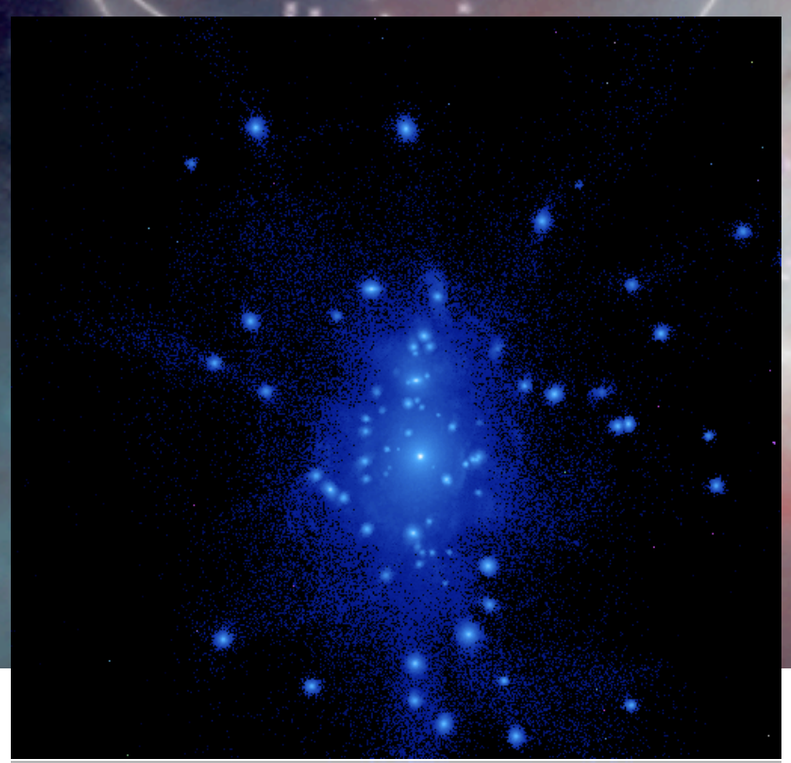
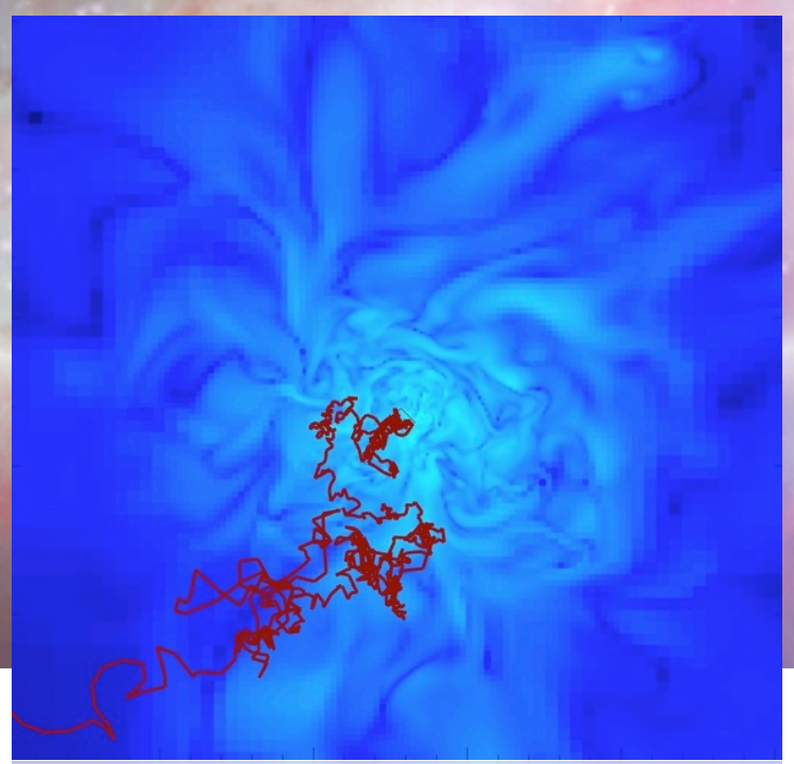
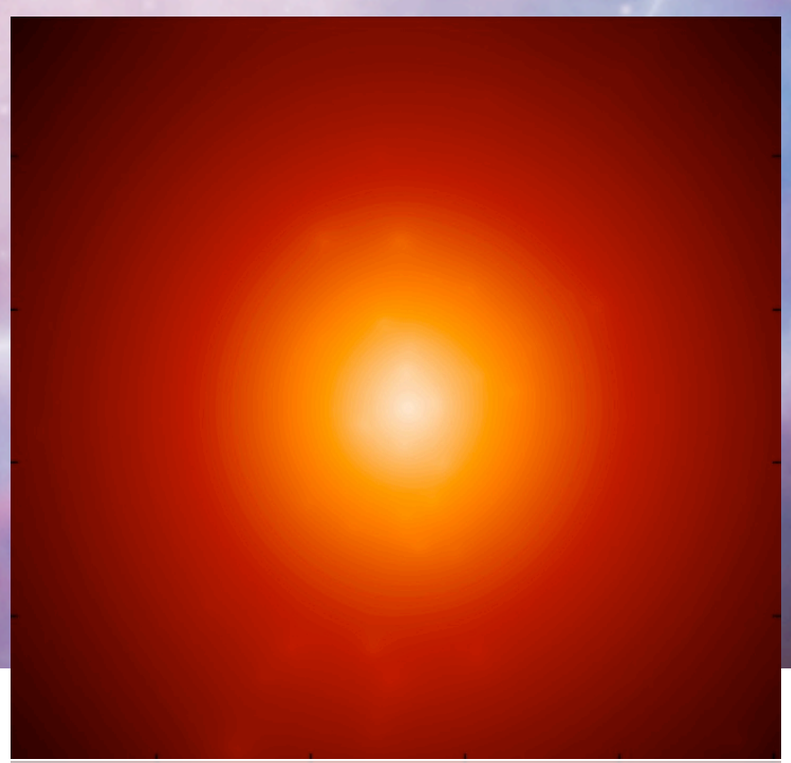
Propagation of ultrahigh energy nuclei in clusters of galaxies: survival and secondary emissions

K.K., D. Allard, K. Murase, J. Aoi, Y. Dubois, T. Pierog, S. Nagataki, arXiv:0907.2433







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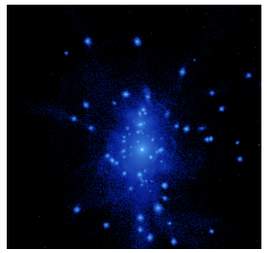

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AGN (FR-I), but also cosmological shock regions

Best 2004, Gilmour 2009

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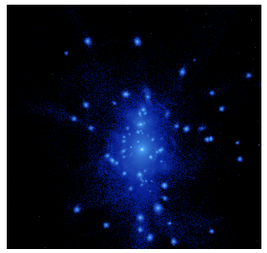

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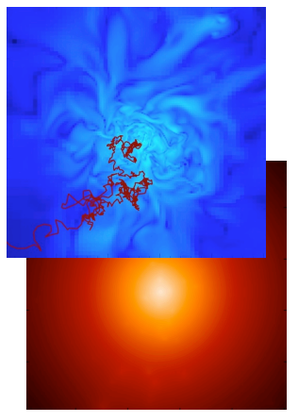

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strong magnetic field (up to 40 μG in core) *e.g. Carilli & Taylor 2002*

confinement of cosmic rays of energy $E < 10^{17}$ eV

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higher IR photon density as compared to the extragalactic background

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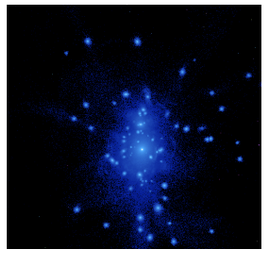

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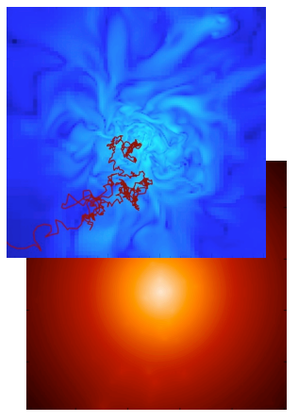

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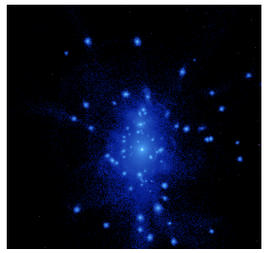

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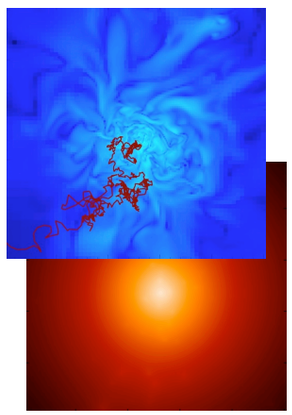

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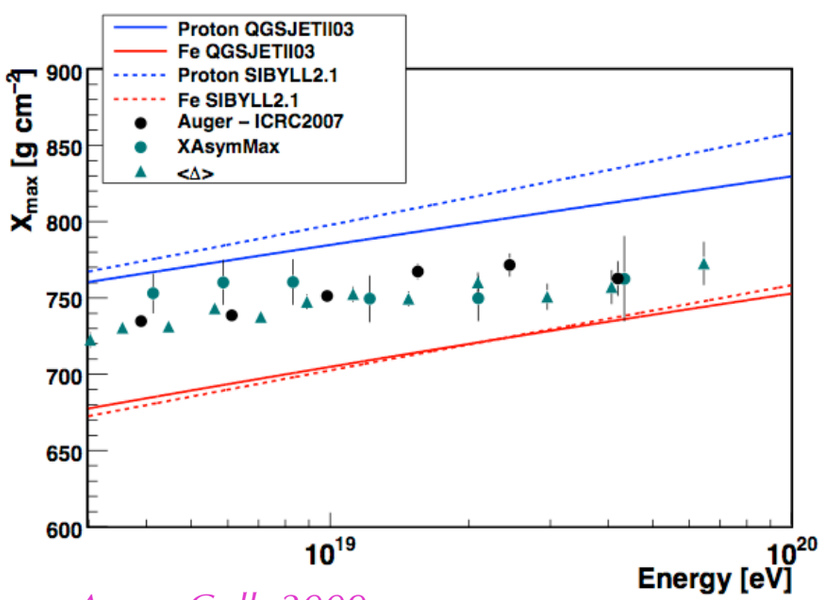

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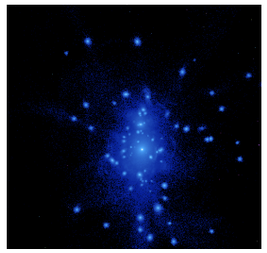

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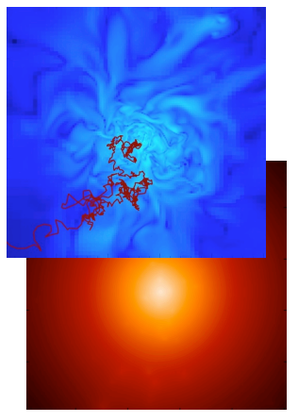

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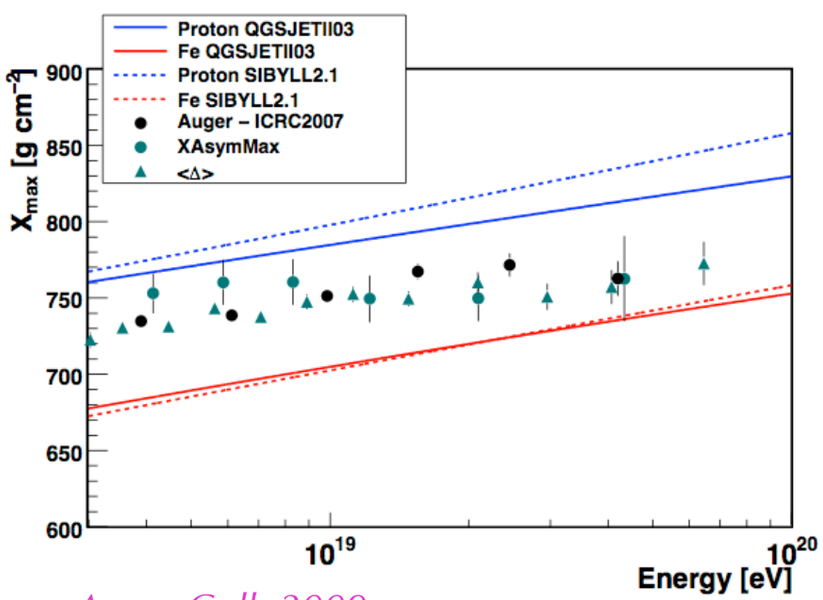

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Anchordoqui et al. 99, 08, Allard & Protheroe 09

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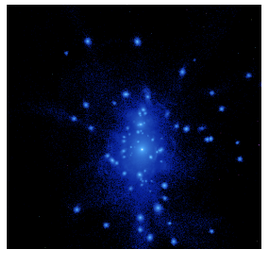

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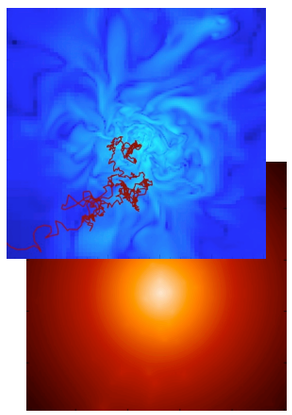

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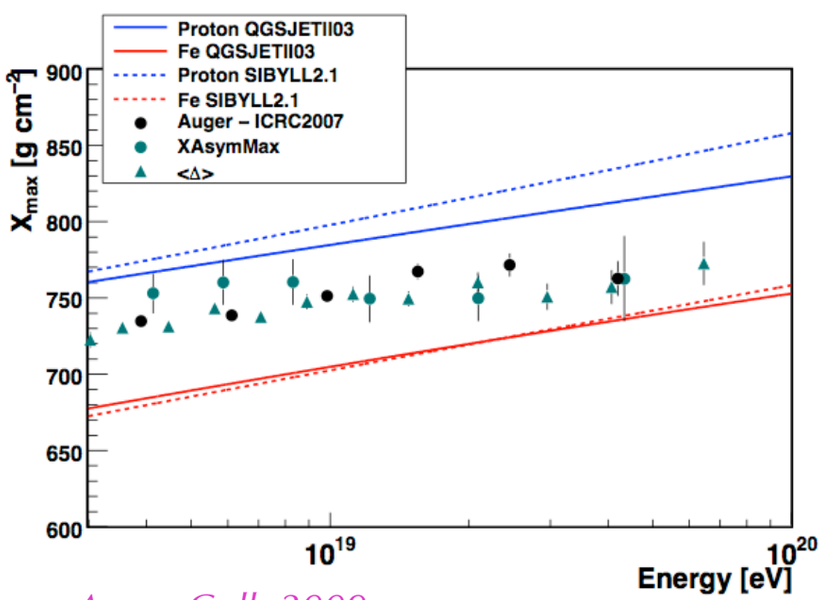

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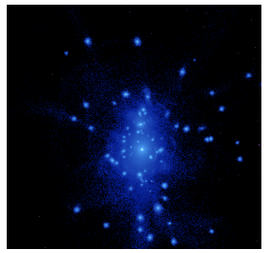

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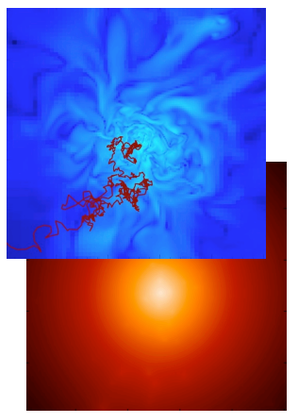

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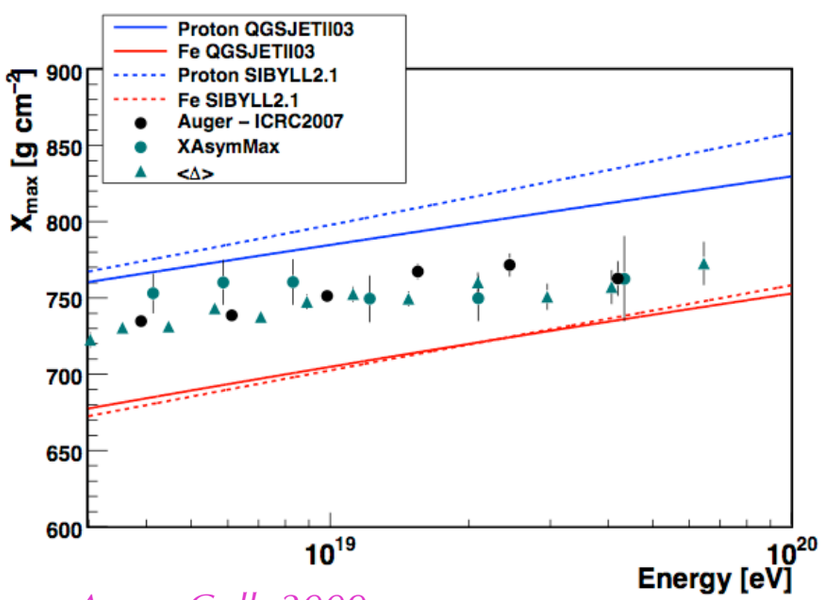

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survival of injected heavy nuclei?

what secondary emission?

Modeling cluster backgrounds and nuclei propagation

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Magnetic field, photonic and baryonic density of cluster of galaxies:
(3D MHD simulations by *Dubois & Teyssier 2008*)

photon density calculated by scaling
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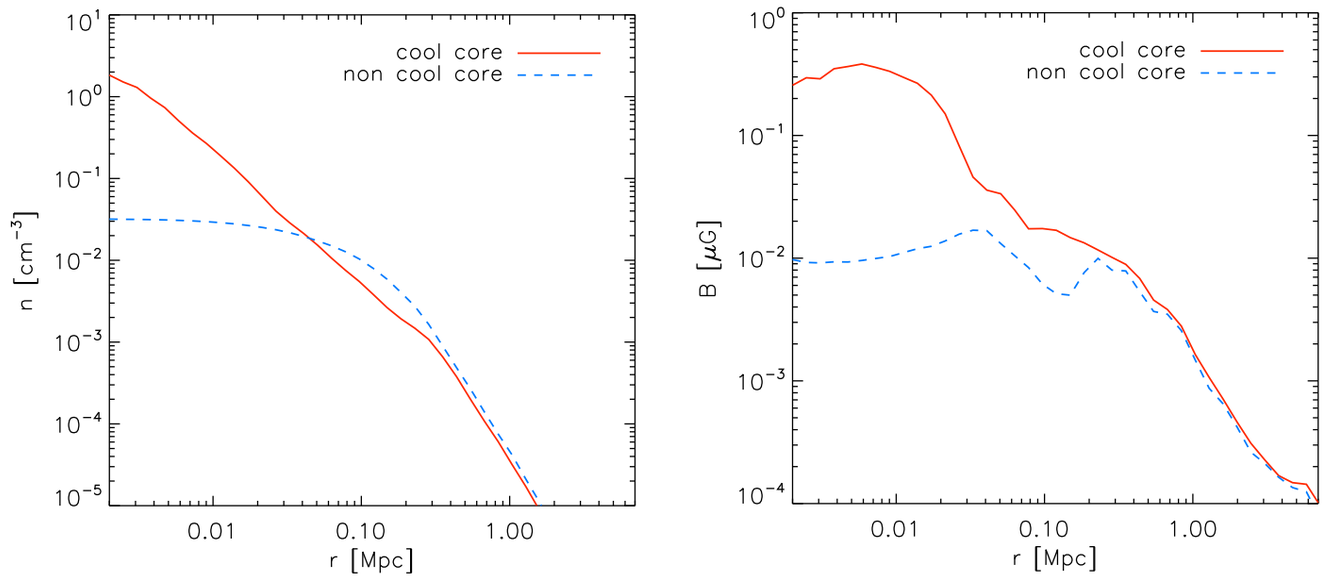

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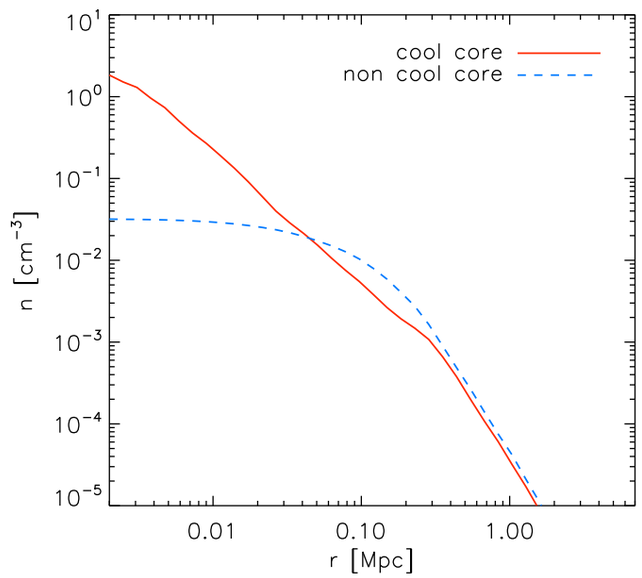
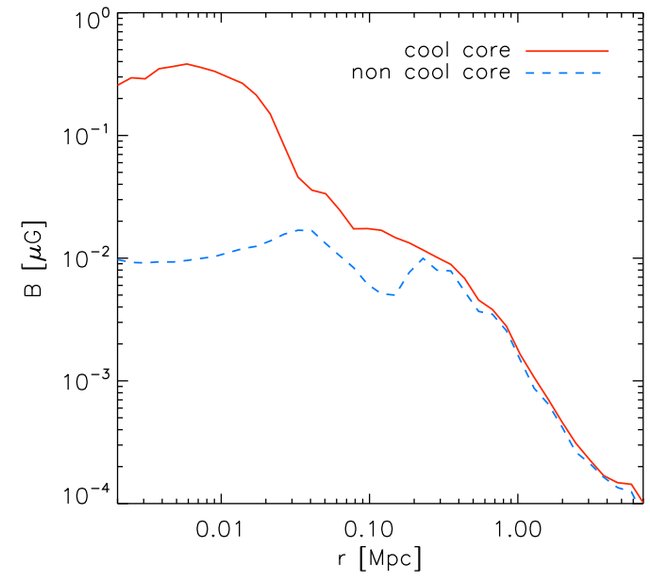
normalization of overall B
position of source
injection duration

STUDIED PARAMETERS





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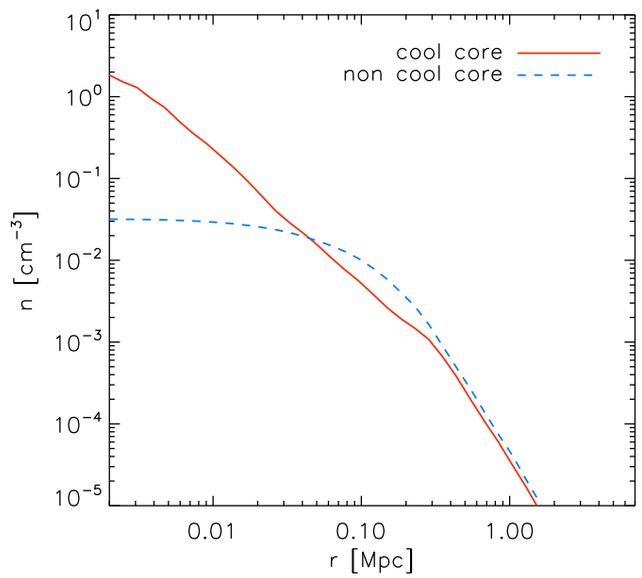

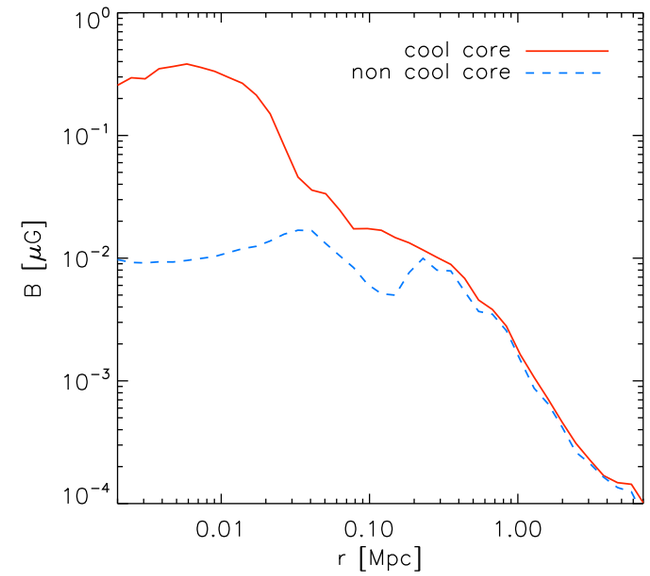

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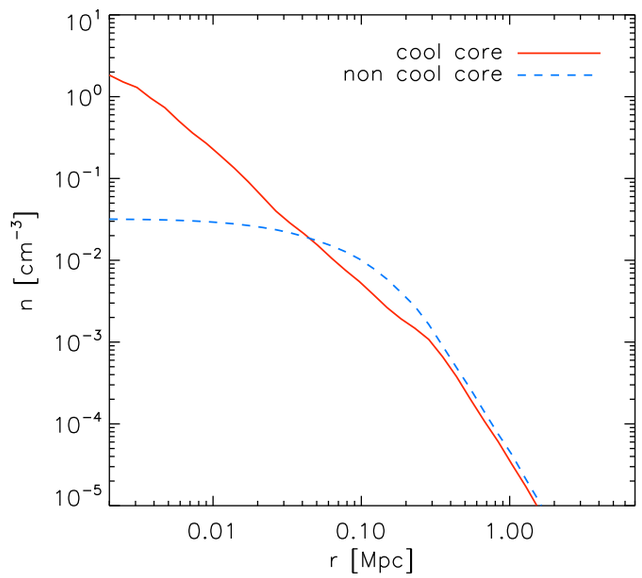

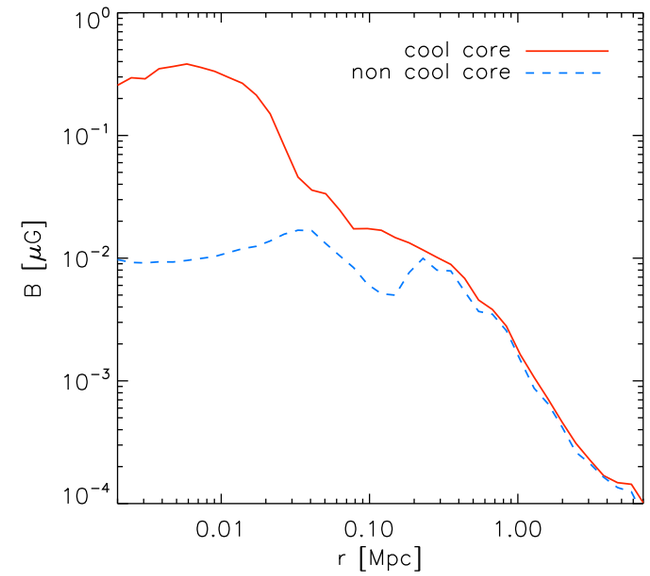

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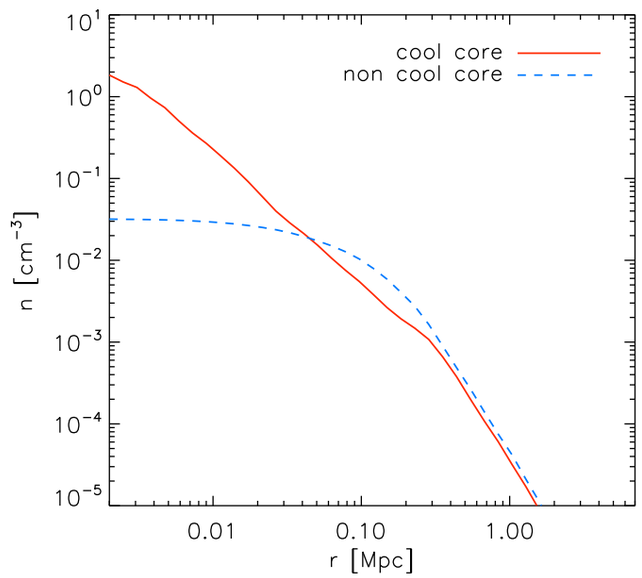

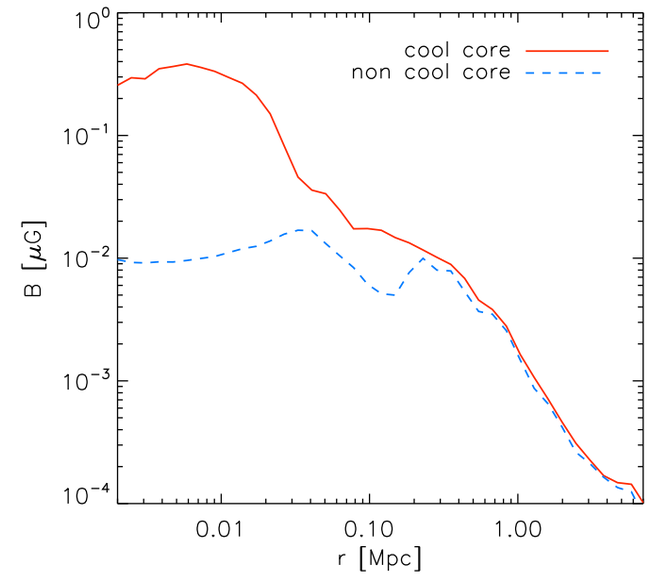

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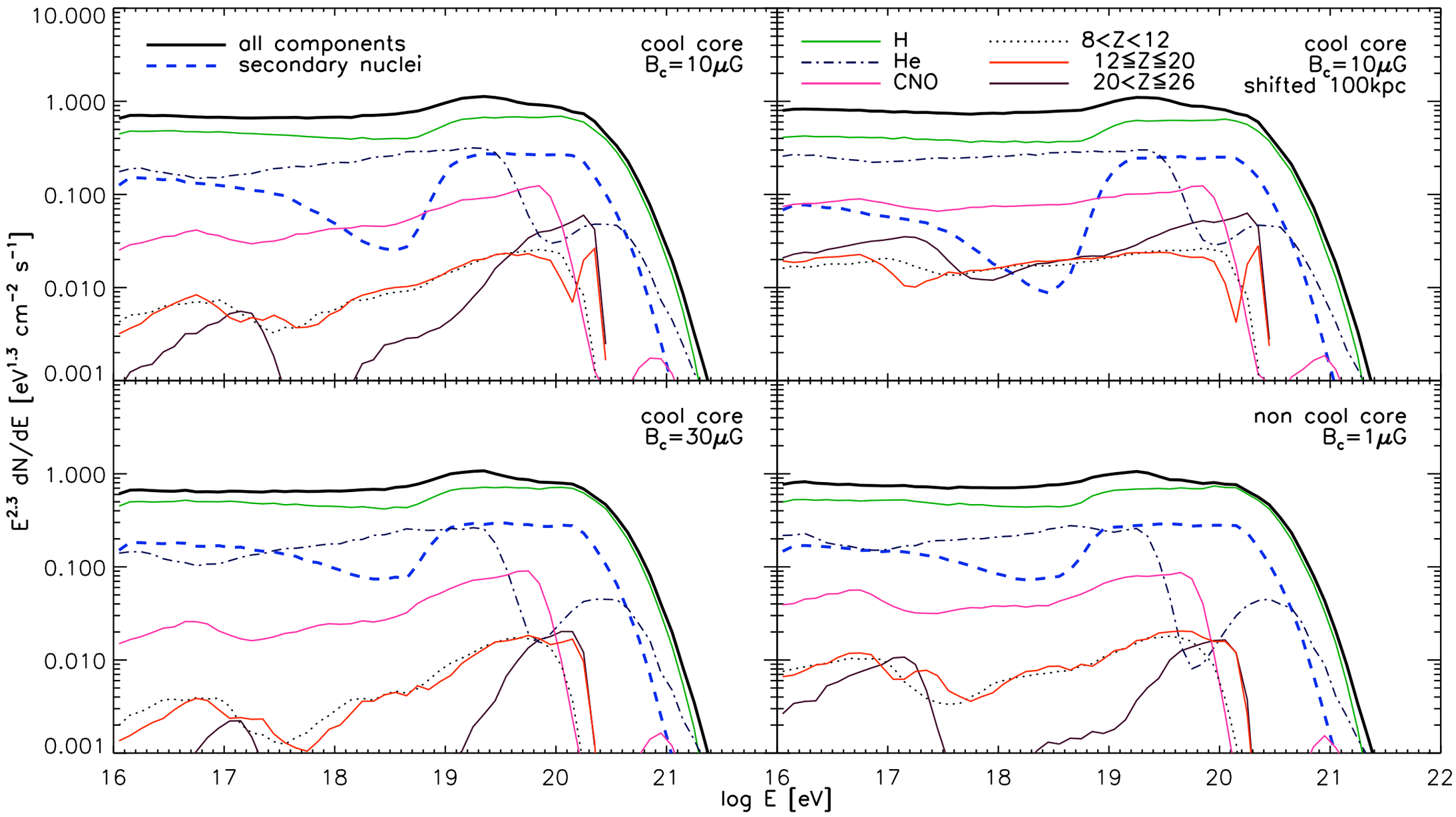
Gamma-ray cascades:
Treated as post-analysis (method of *Murase et al. 2008*)

Mixed composition cosmic rays propagating in clusters of galaxies



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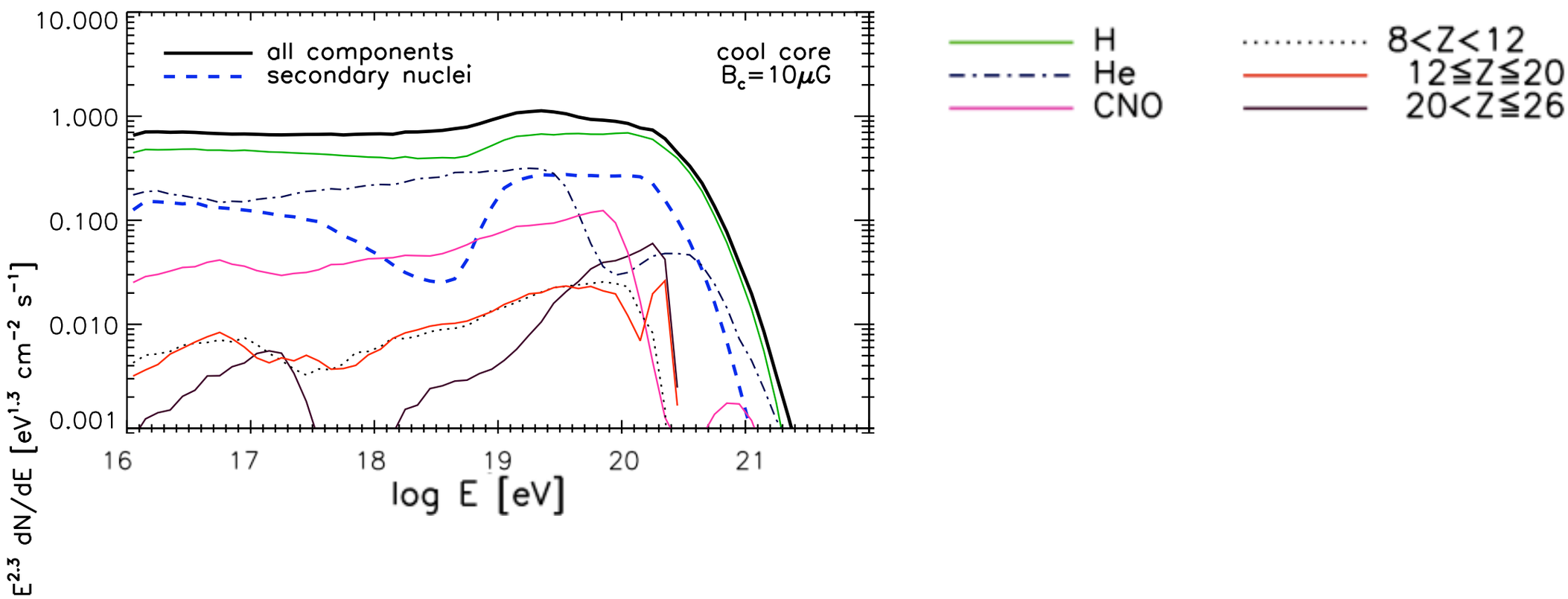

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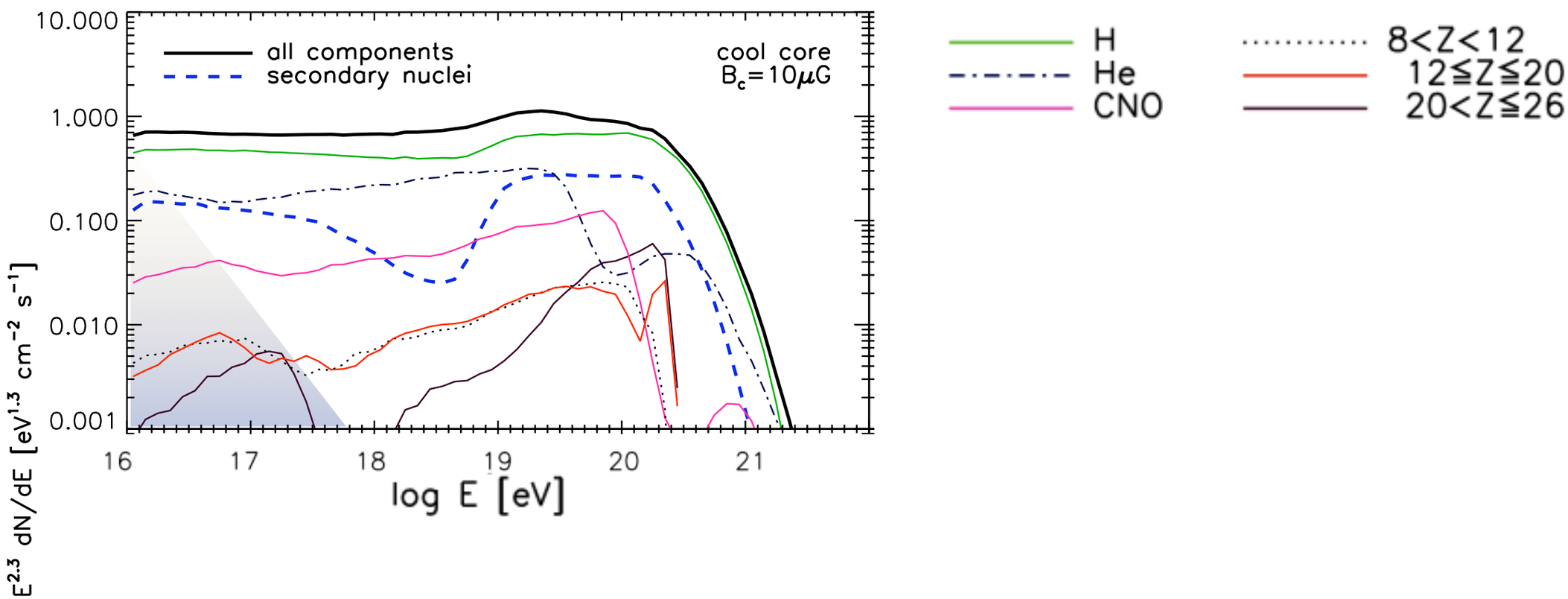

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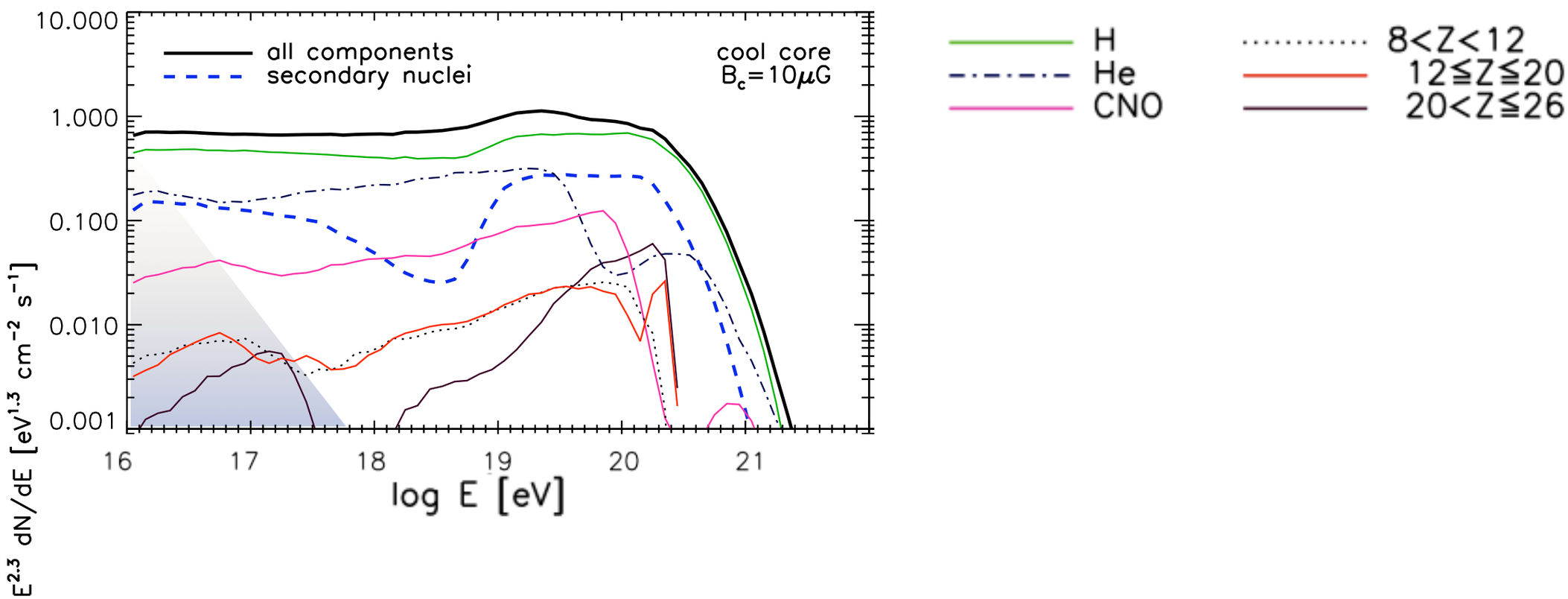

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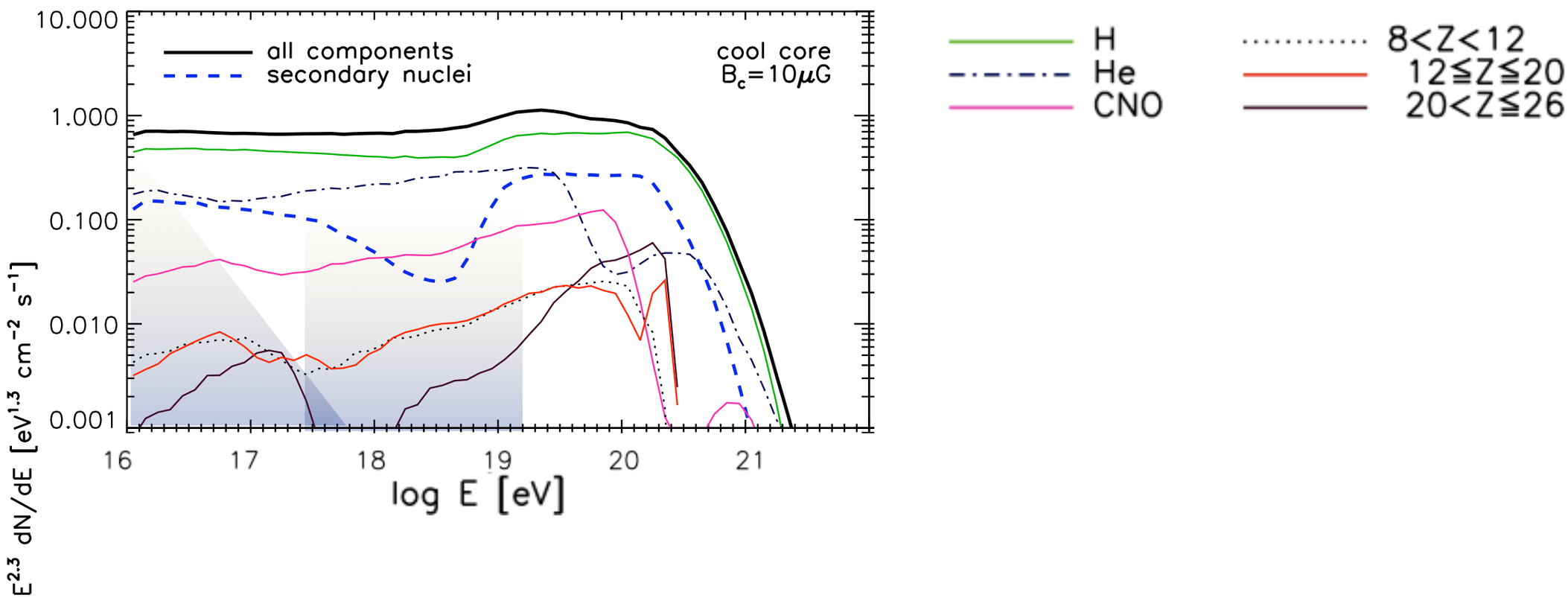

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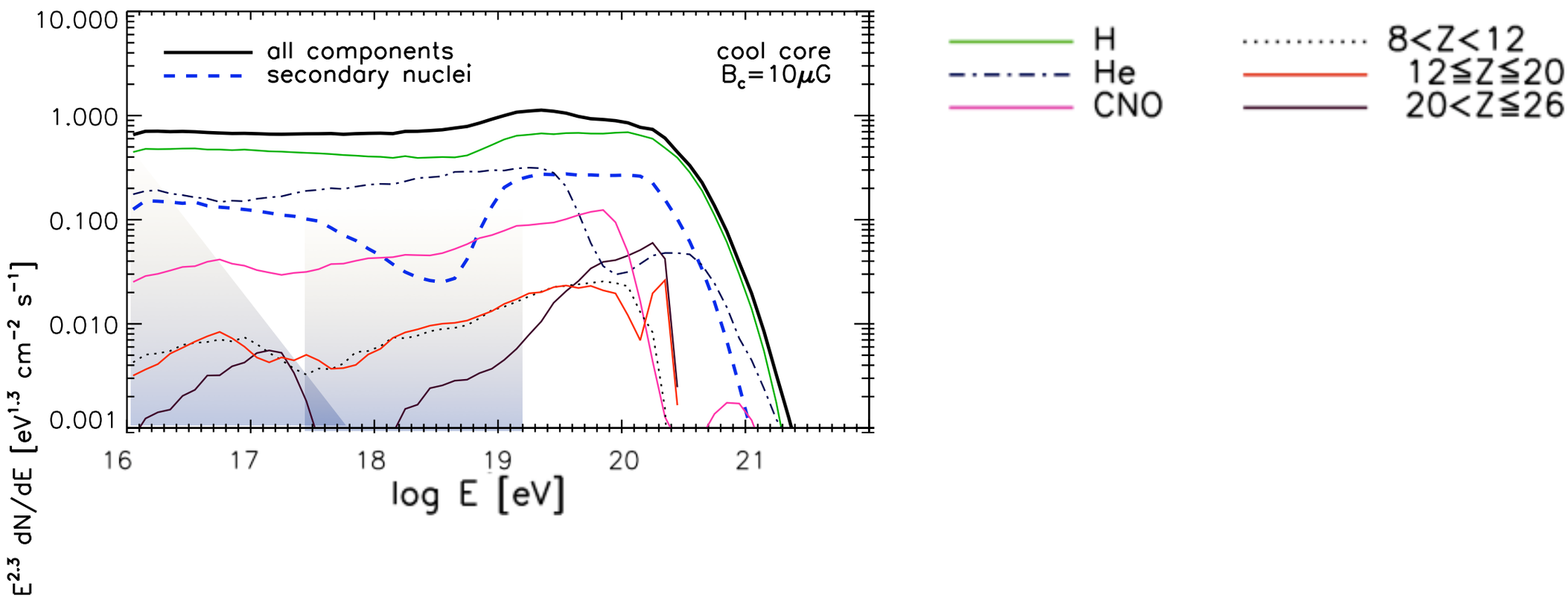

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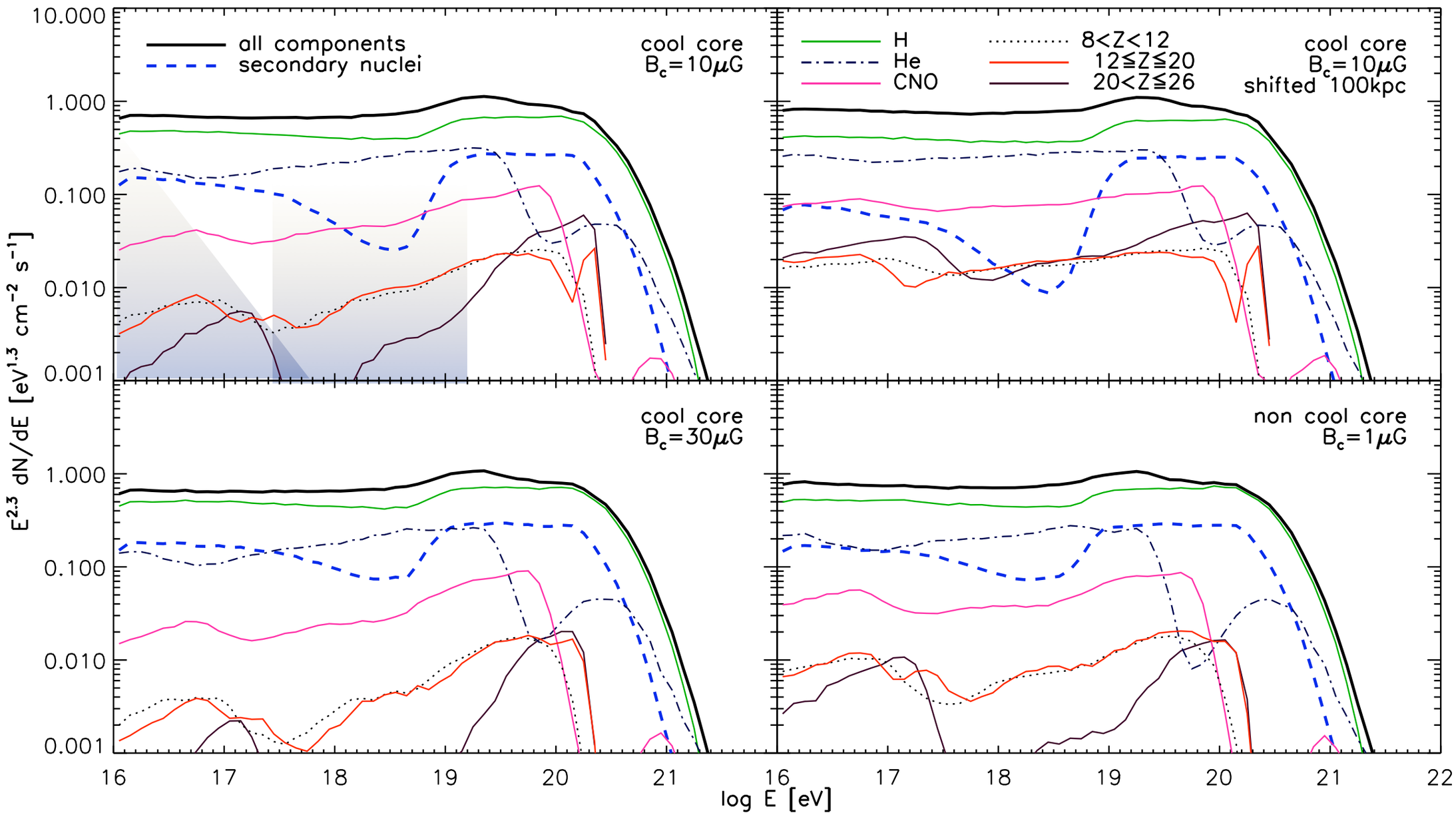

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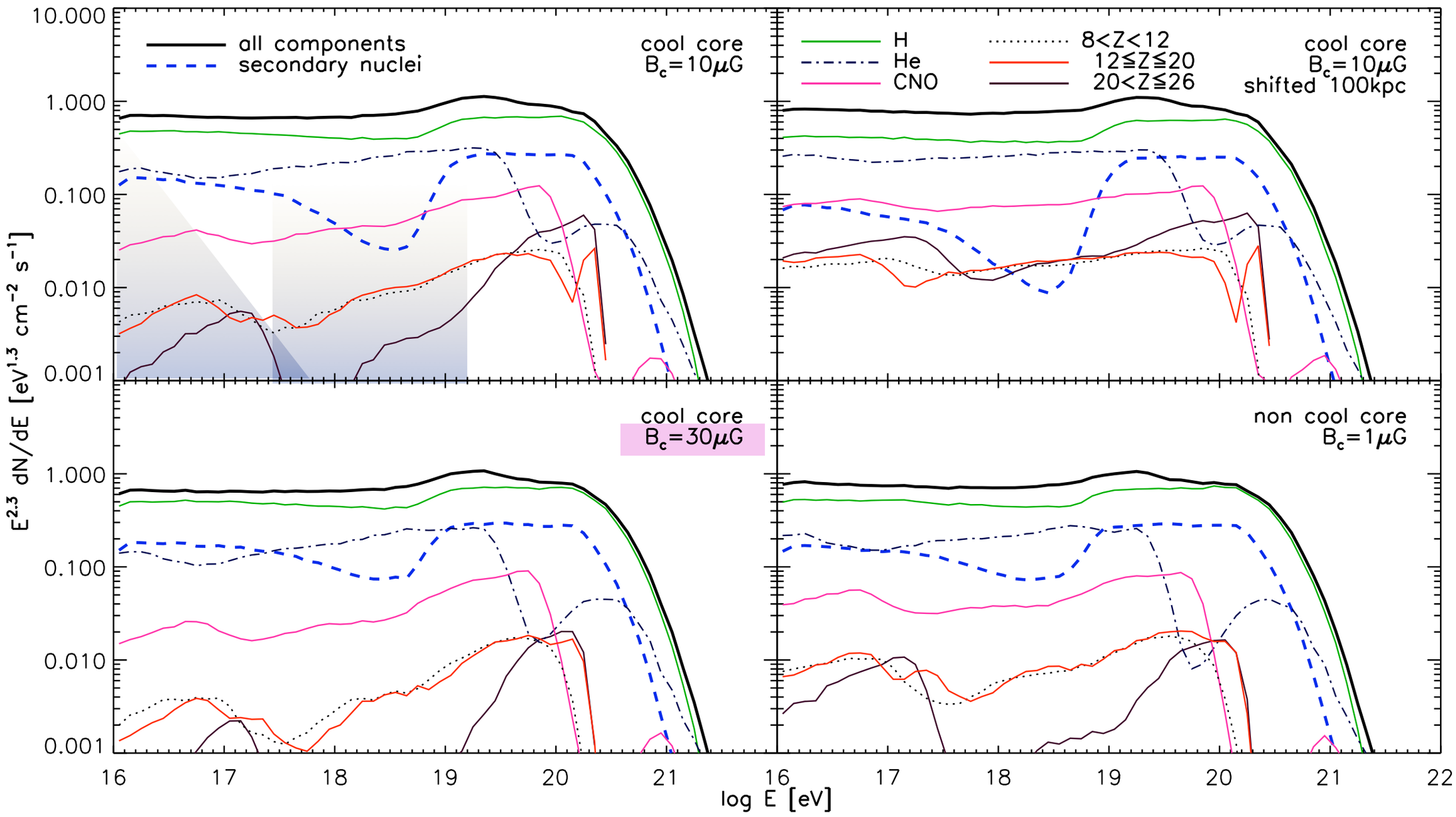

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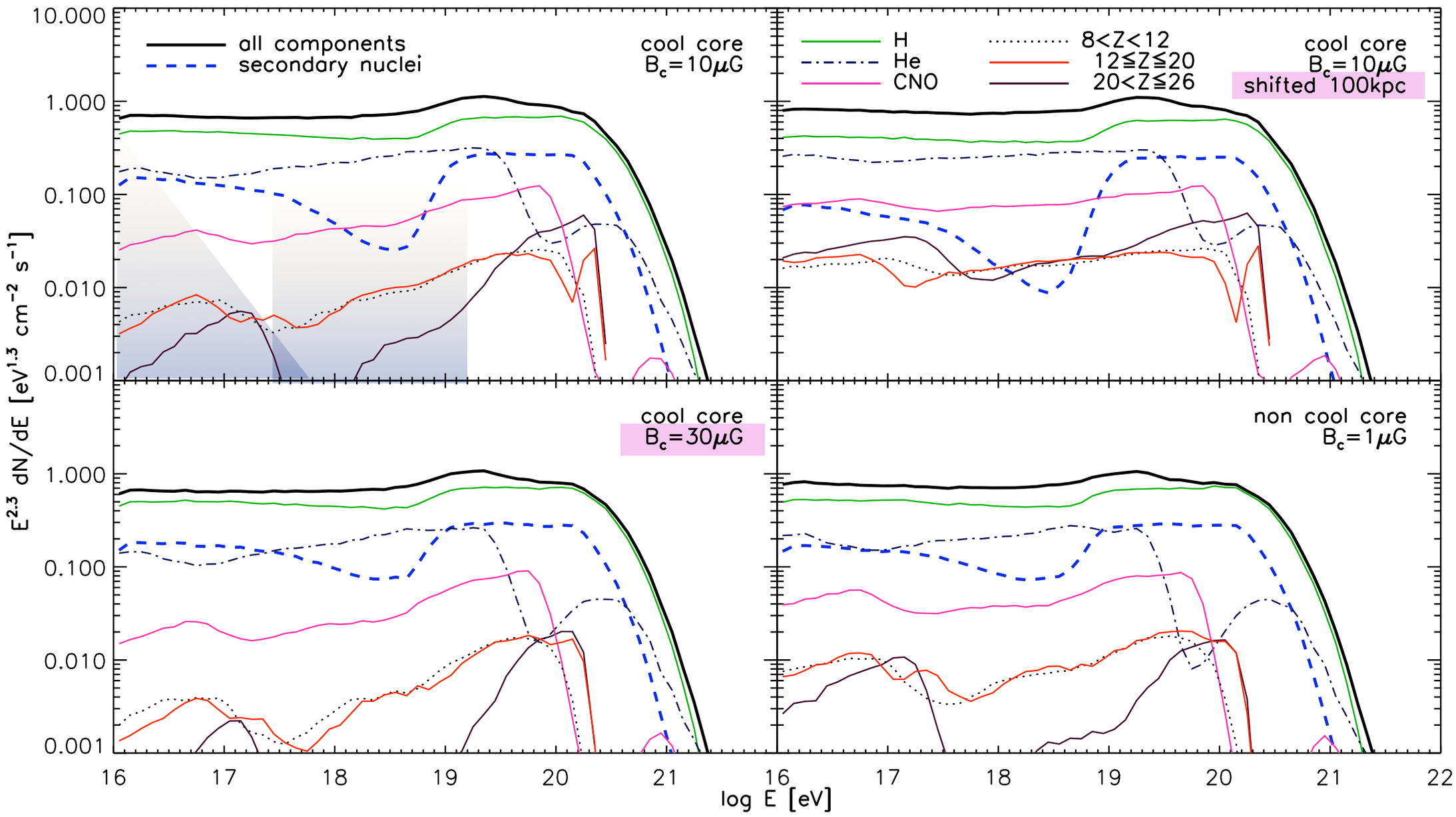

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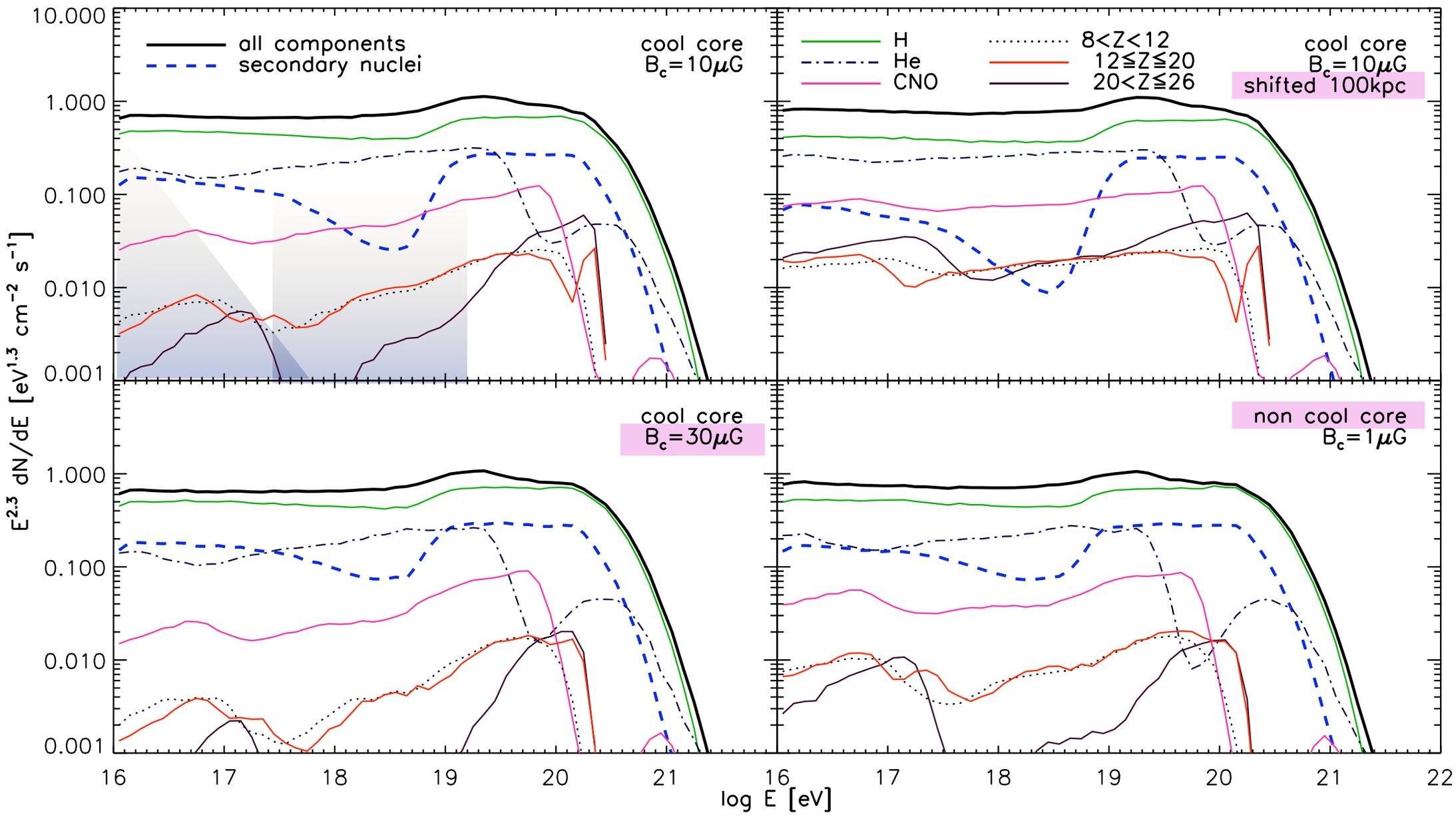
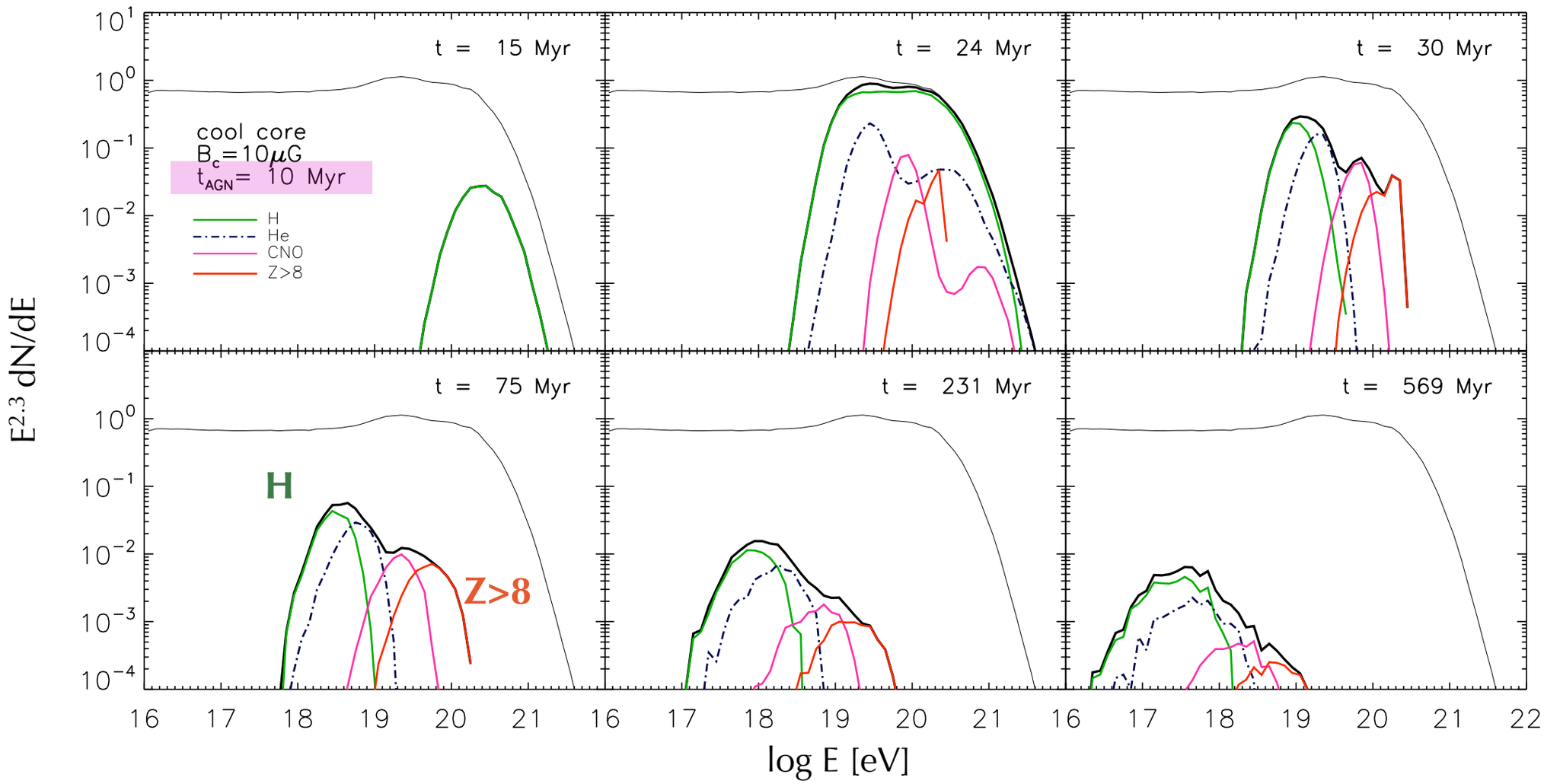


Taking into account the limited AGN lifetime



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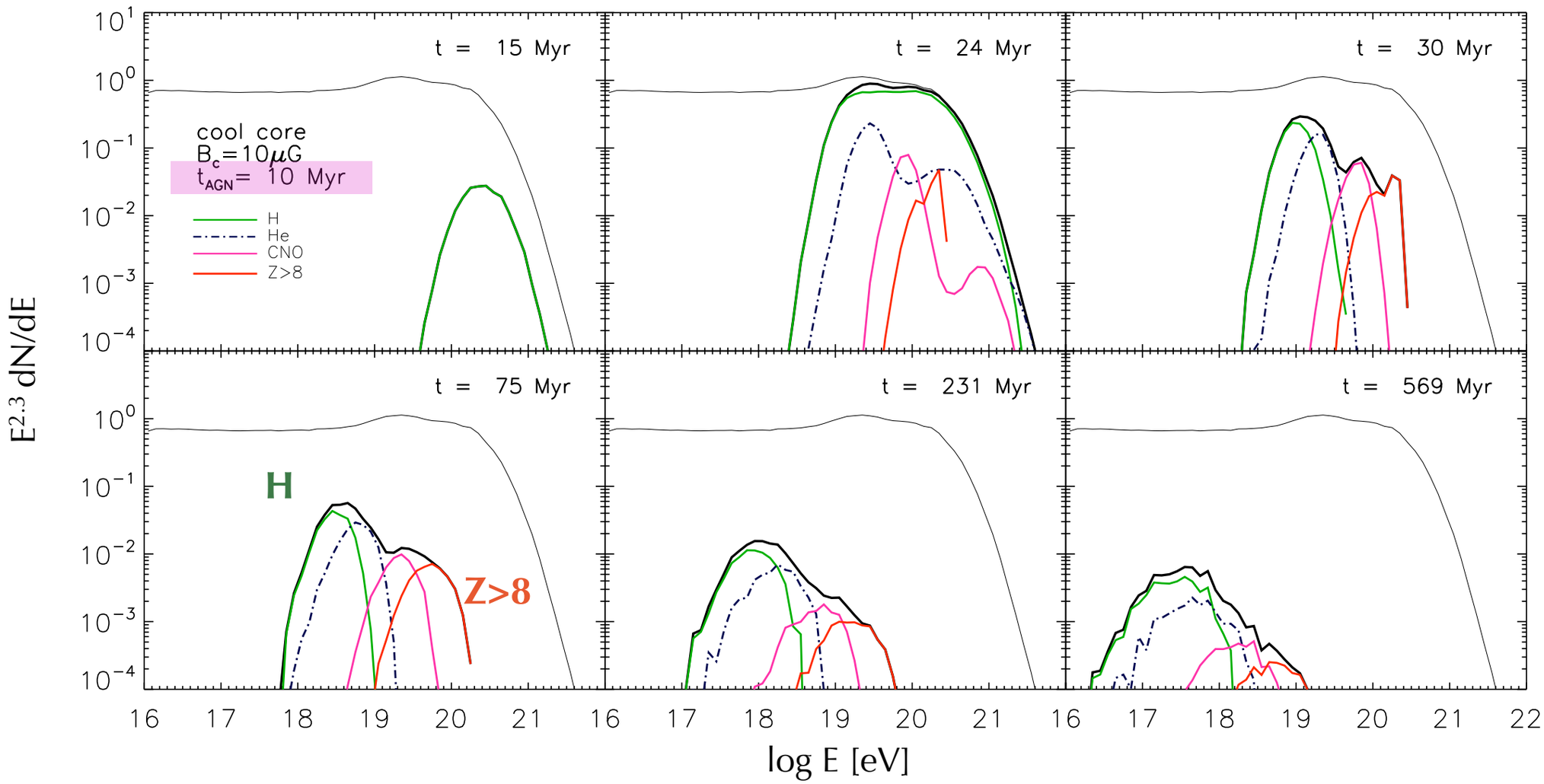

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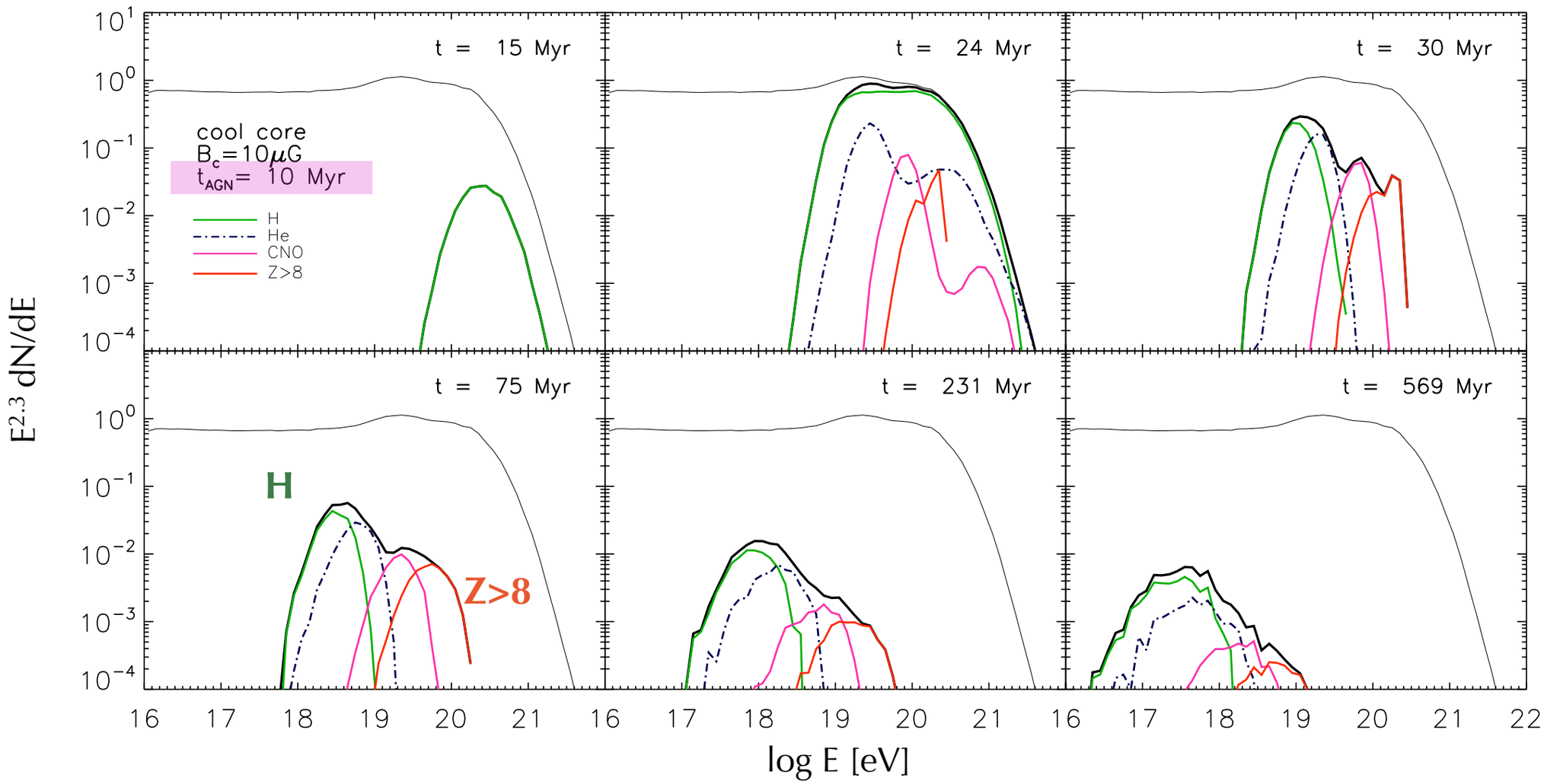

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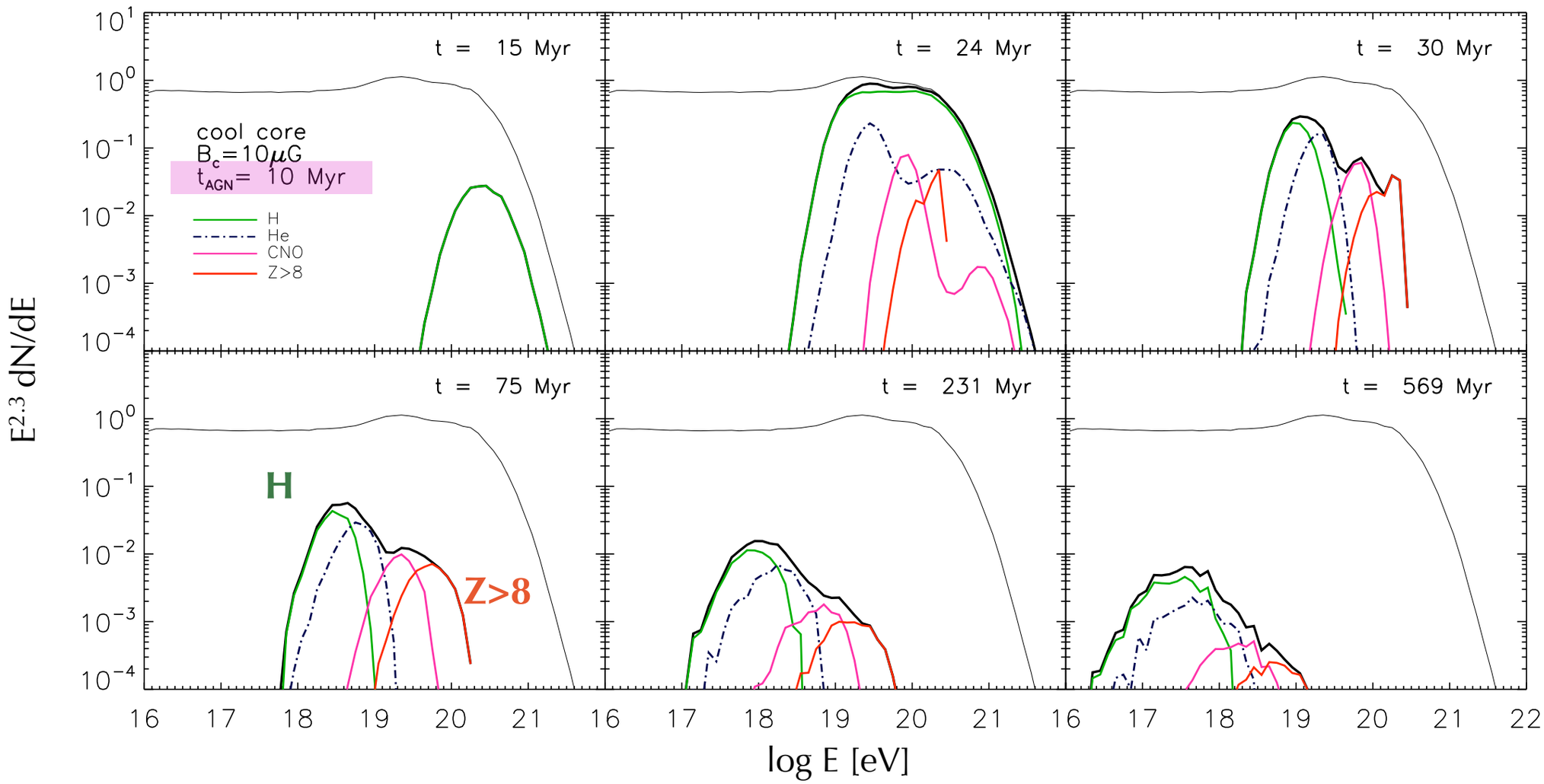

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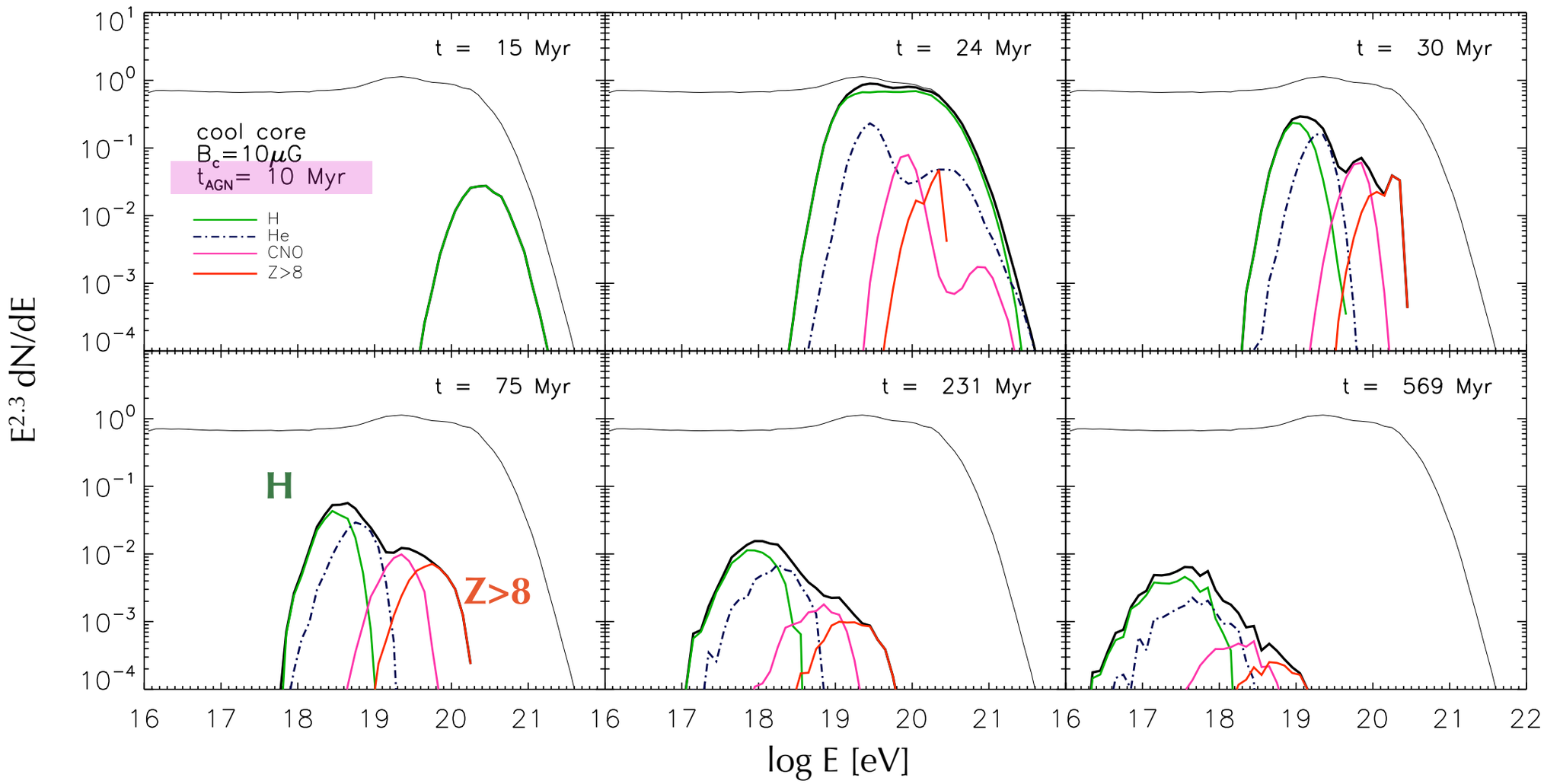
but possible cosmic ray afterglow **decorrelated from secondary emissions** when looking at single objects

Taking into account the limited AGN lifetime



due to higher confinement times t_{conf} and spread around t_{conf}, heavier nuclei escape later from cluster

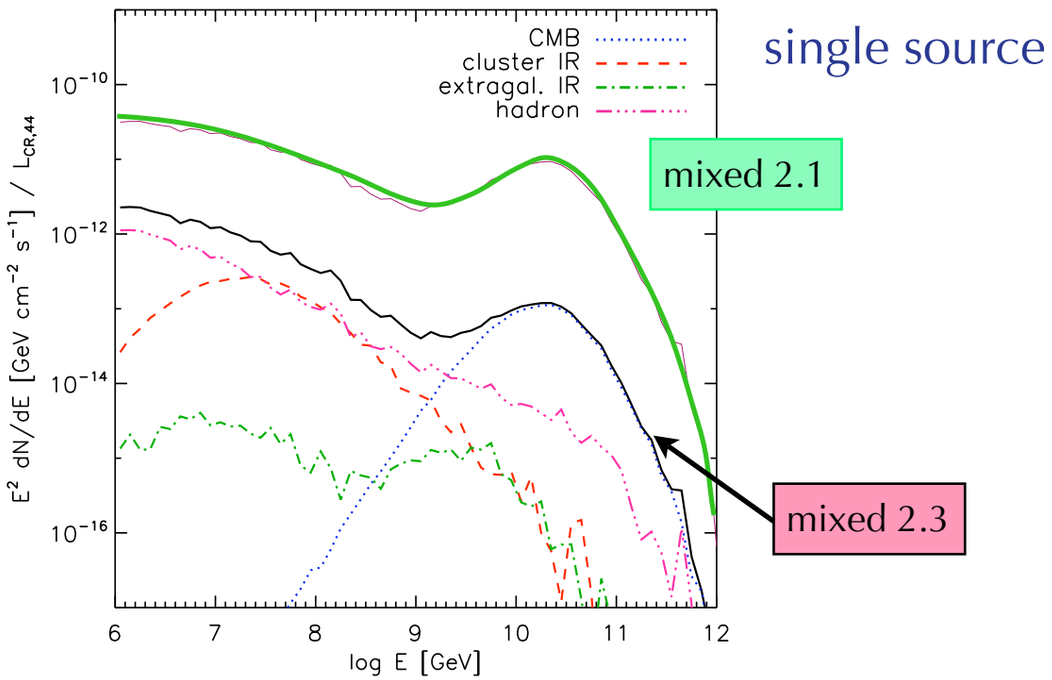
flux diminishes due to spread in time

but possible cosmic ray afterglow **decorrelated from secondary emissions** when looking at single objects

these effects should not be observed on average
(unless there is a nearby source that highly contributes to the total cosmic ray spectrum)

Secondary neutrino emission

AGN luminosity for $E_{min}=10^9$ eV and $E_{max} = 10^{20.5}$ eV: $L_{cr} = 10^{44}$ erg s^{-1}



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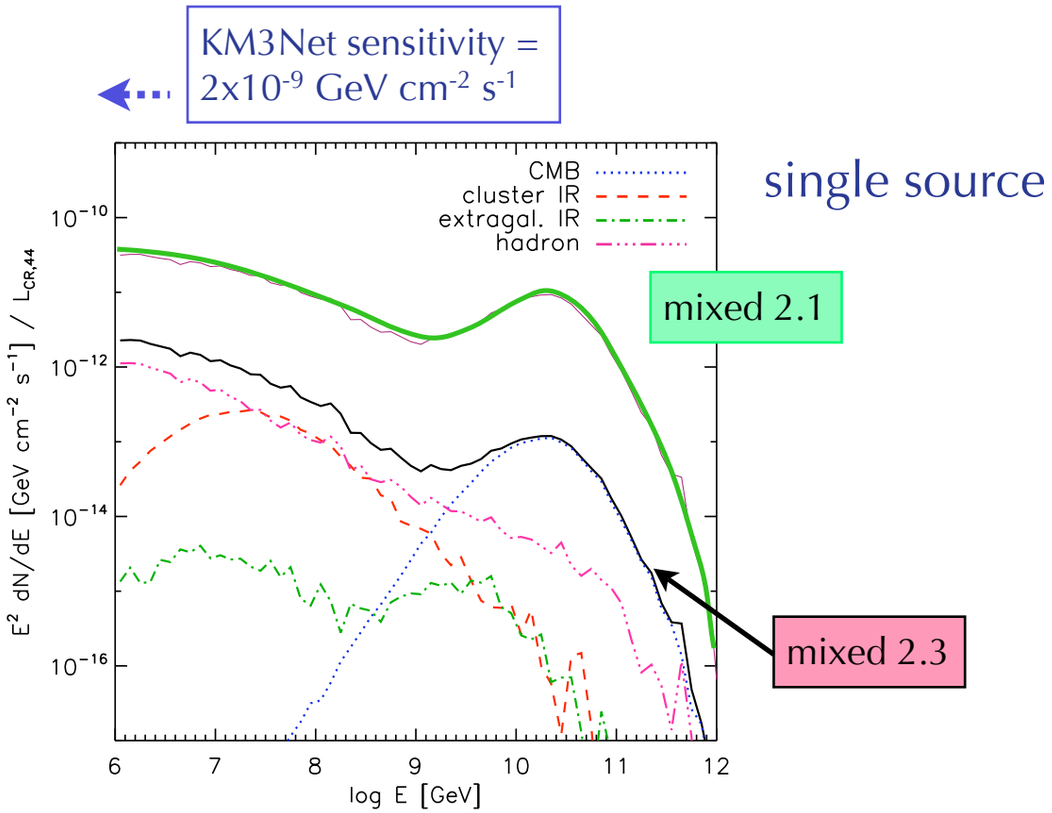

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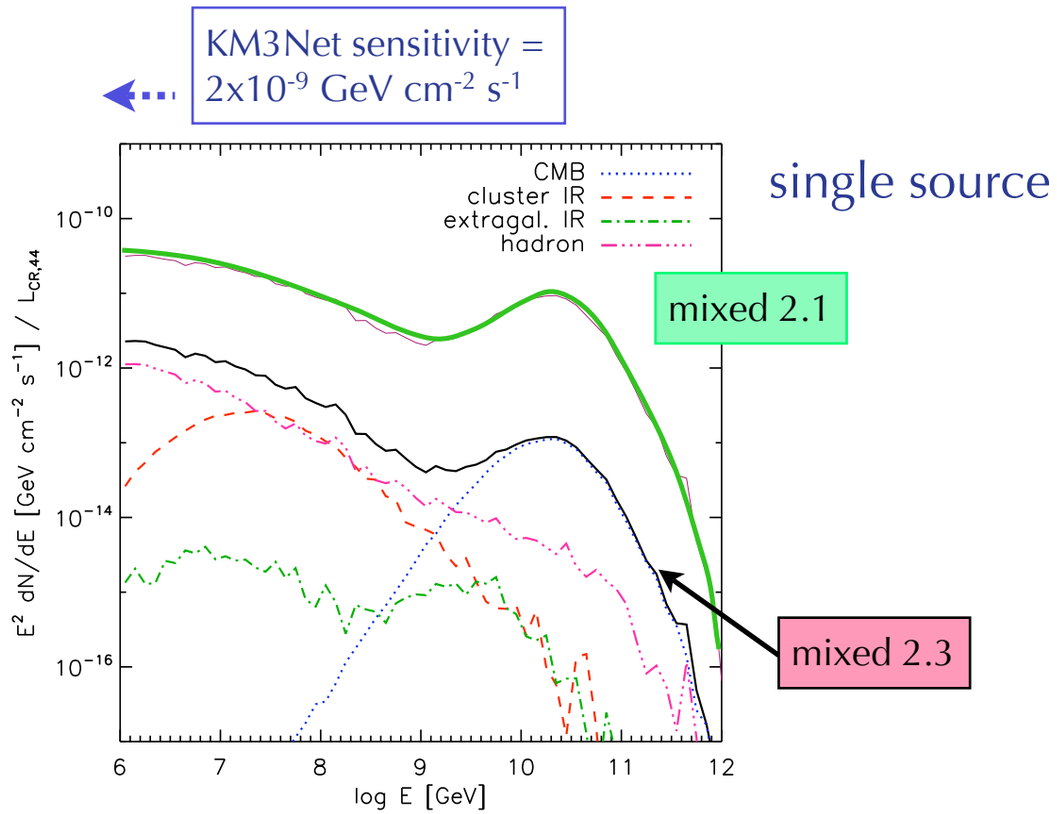
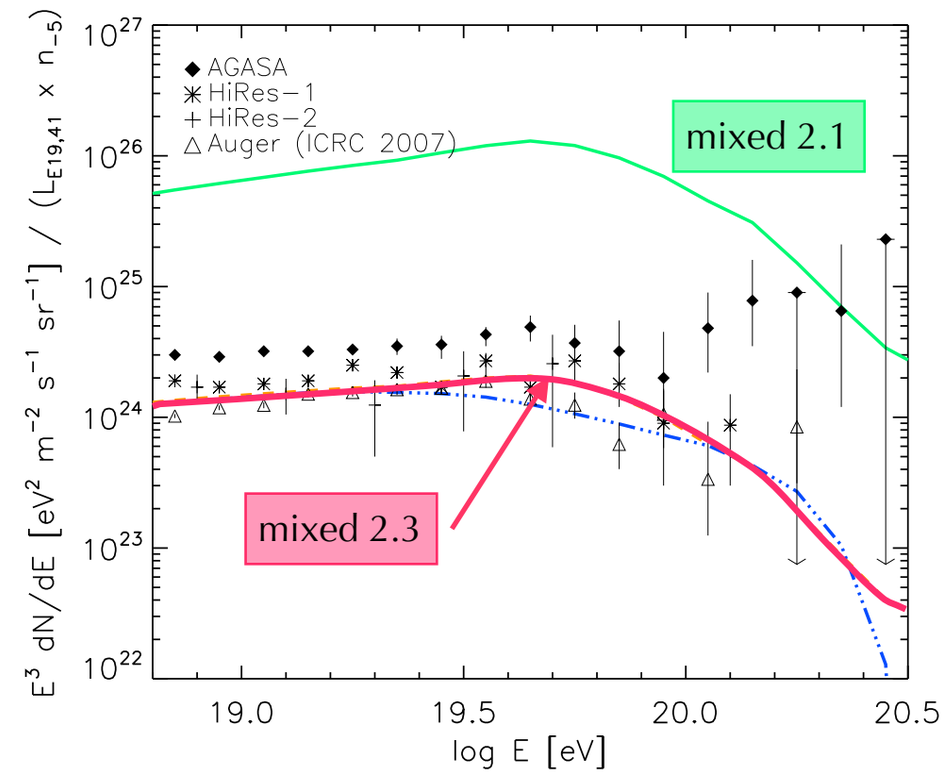


single source



total UHECR flux compared to observed data

$n_{sources} = 10^{-5}$ Mpc^{-3}

Secondary neutrino emission

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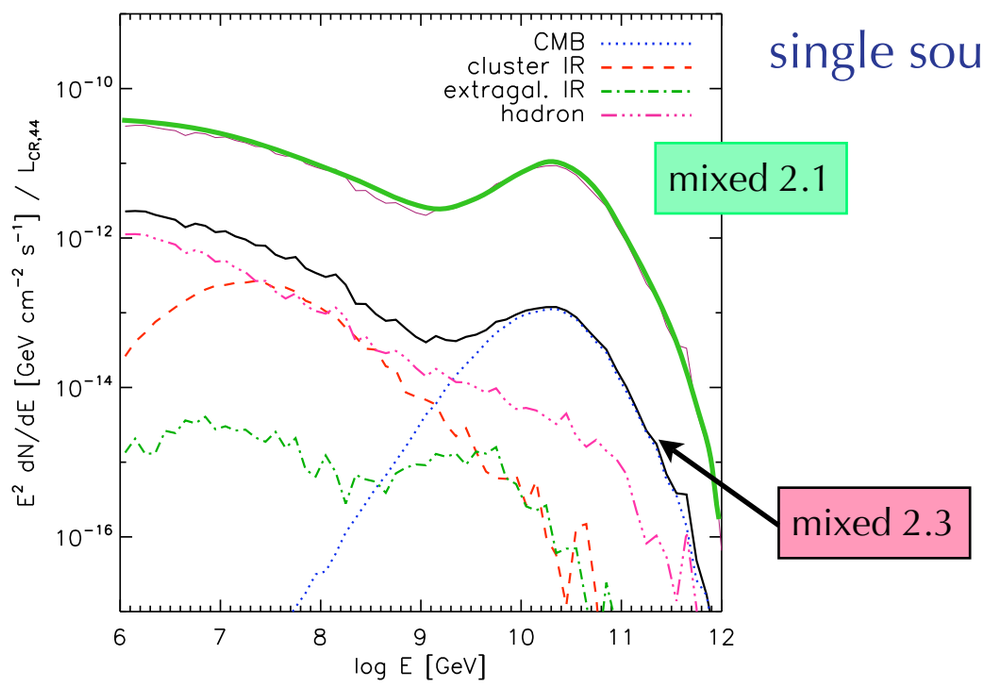

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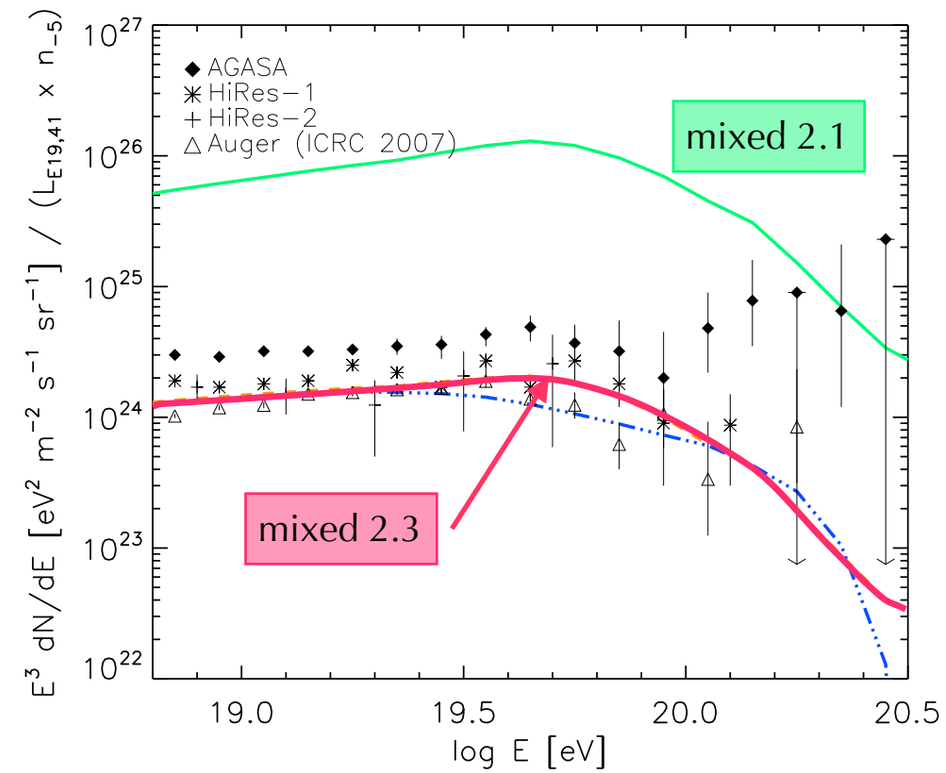

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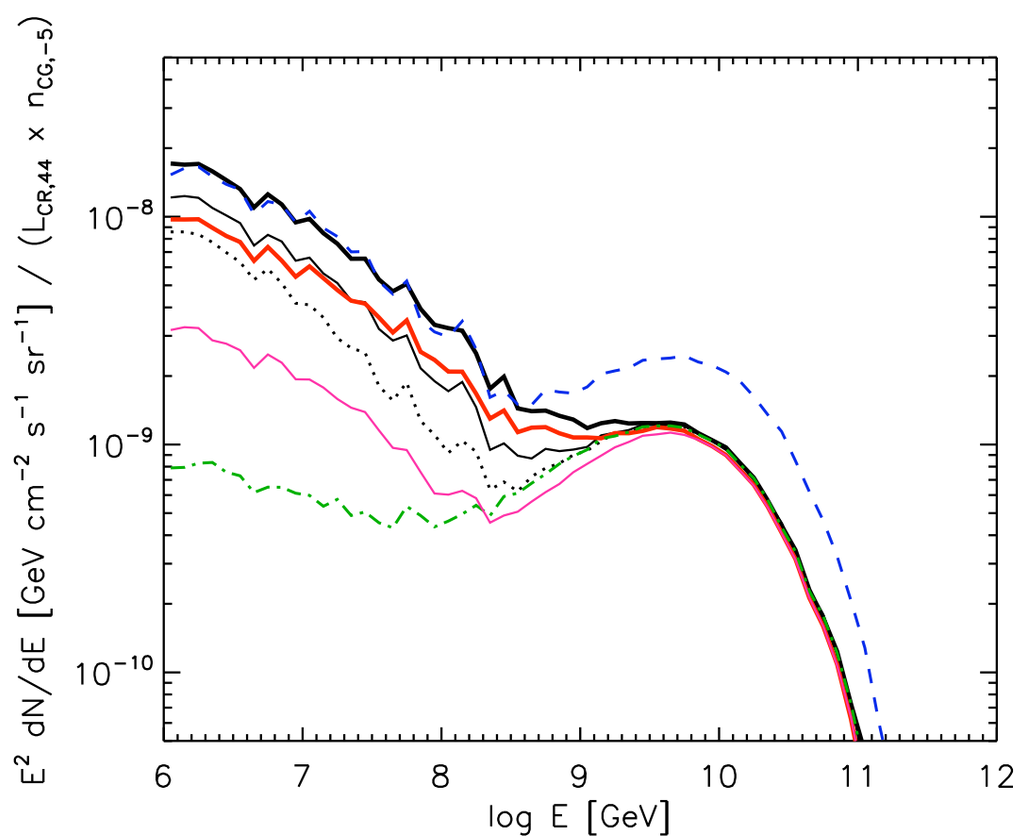

diffuse neutrino flux

$n_{sources} = 10^{-5}$ Mpc^{-3}
spectral index = 2.3

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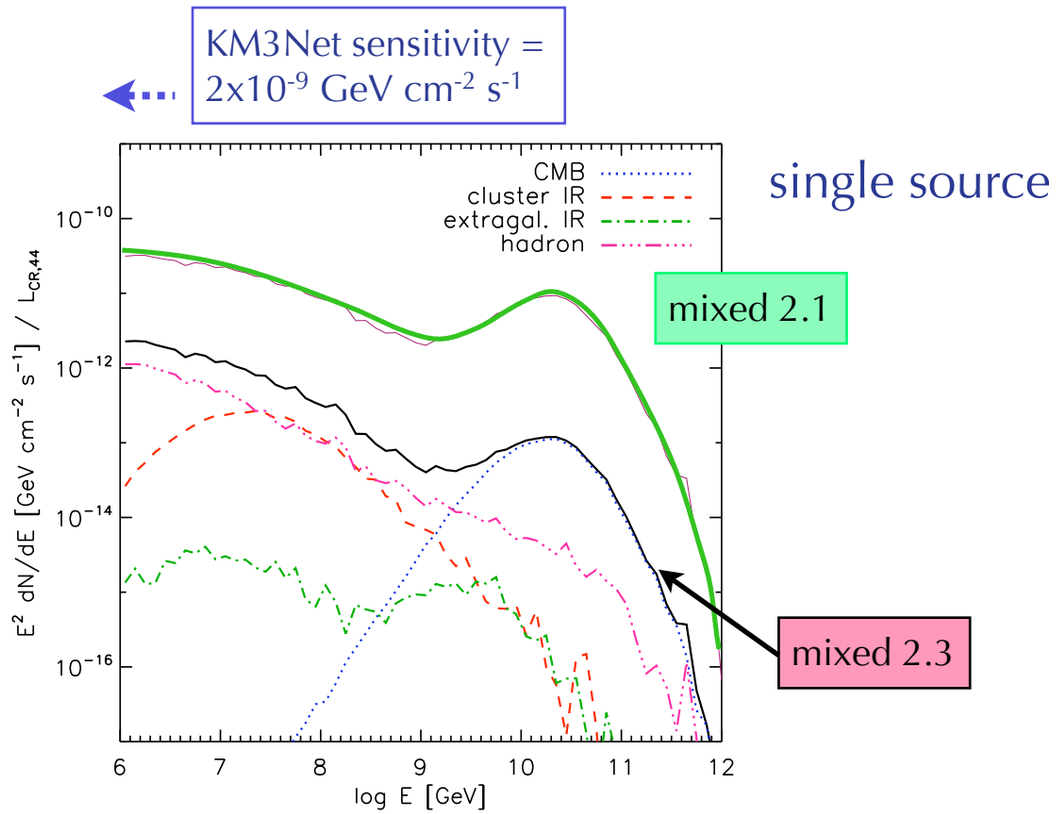

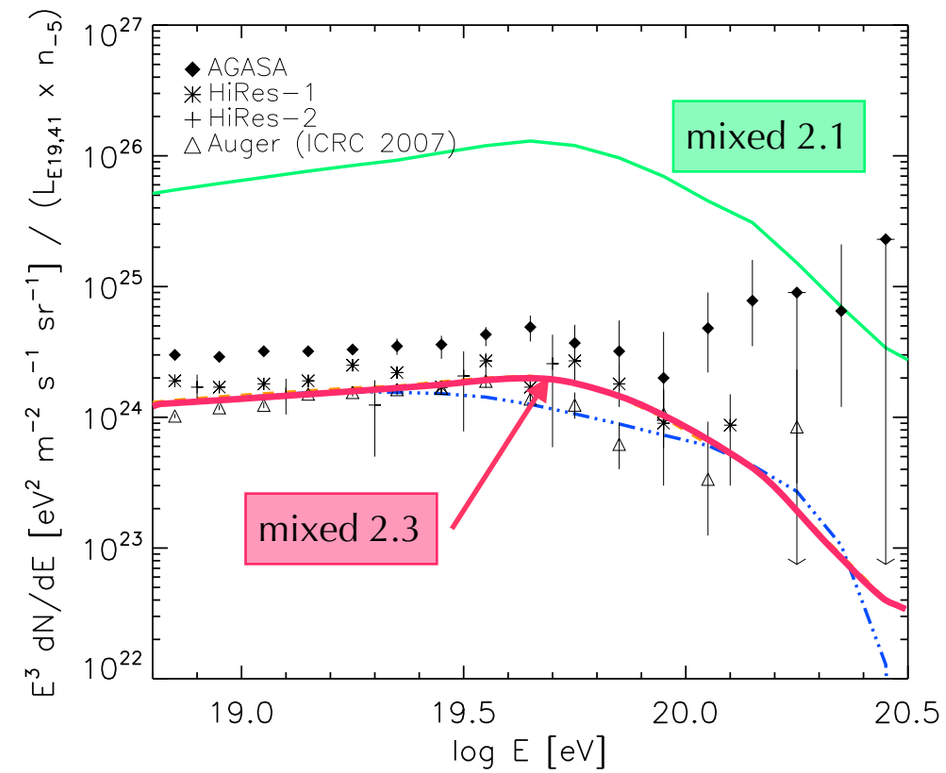

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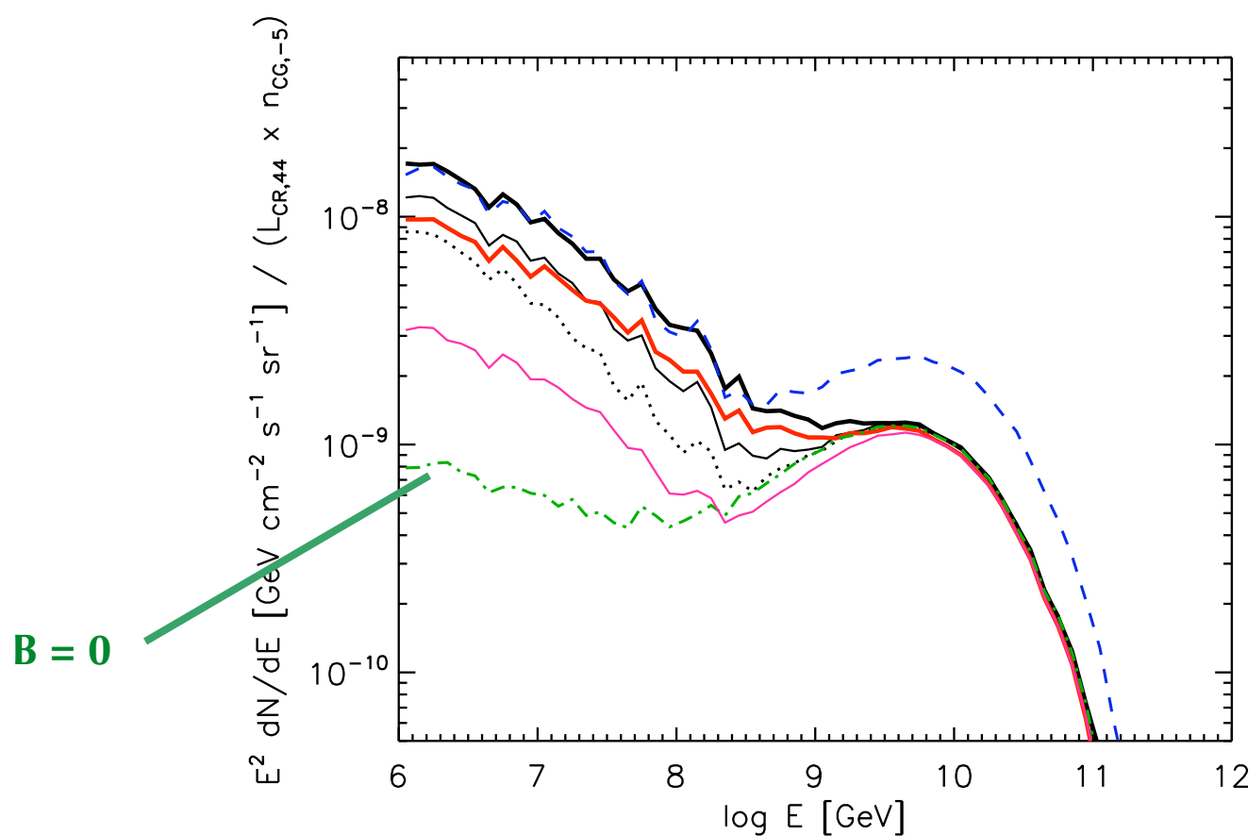

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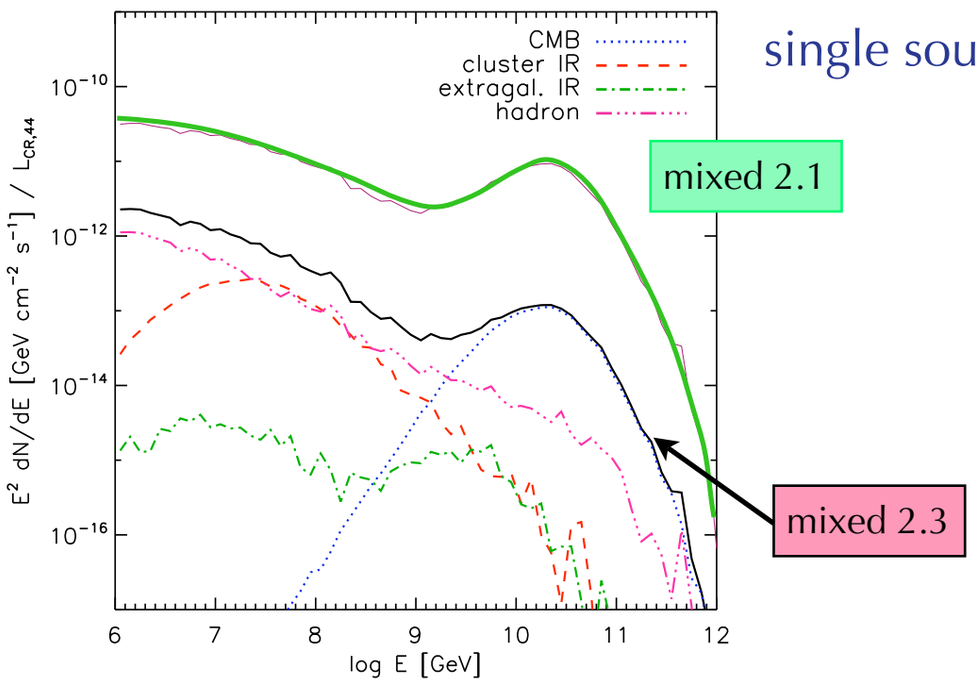

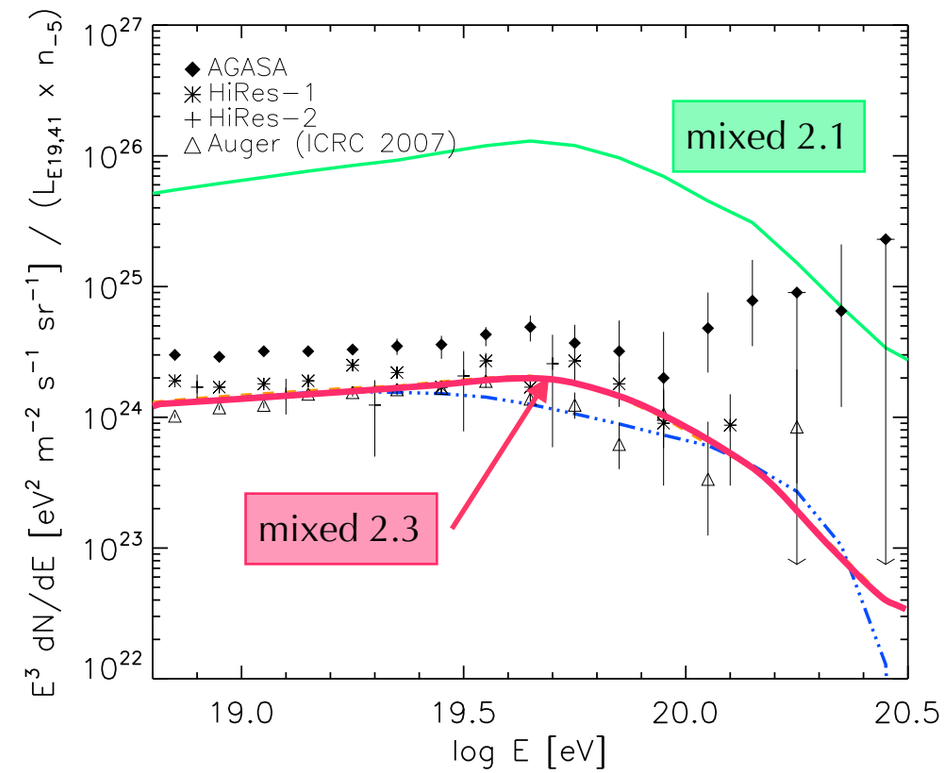

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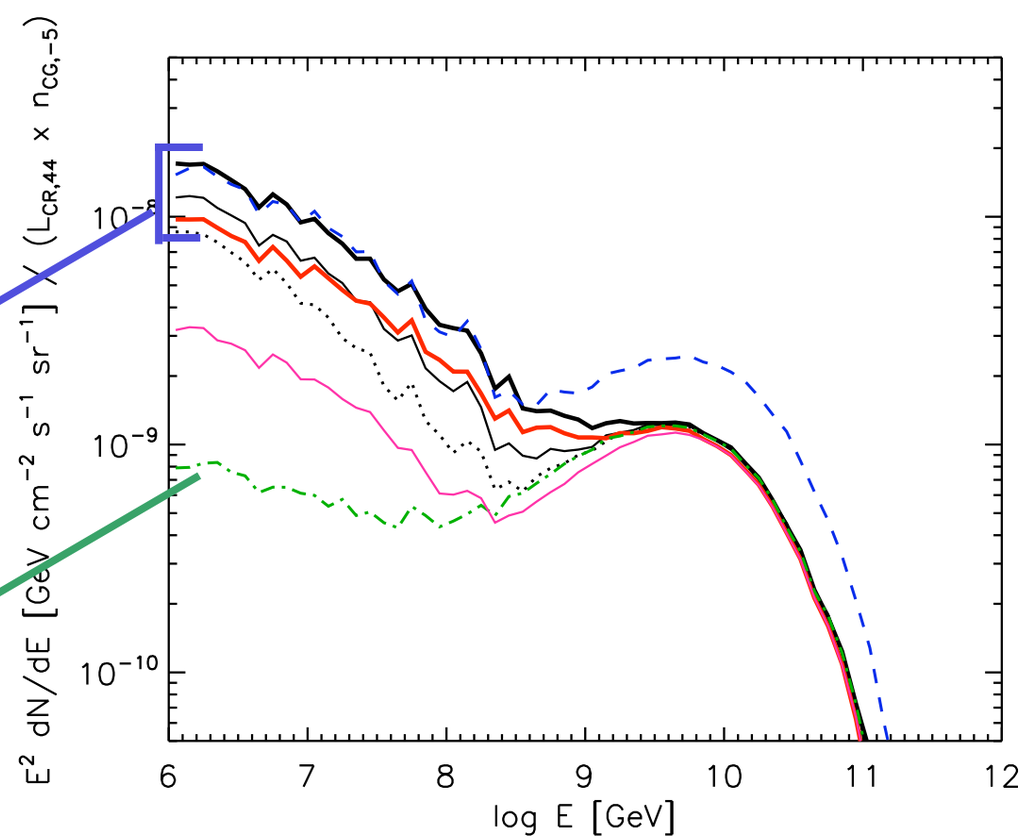

various B intensity, profiles, compositions

B = 0

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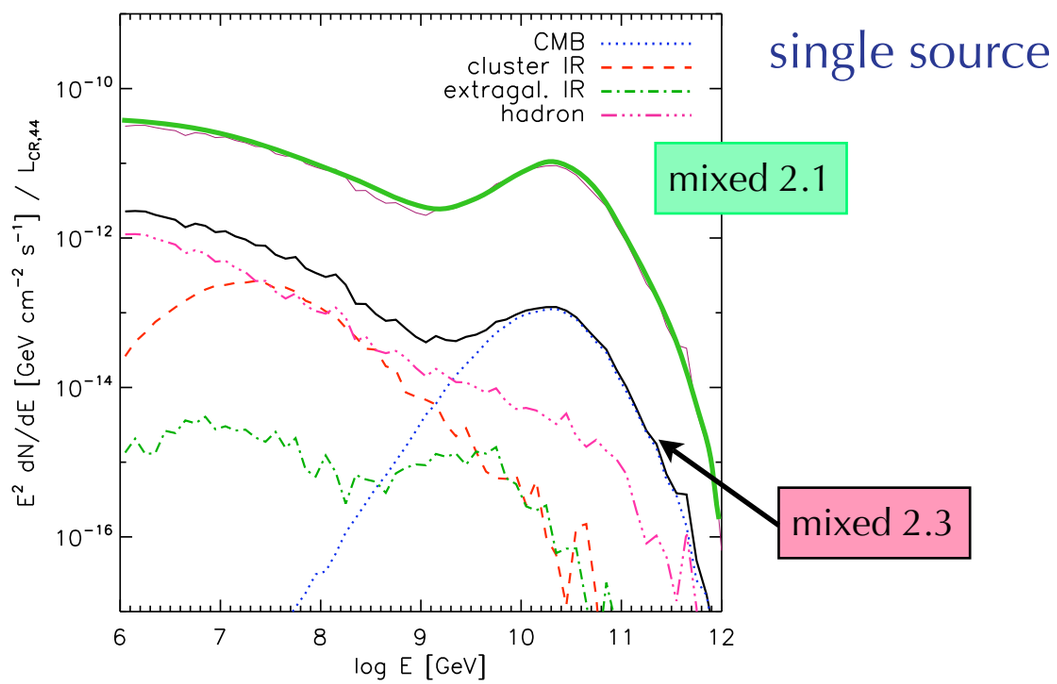

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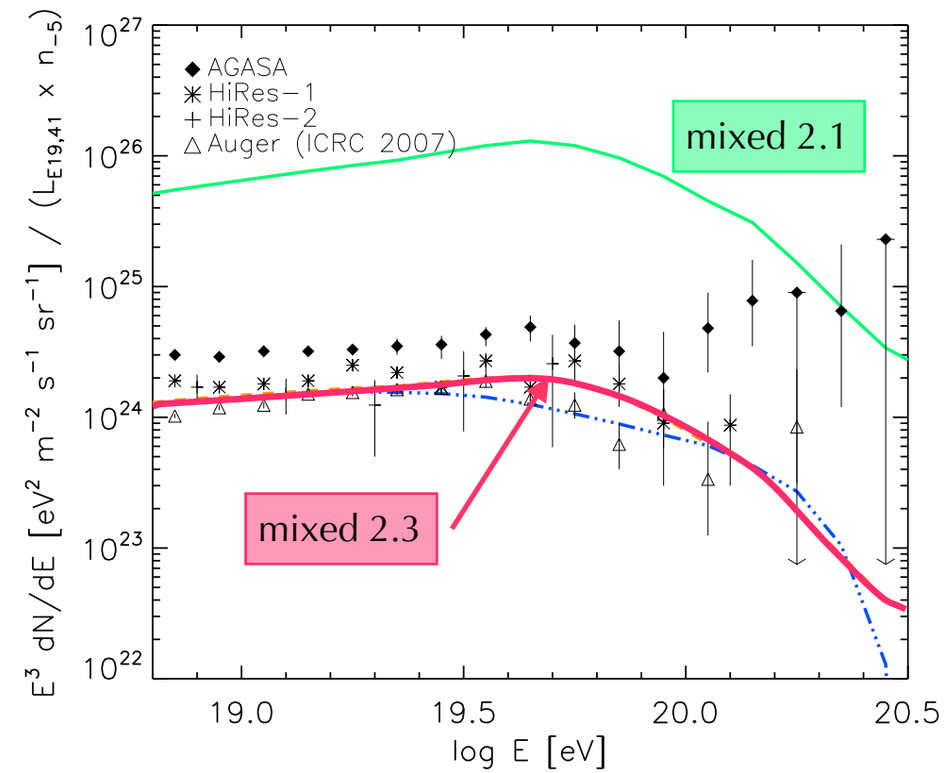

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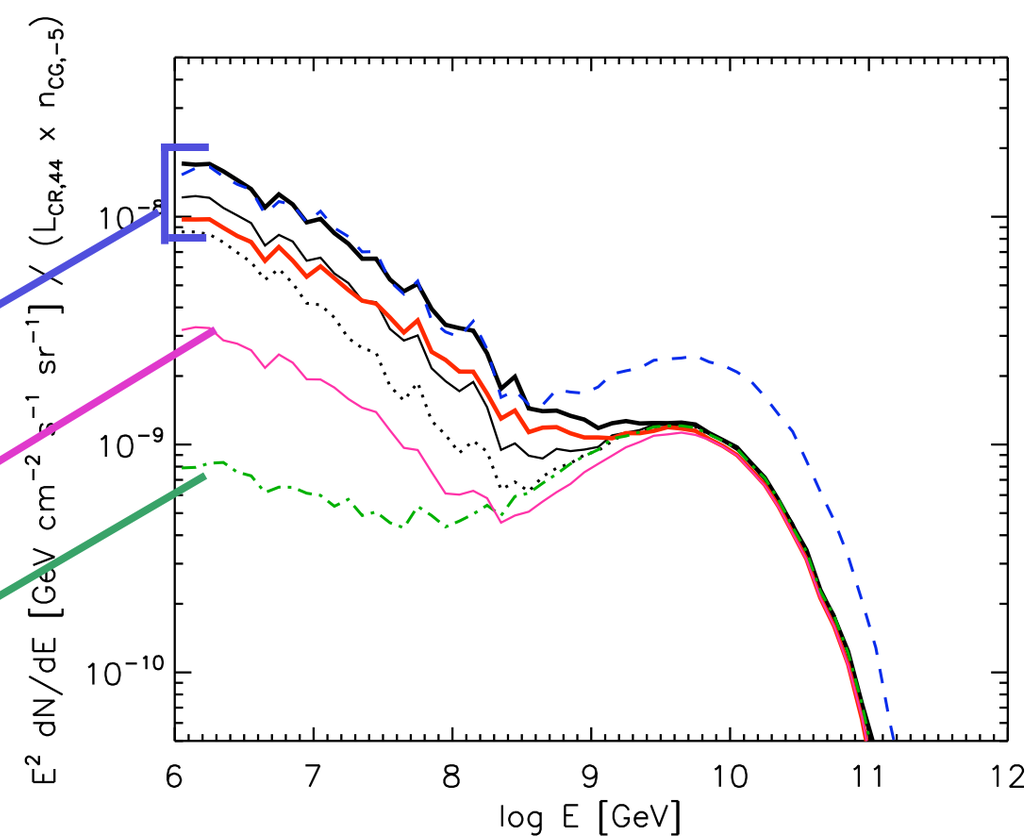

various B intensity, profiles, compositions

source shifted of 100 kpc from center

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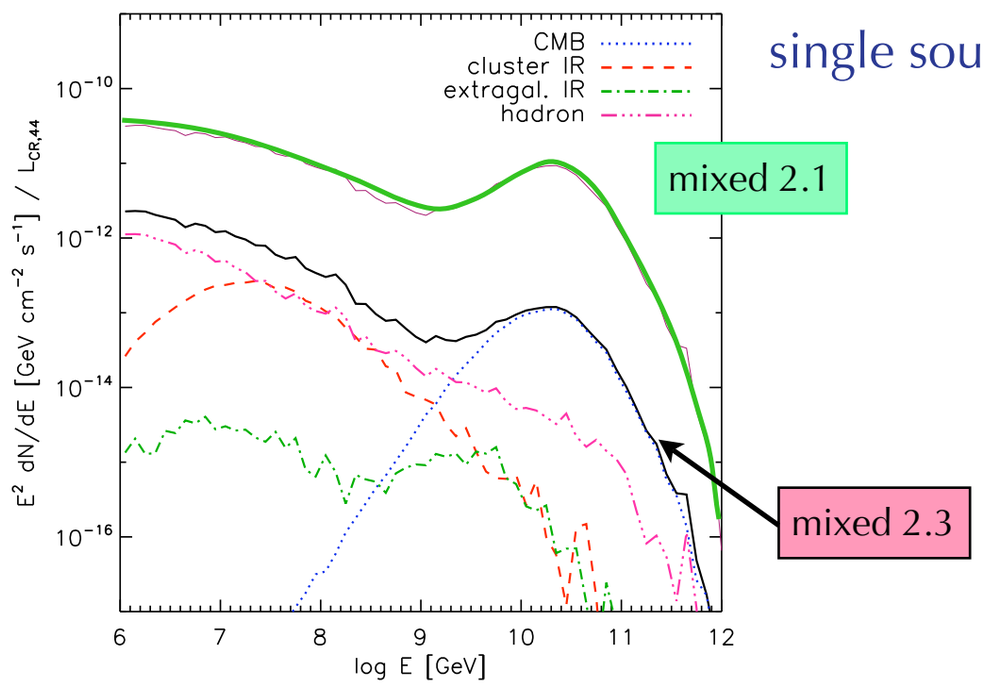

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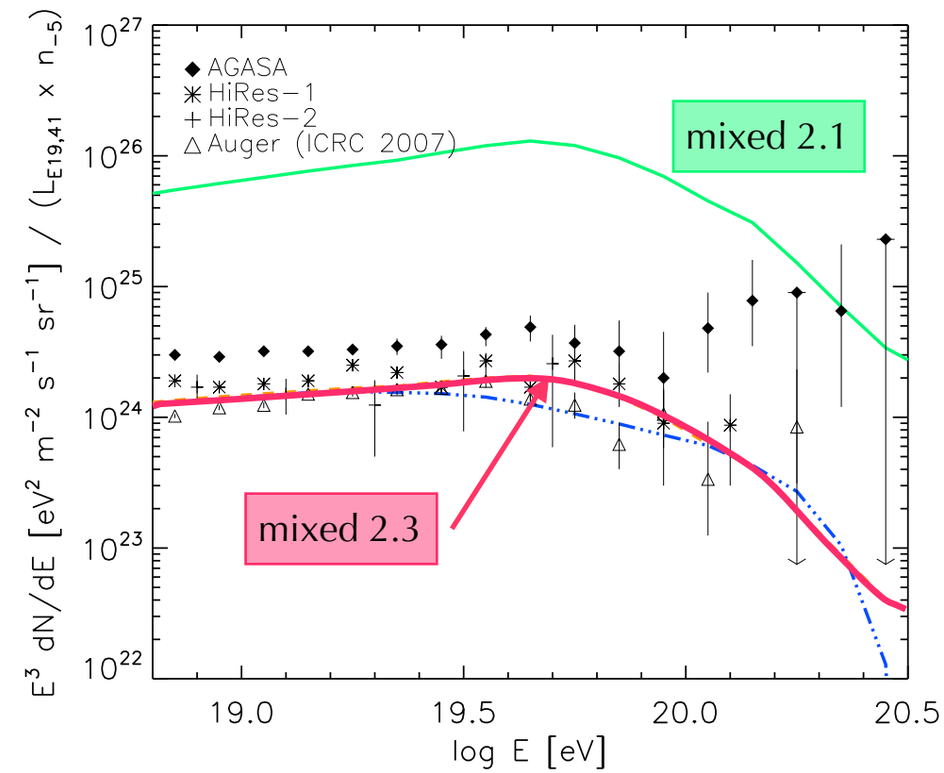

total UHECR flux compared to observed data

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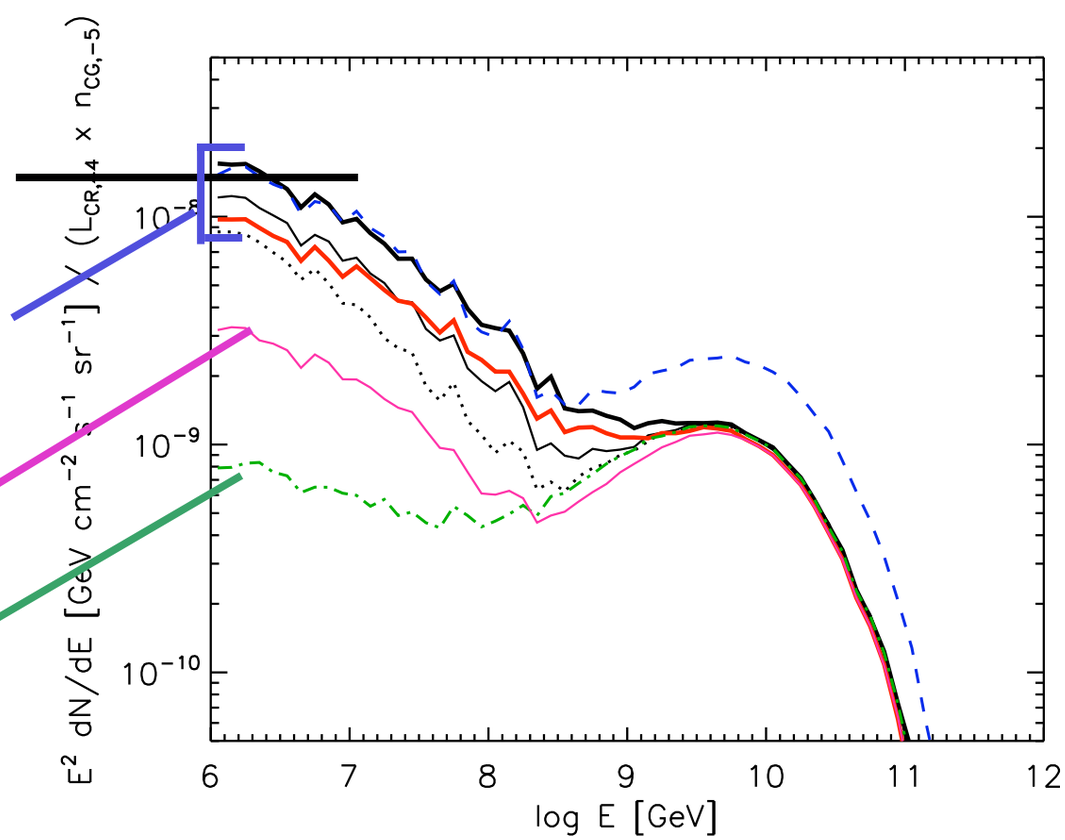
IceCube sensitivity (diffuse) = 1.5×10^{-8} GeV cm^{-2} s^{-1}

various B intensity, profiles, compositions

source shifted of 100 kpc from center

B = 0



diffuse neutrino flux

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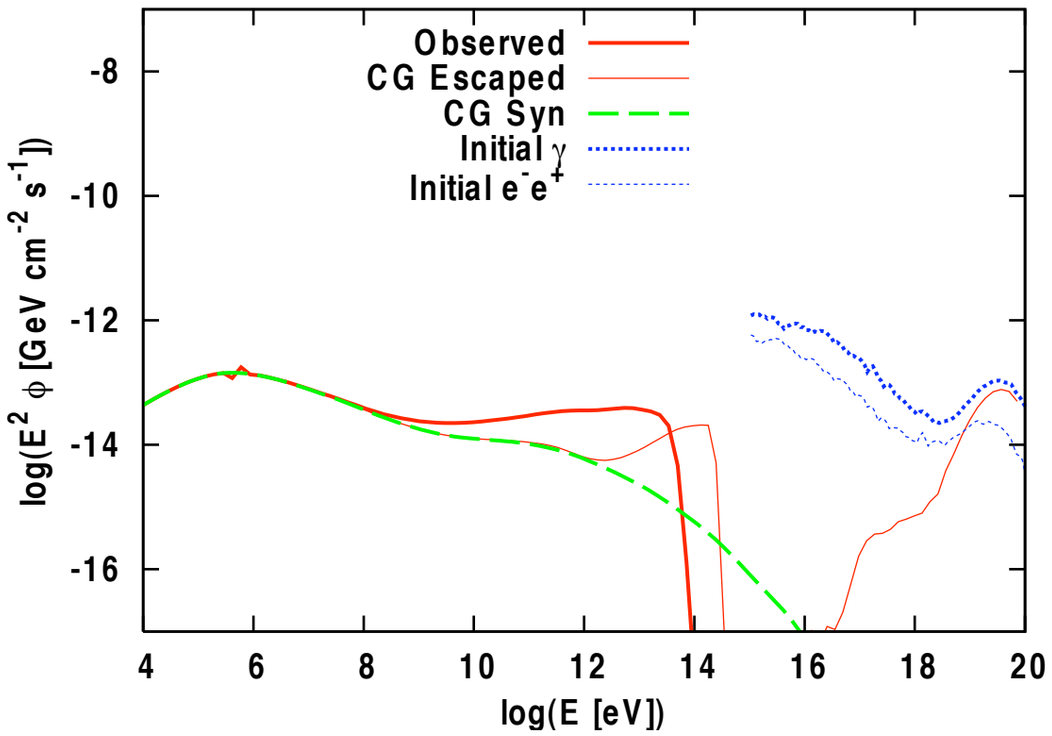
Gamma ray emission

B = 10 μG
spectral index = 2.3

AGN luminosity for $E_{min}=10^9$ eV and $E_{max} = 10^{20.5}$ eV: $L_{cr} = 10^{44}$ erg s^{-1}



gamma rays from UHECR injected in a cool core cluster

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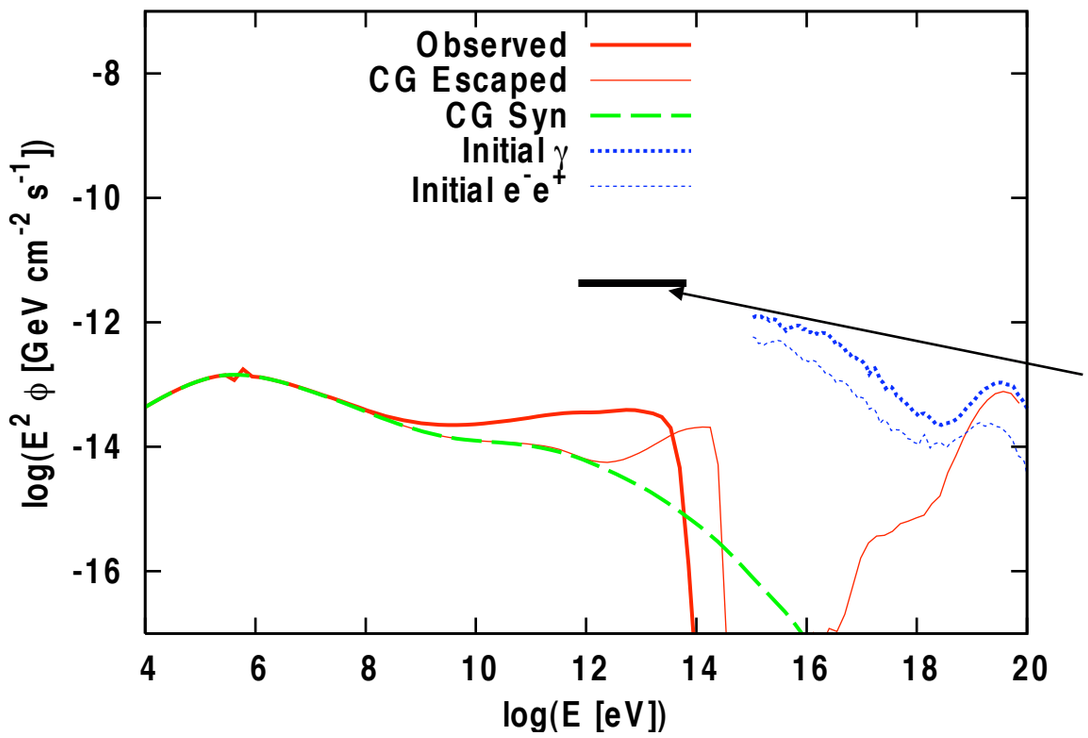

gamma rays from UHECR injected in a cool core cluster

CTA: point source **~ 10^{-11} GeV cm^{-2} s^{-1}**

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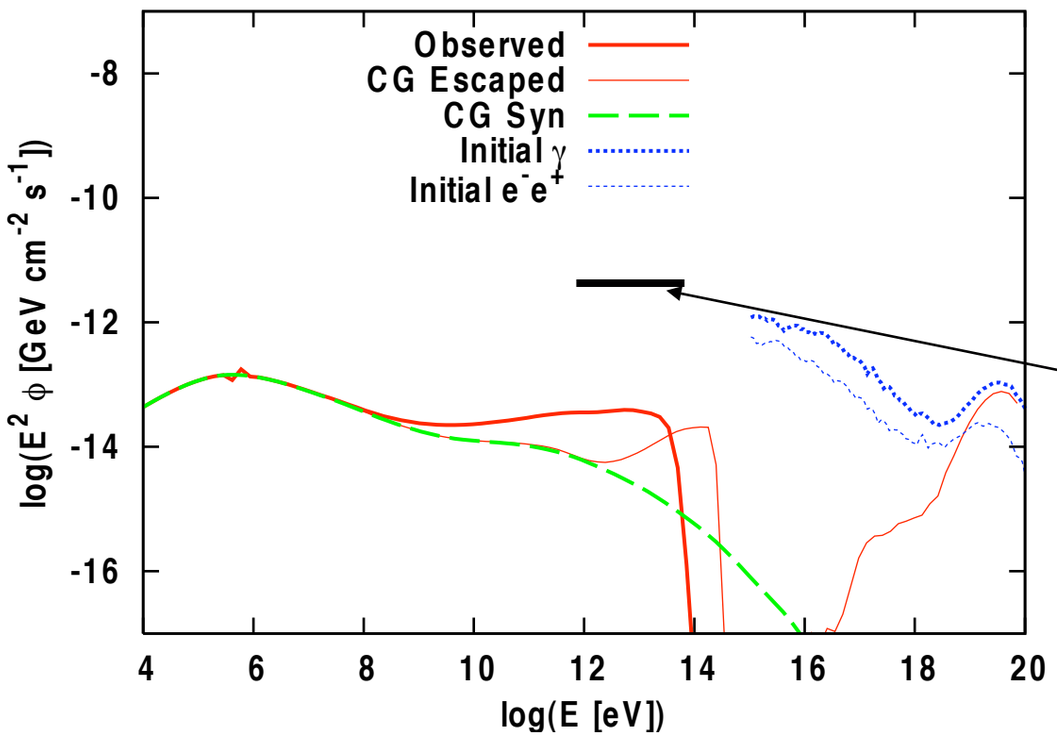

gamma rays from UHECR injected in a cool core cluster

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cluster of R ~ 5Mpc at 100 Mpc: $\theta_{source} \sim 3^o$

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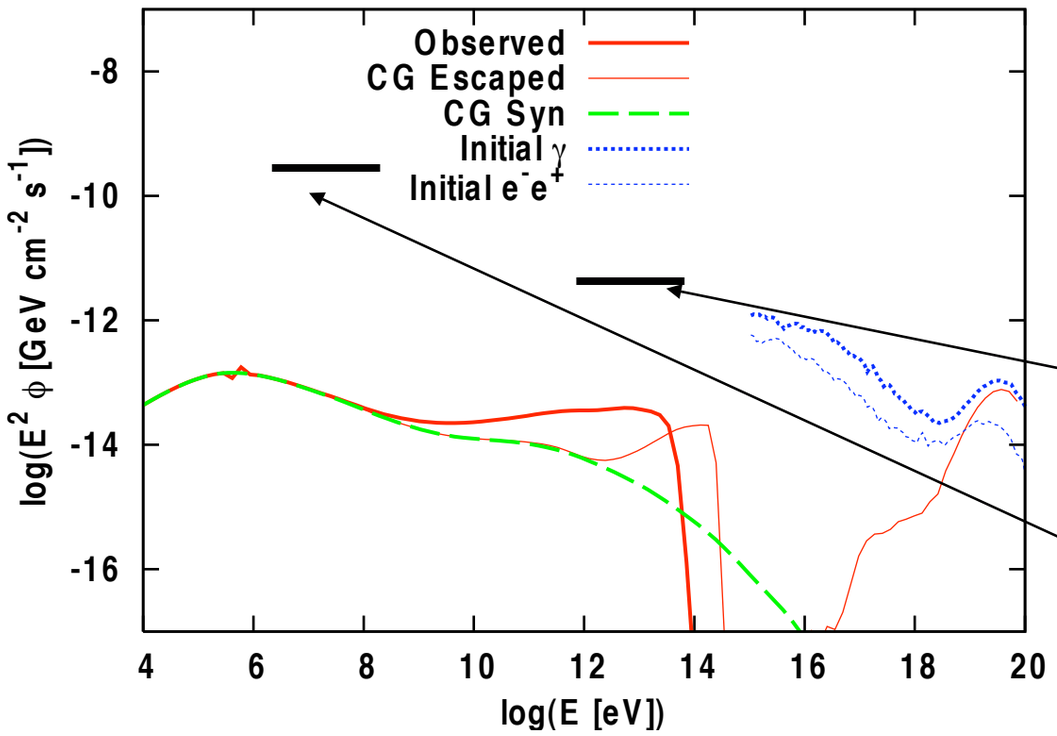

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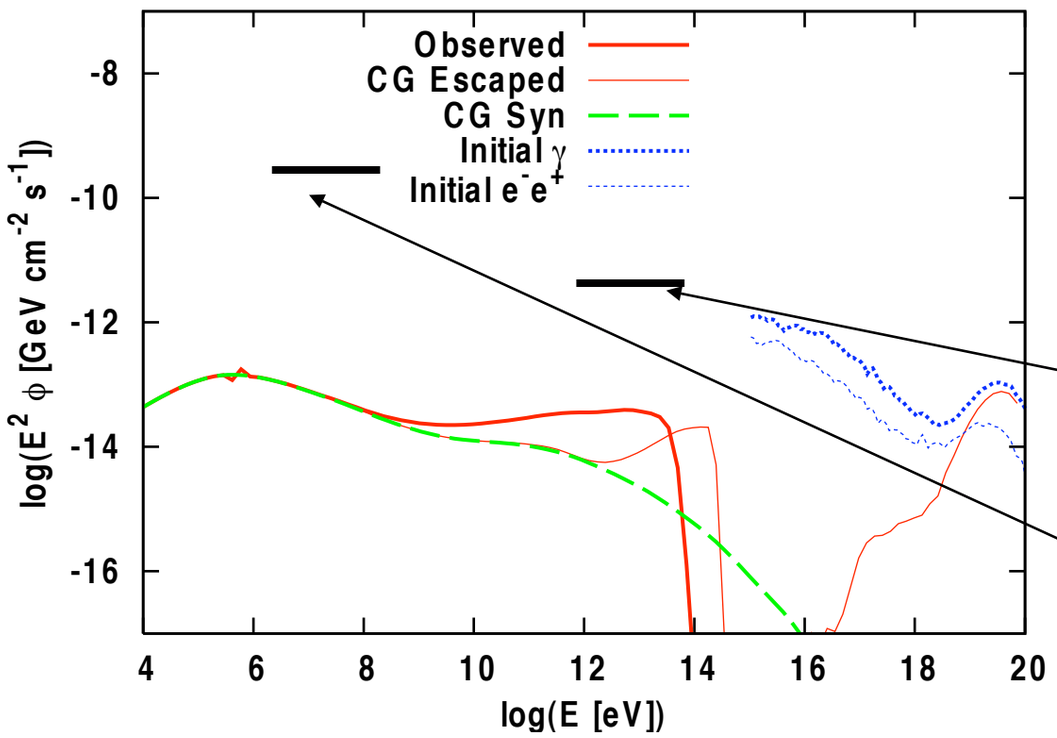

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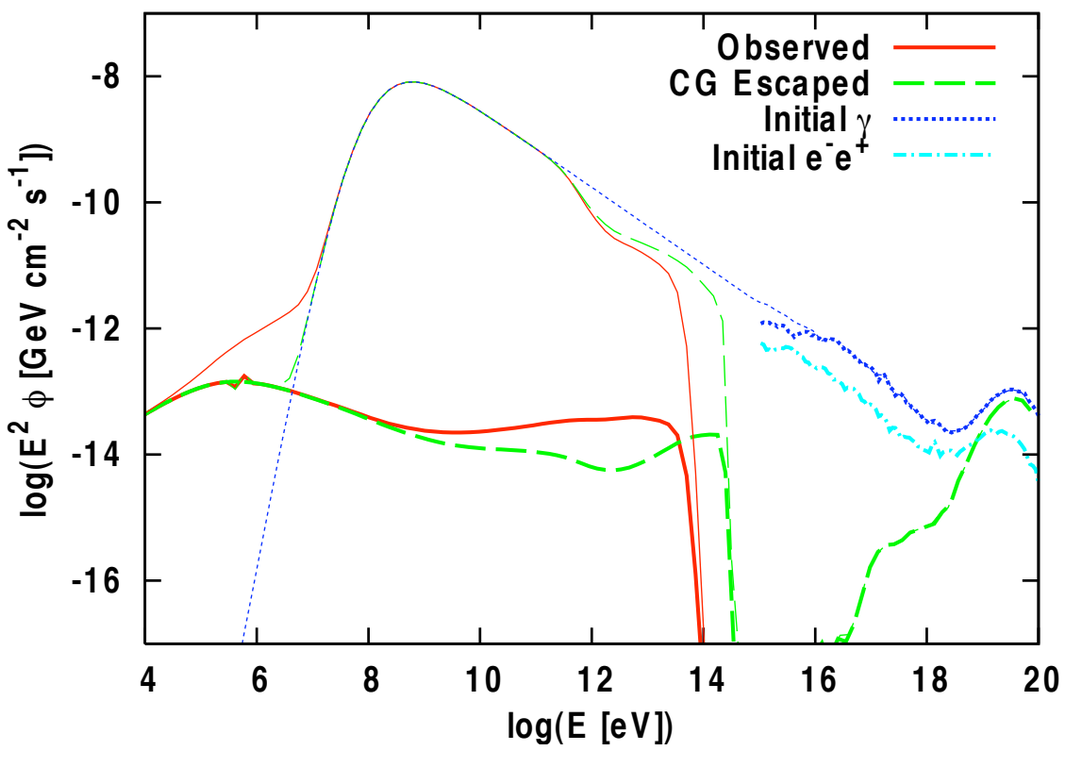

effects of lower energy cosmic rays (E < 1 PeV)

contribution from UHECRs overwhelmed by that of lower energy cosmic rays

Gamma ray emission

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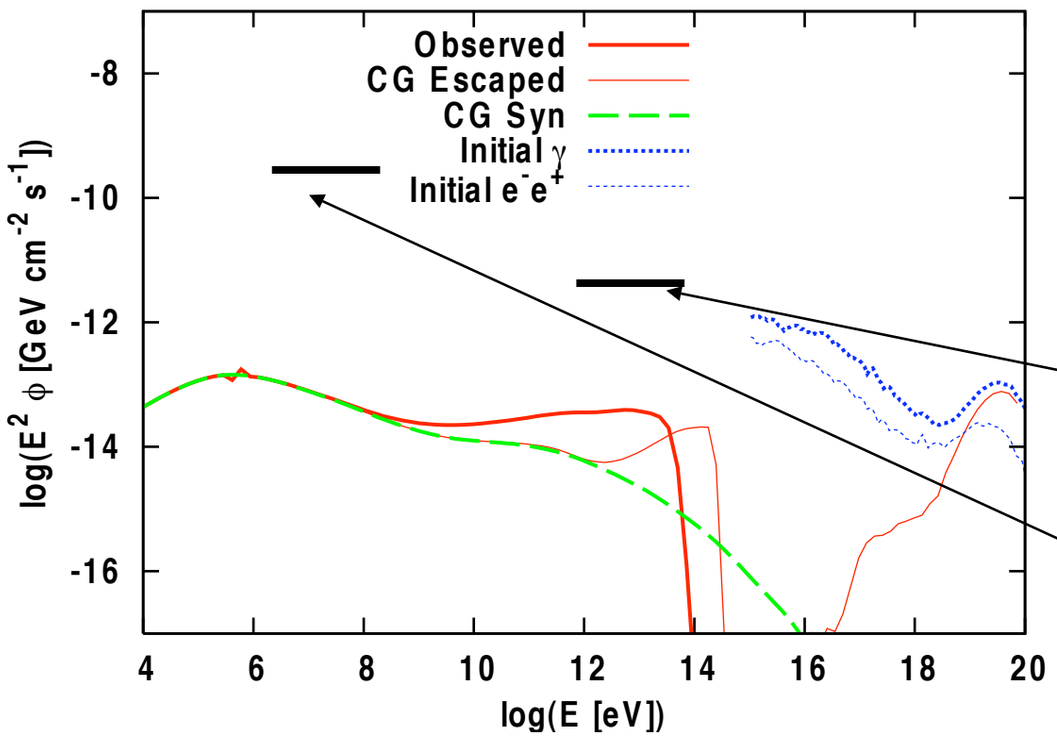

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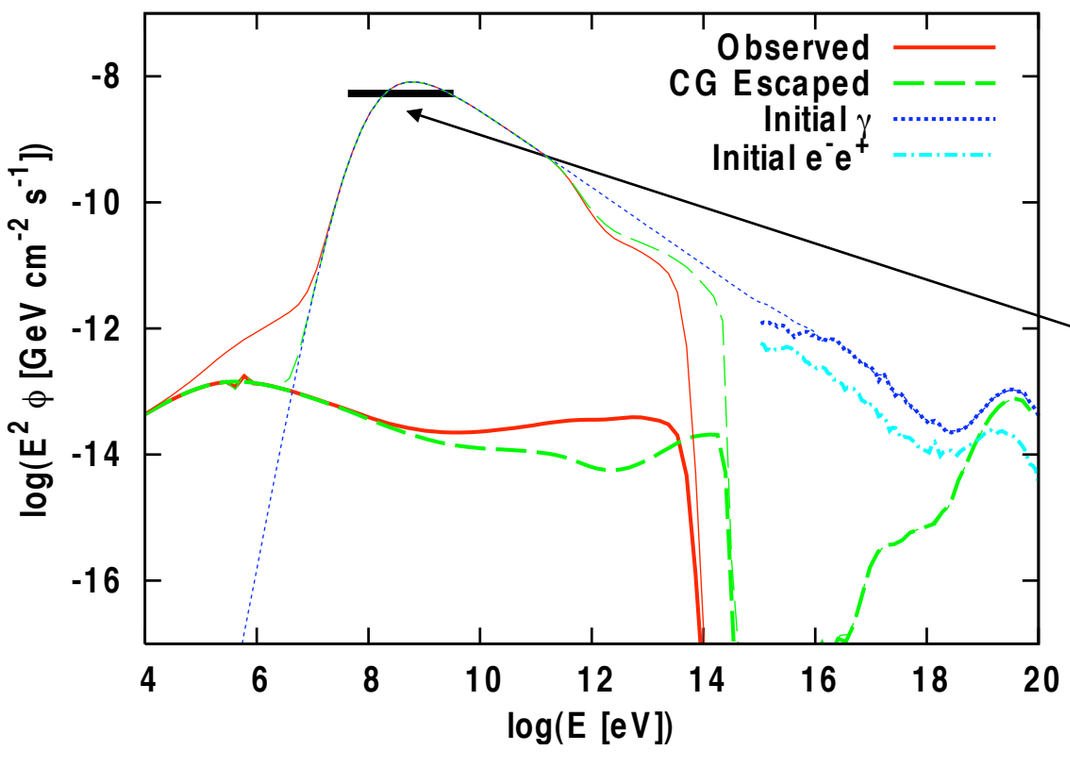

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EGRET limit (point source)

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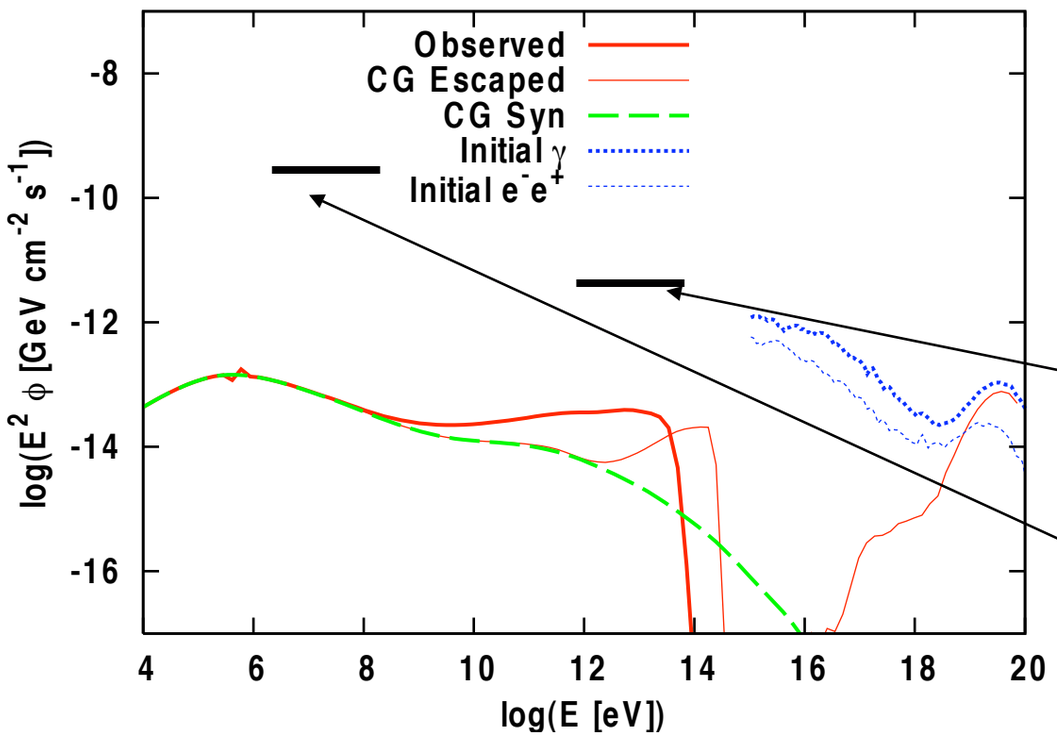

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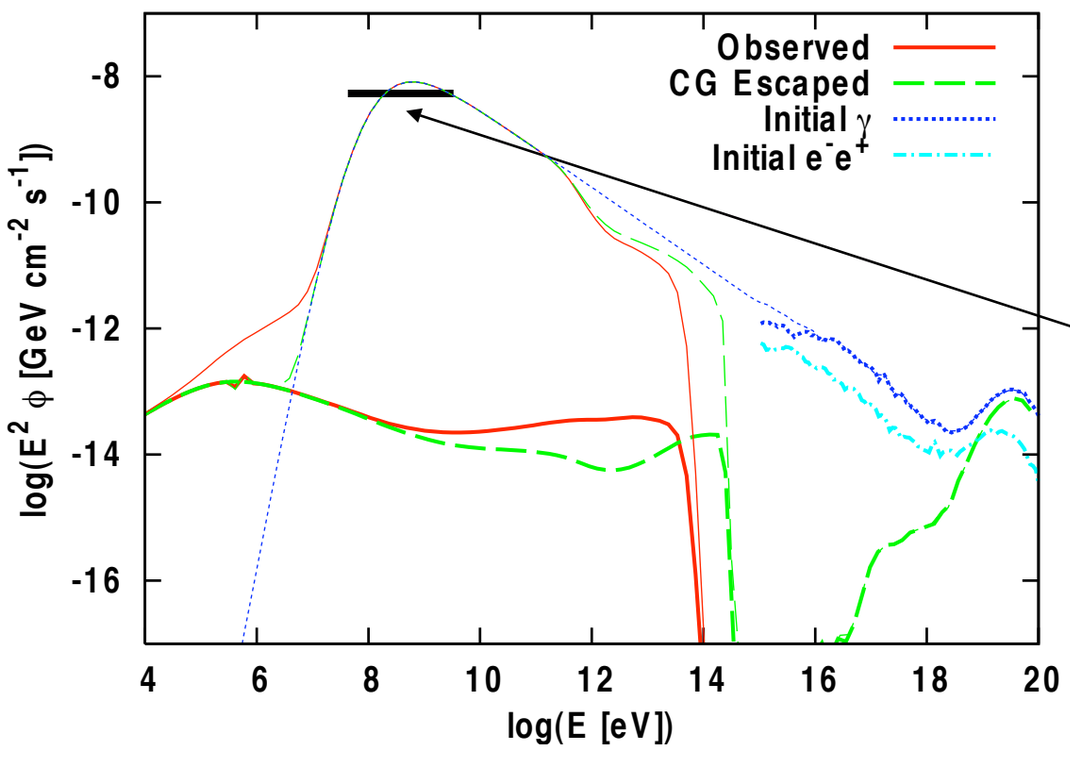

effects of lower energy cosmic rays (E < 1 PeV)

contribution from UHECRs overwhelmed by that of lower energy cosmic rays

EGRET limit (point source)

harder spectral index with $L=10^{44}$ erg s^{-1} would overshoot UHECR spectrum

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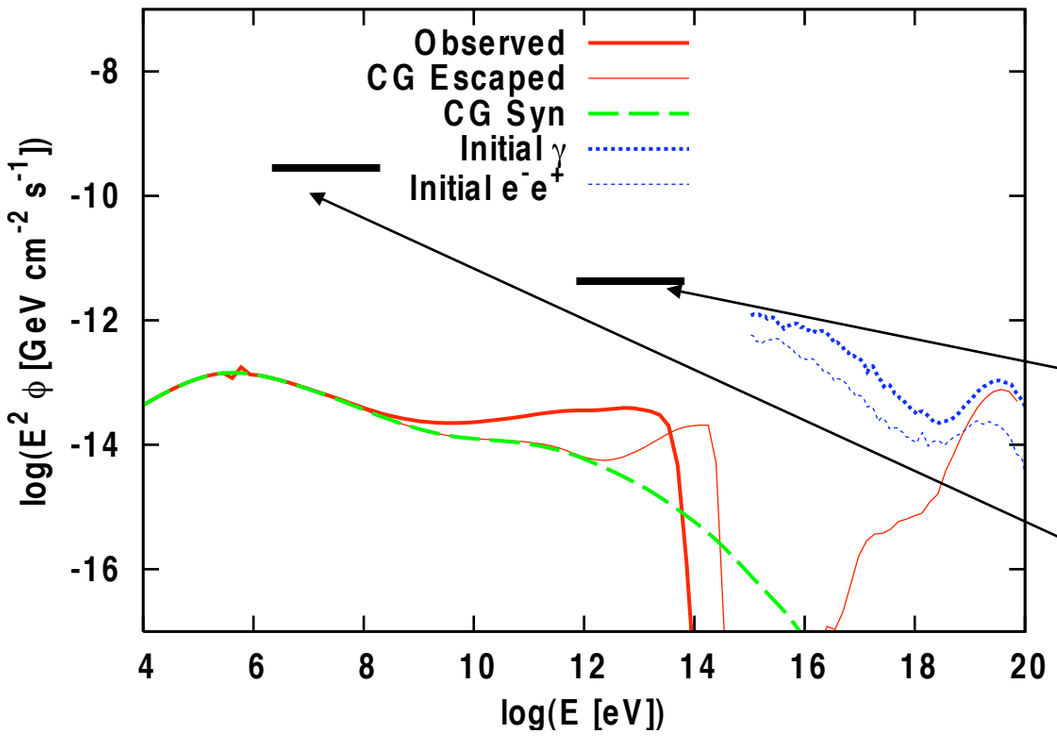

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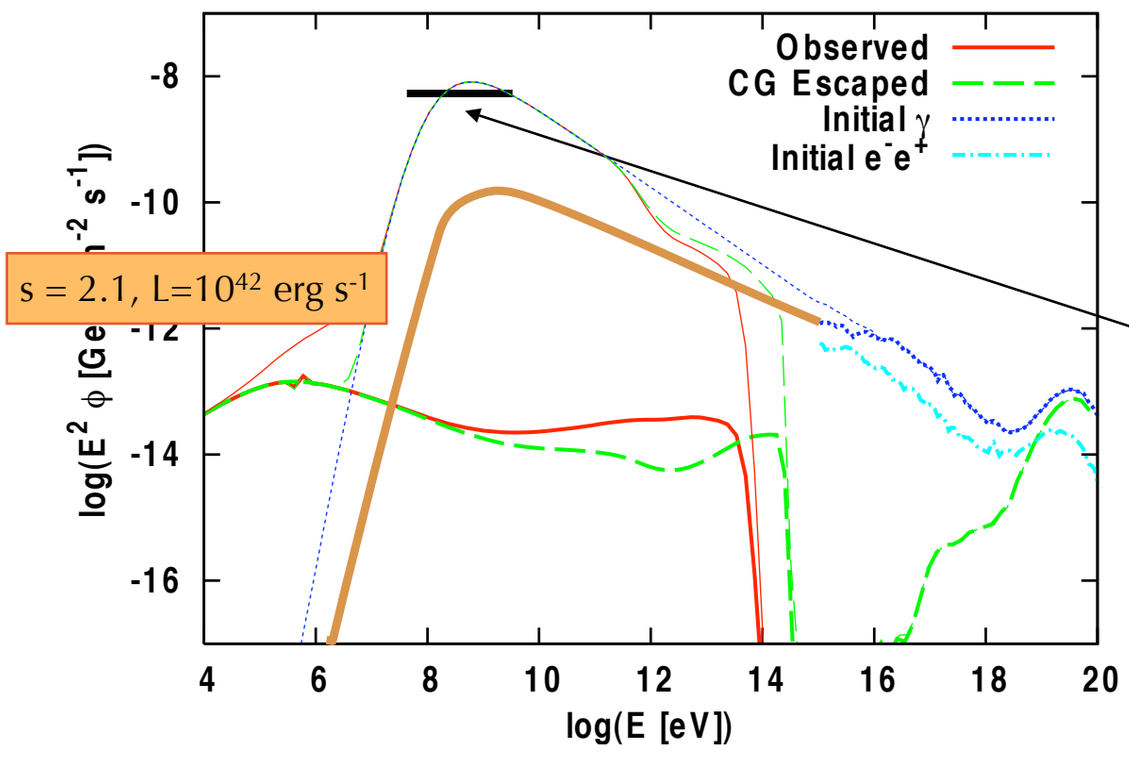

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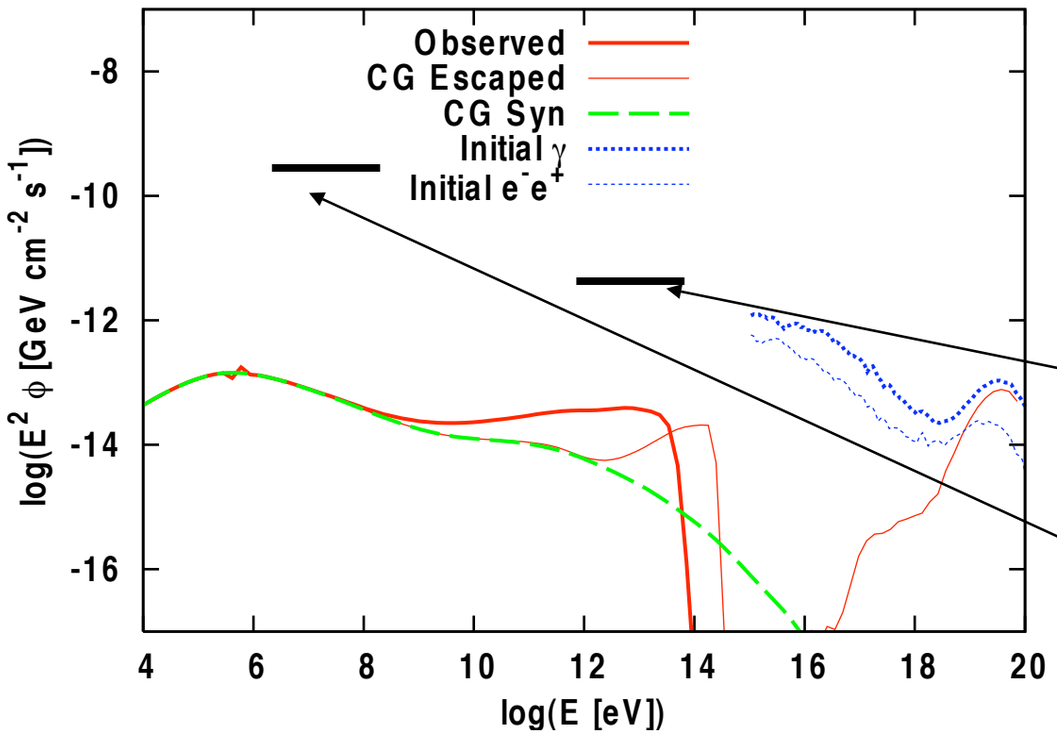

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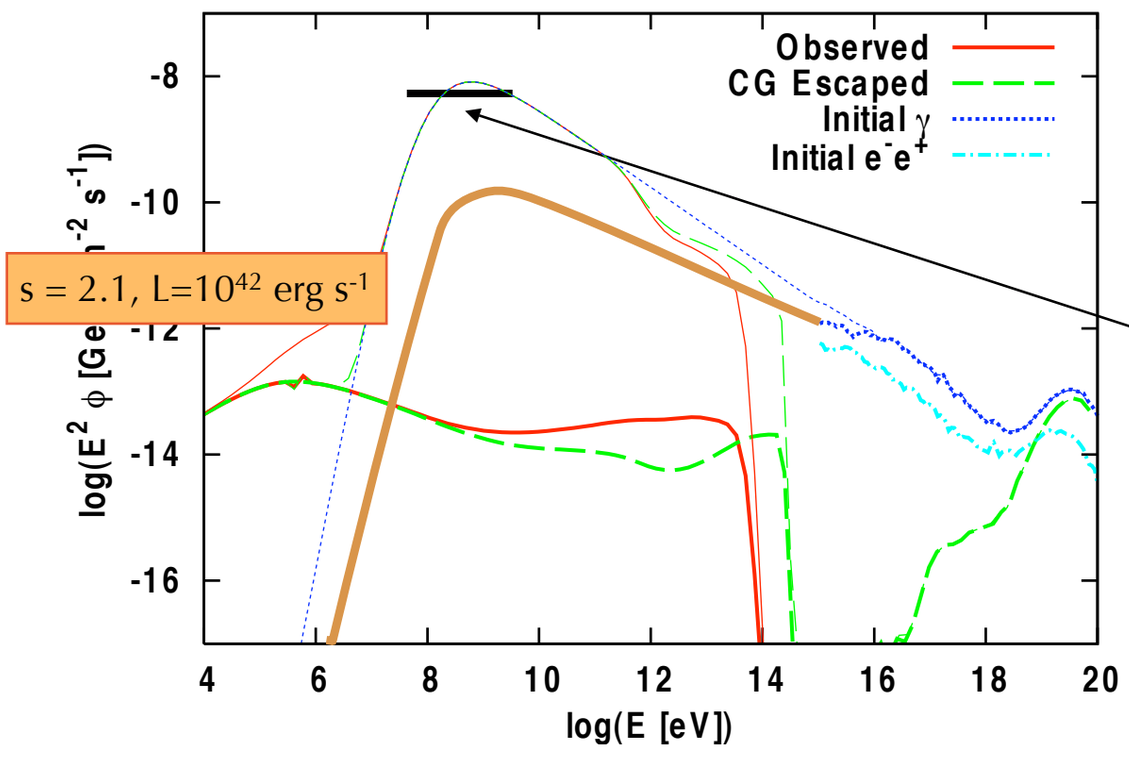

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question of minimum injection energy

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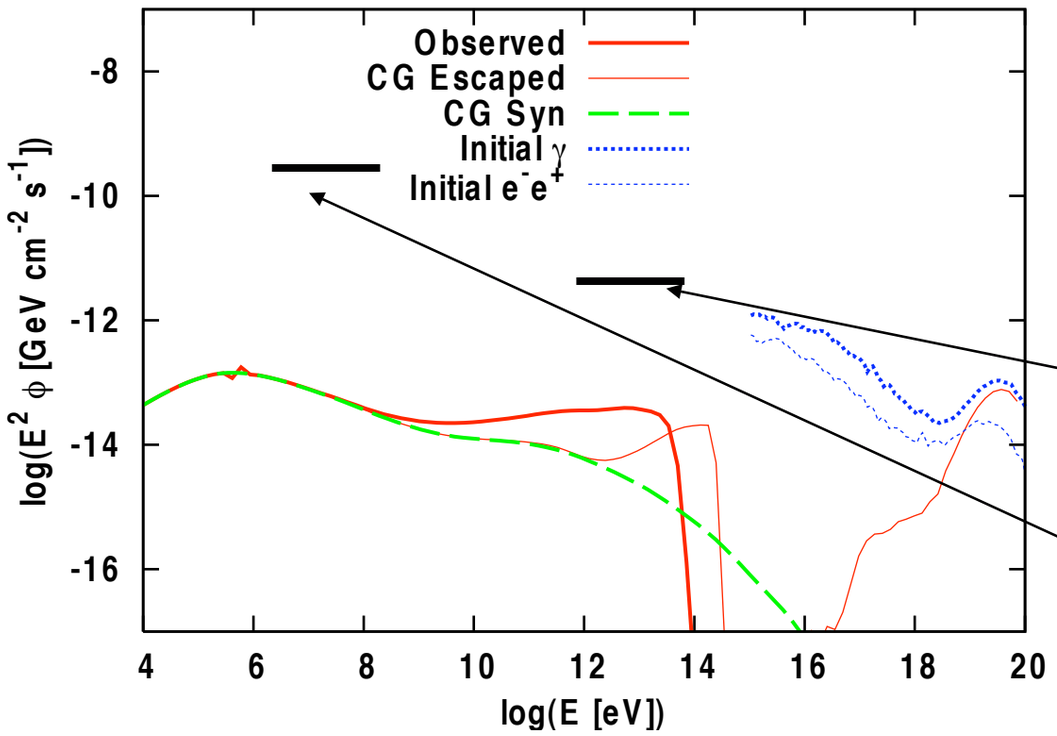

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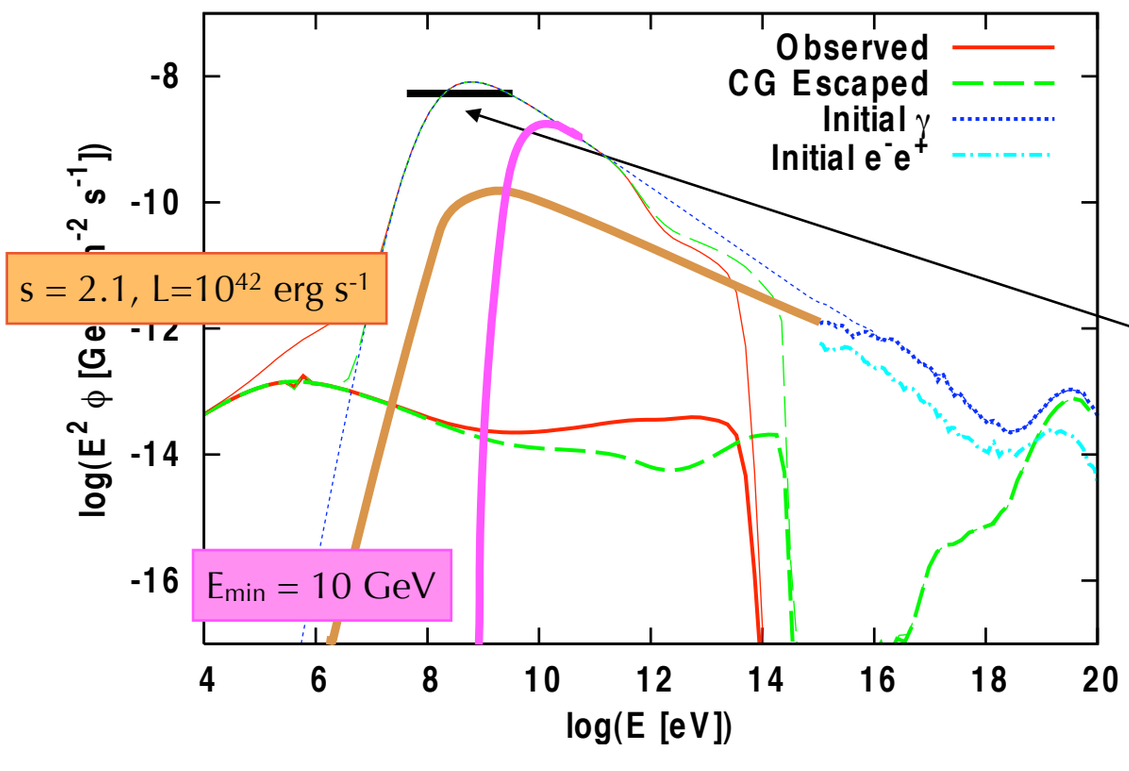

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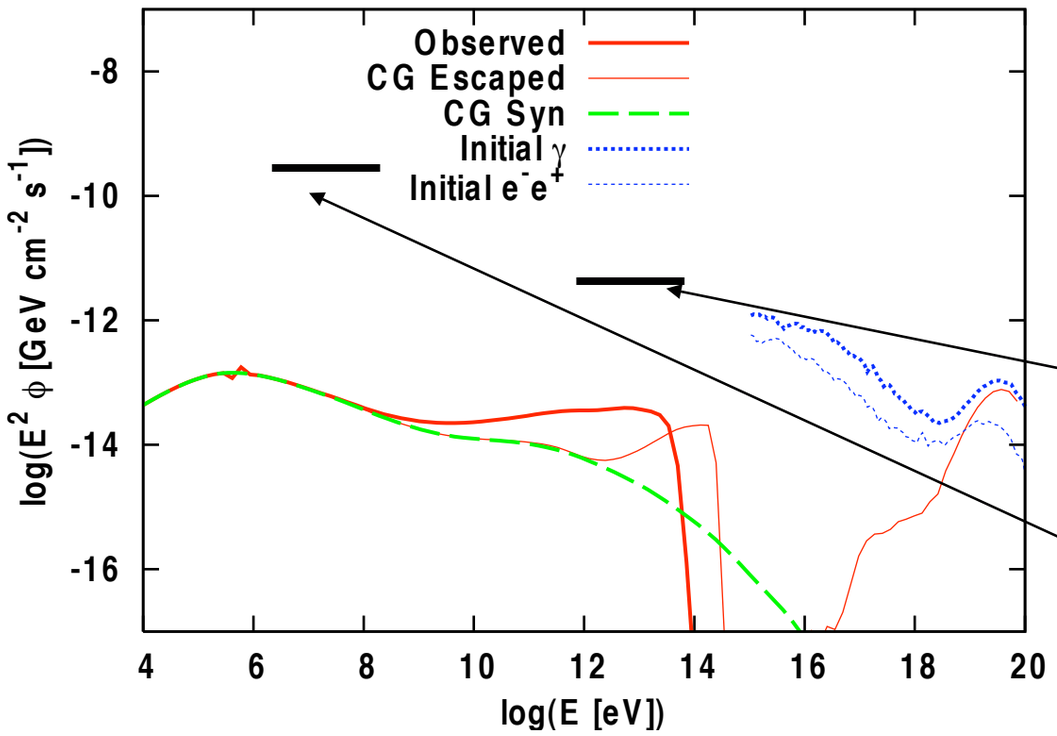

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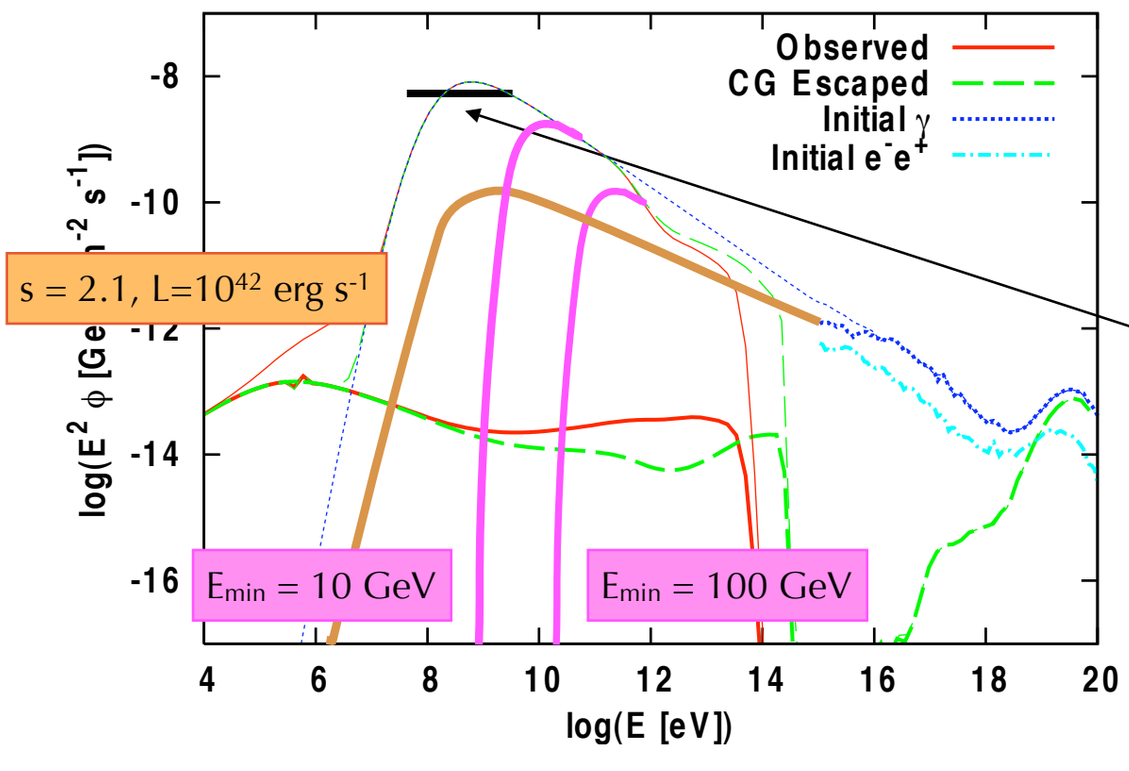

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EGRET limit (point source)

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Conclusion

K.K., D. Allard, K. Murase, J. Aoi, Y. Dubois, T. Pierog, S. Nagataki, *arXiv:0907.2433*

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- using a complete propagation code
- and based on a detailed study of the physical properties of clusters of galaxies.

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Gamma ray signals coming from **lower energy cosmic rays** ($E < 1$ PeV), if they exist, might however be detected by Fermi, for reasonable sets of parameters.