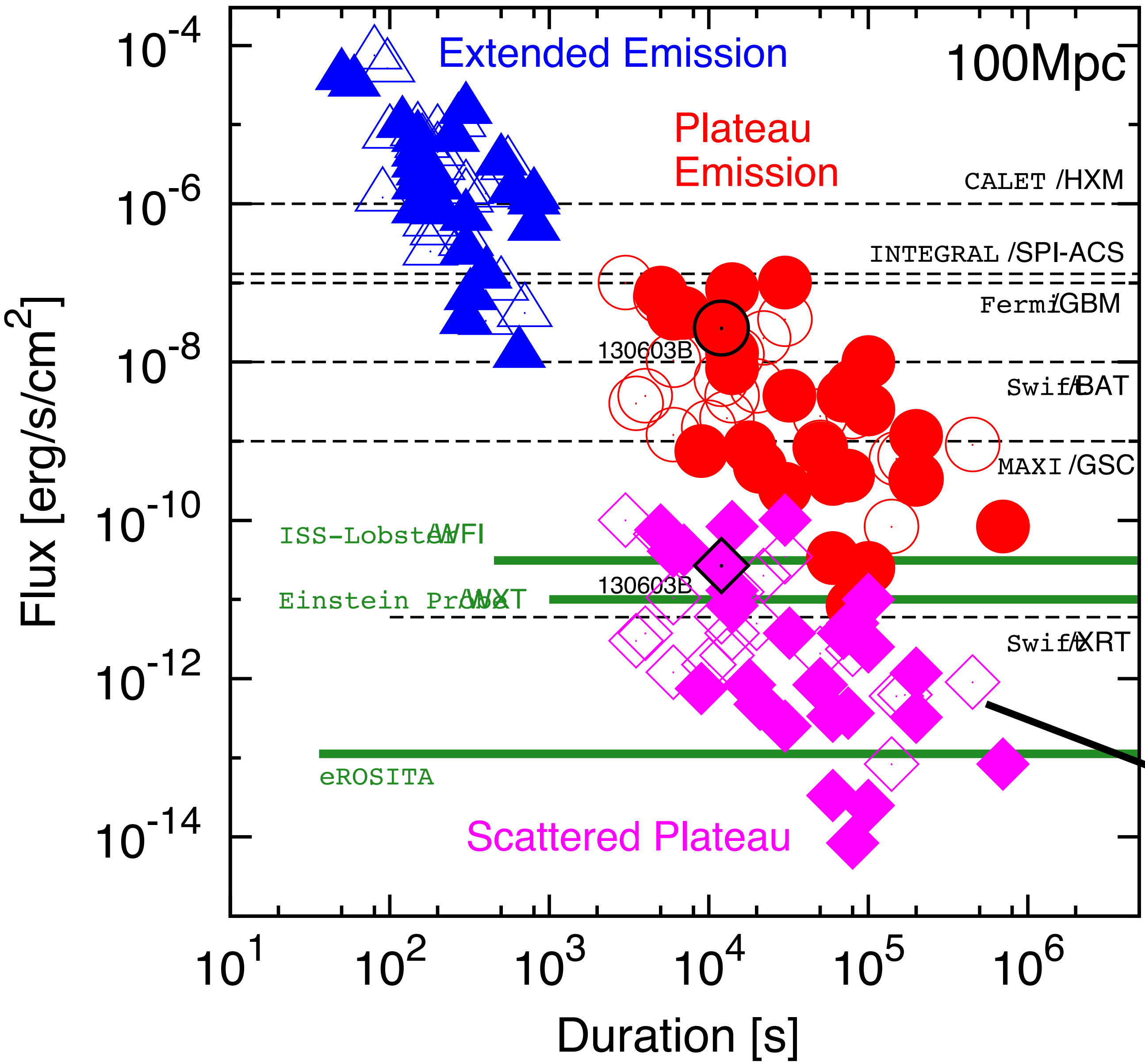
X-ray “spectra” through NS merger ejecta

assume τ~1 for 3rd peak K edge
for line of sight at $t=t_0$
$\tau \propto t^{-2}$





extended/plateau X-rays as GW counterparts

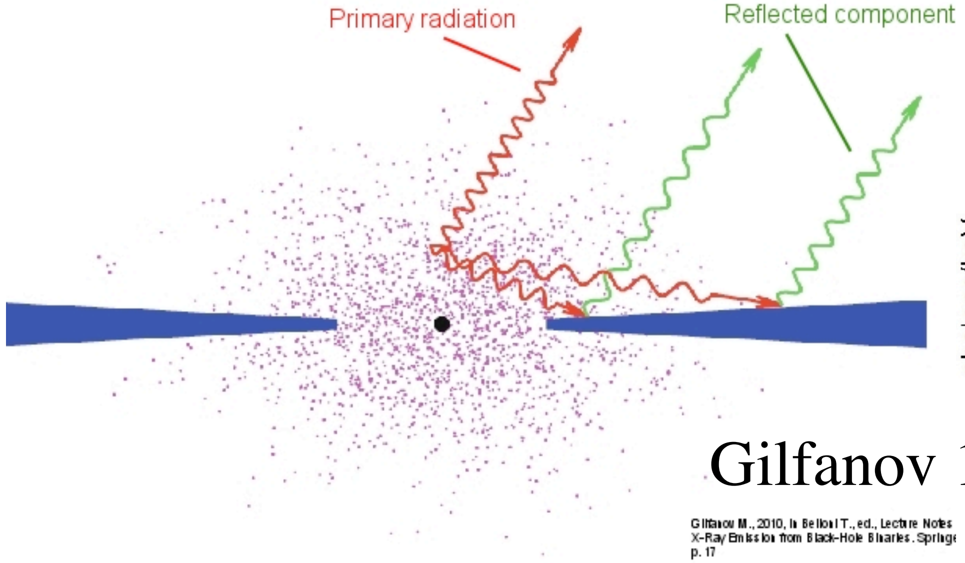


Kisaka+ 17

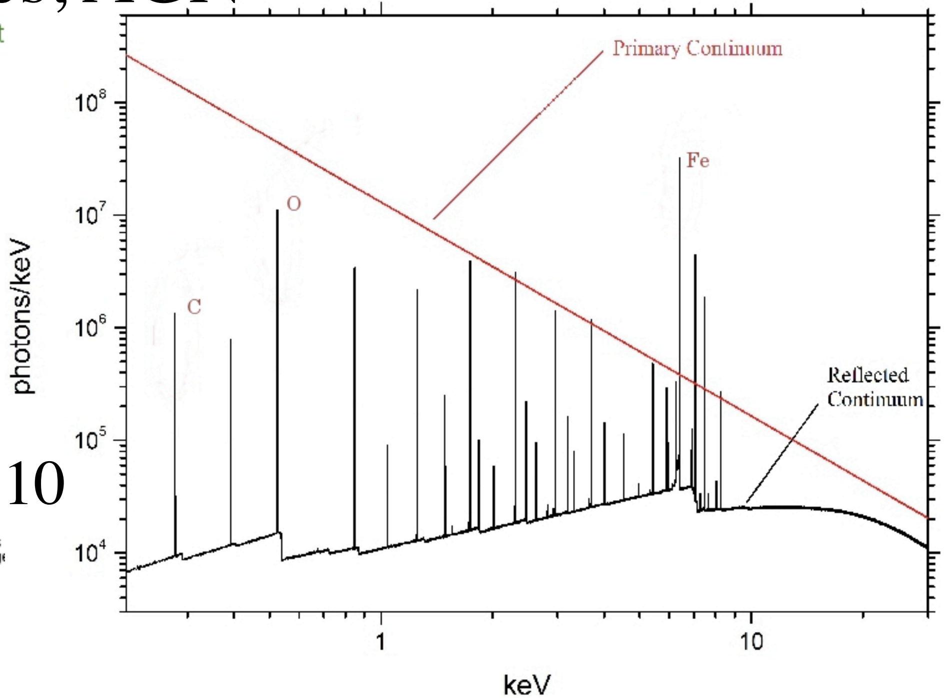
NB:
"scattered component"
quasi-isotropic
->
fluorescent line features?

X-ray reflection spectra

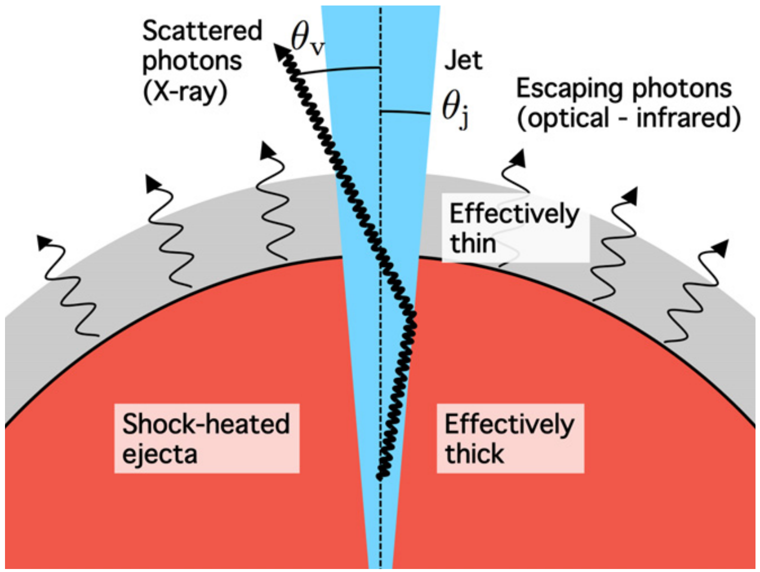
accretion disks in X-ray binaries, AGN



Gilfanov 10



NS merger ejecta



Kisaka+ 15

spectra?

まとめ

I. 遠方宇宙

high-z GRB：伸び悩み？（期待外れ？）

宇宙再電離：

以前ほど派手なことは起こっていないかも

が、まもなく手が届くところに?

後の銀河の進化、宇宙のバリオン・DM分布などの

理解にとっても重要

クエーサーの寄与再考の価値あり

ガンマ線吸収も

II. 元素の起源

NS mergerにおけるr-processのX線診断

macro/kilonovaより直接的検証、モデル判定の可能性

より詳細な検討中