Evidence for UHECR origin in starburst galaxies

by

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- production of supernovae
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- production of supernovae
- most star forming regions around the center
- overall production of winds collectively create expanding bubbles
- scenario for shock acceleration
- multiple shocks: hardening of the spectrum
  [doi:10.1017/S1323358000019858]

$$f(p) \propto p^{-4} \longrightarrow f(p) \propto p^{-3}$$

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  - suppression in the spectrum above $50 \pm 7\,\mathrm{EeV}$

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    - rejection of isotropy at 4.5σ
- spectrum at the source $\sim 1 - 1.5$ [1612.07155, 1505.02153]

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- suggested explanations
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- our approach is to combine both at SBGs
- if acceleration lasts enough, the CMB becomes relevant

Acceleration mechanism

- diffusive shock acceleration at each shock

$$g = \frac{\mathrm{d}E}{\mathrm{d}t} = \left\langle \frac{\Delta E}{E} \right\rangle \frac{E}{T_{\mathrm{cycle}}}$$

$$\left\langle \frac{\Delta E}{E} \right\rangle \sim \frac{4}{3}(u_1 - u_2) \qquad T_{\mathrm{cycle}} = 4\kappa \left(\frac{1}{u_1} + \frac{1}{u_2} \right)$$

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- for typical shock parameters

$$g = \frac{3}{20} ZeBu^2$$

Magnetic field

- luminosity carried by the plasma [doi:10.1086/191522]

$$0.035 \lesssim L_B/L_{\rm IR} \lesssim 0.35$$

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- bounds on magnetic field for $L_{\rm IR} \sim 10^{43.9}\,{\rm erg/s}$

$$15\,\mu{\rm G} \lesssim B \lesssim 150\,\mu{\rm G}$$

CMB mean free path

- CMB photons excite giant dipole resonance producing nuclei photodisintegration

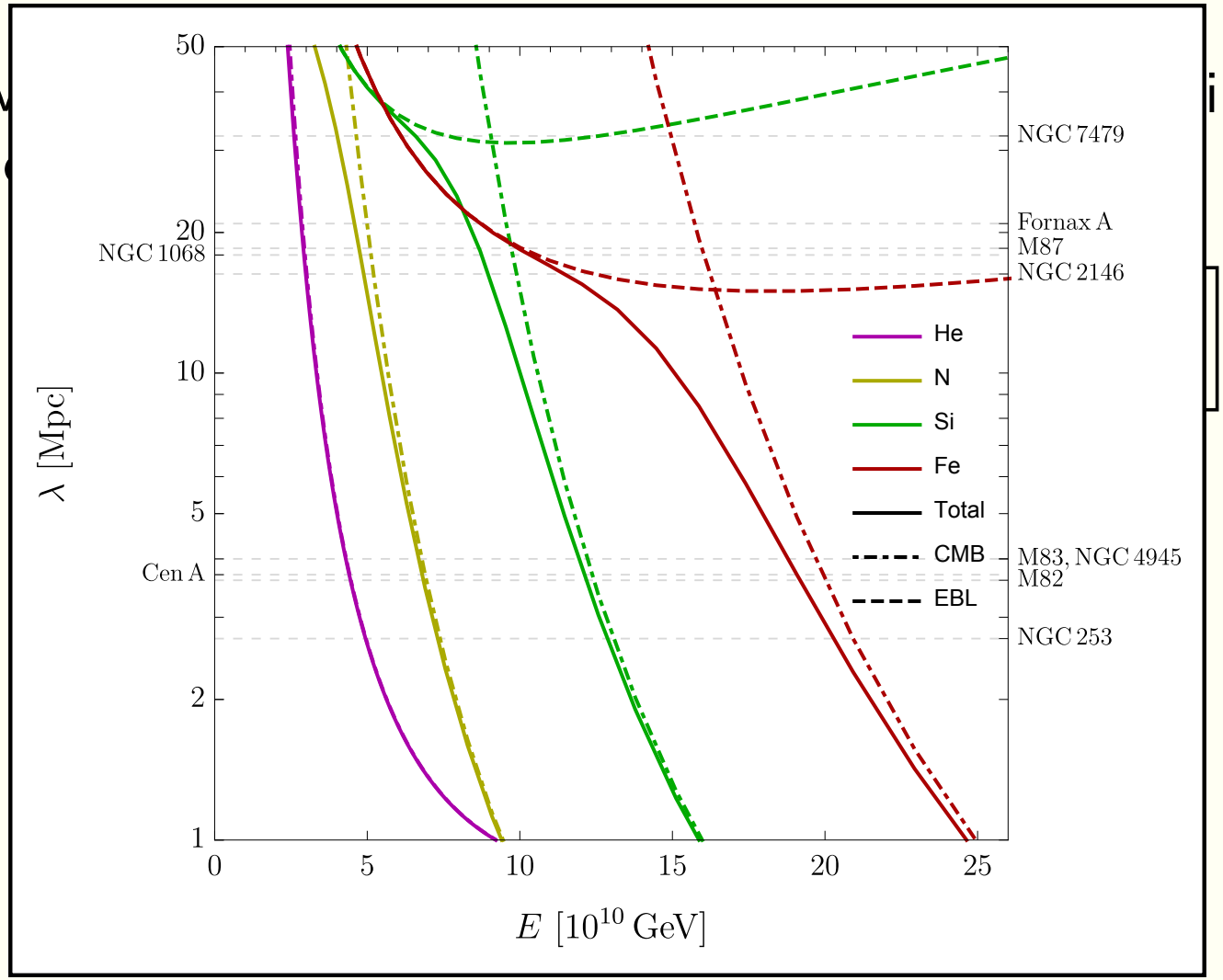
$$\tau_{\mathrm{CMB}}(E) = \left[\frac{c}{4\pi^2}\left(\frac{m}{\hbar c E}\right)^3 \int_0^\infty \frac{J(\varepsilon)}{e^{\varepsilon/kT'(E)} - 1} d\varepsilon\right]^{-1}$$

$$J(\varepsilon) = \int_0^\varepsilon \varepsilon' \sigma(\varepsilon') d\varepsilon'$$

$$T'(E) = \frac{2\,E\,T_{\mathrm{CMB}}}{A\,mc^2}$$

CMB mean free path

- CM… ing nu… -1



Acceleration *vs* photodisintegration

- pdf of photodisintegration at a time in $[t, t + \mathrm{d}t]$

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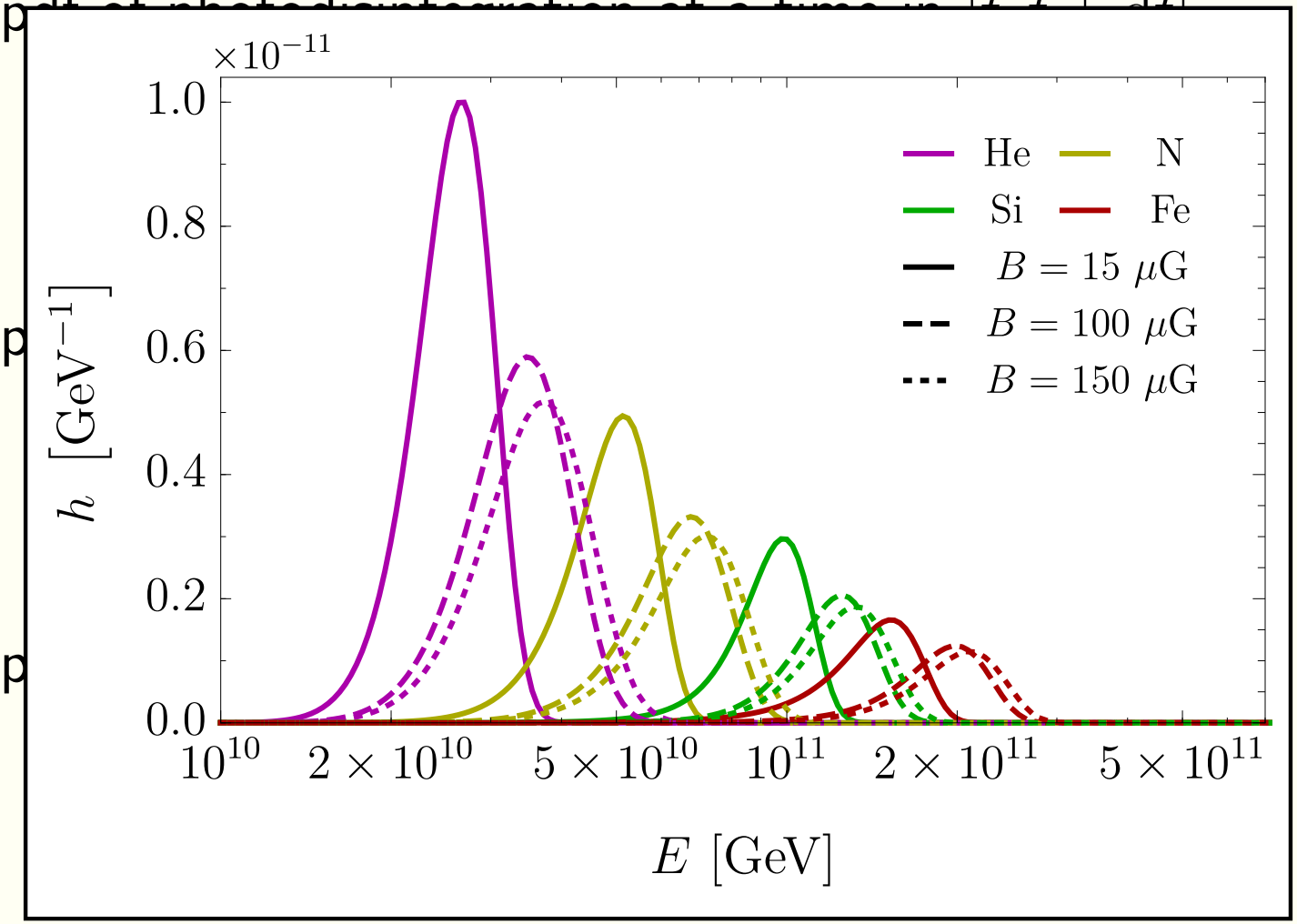
- probability of reaching an energy E

$$\mathcal{H}(E) = \exp\left(- \int_{E_0}^E \frac{dE'}{g\tau(E)} \right)$$

Acceleration *vs* photodisintegration

- pdf of photodisintegration at a time in $[t, t + dt]$
- p
- p



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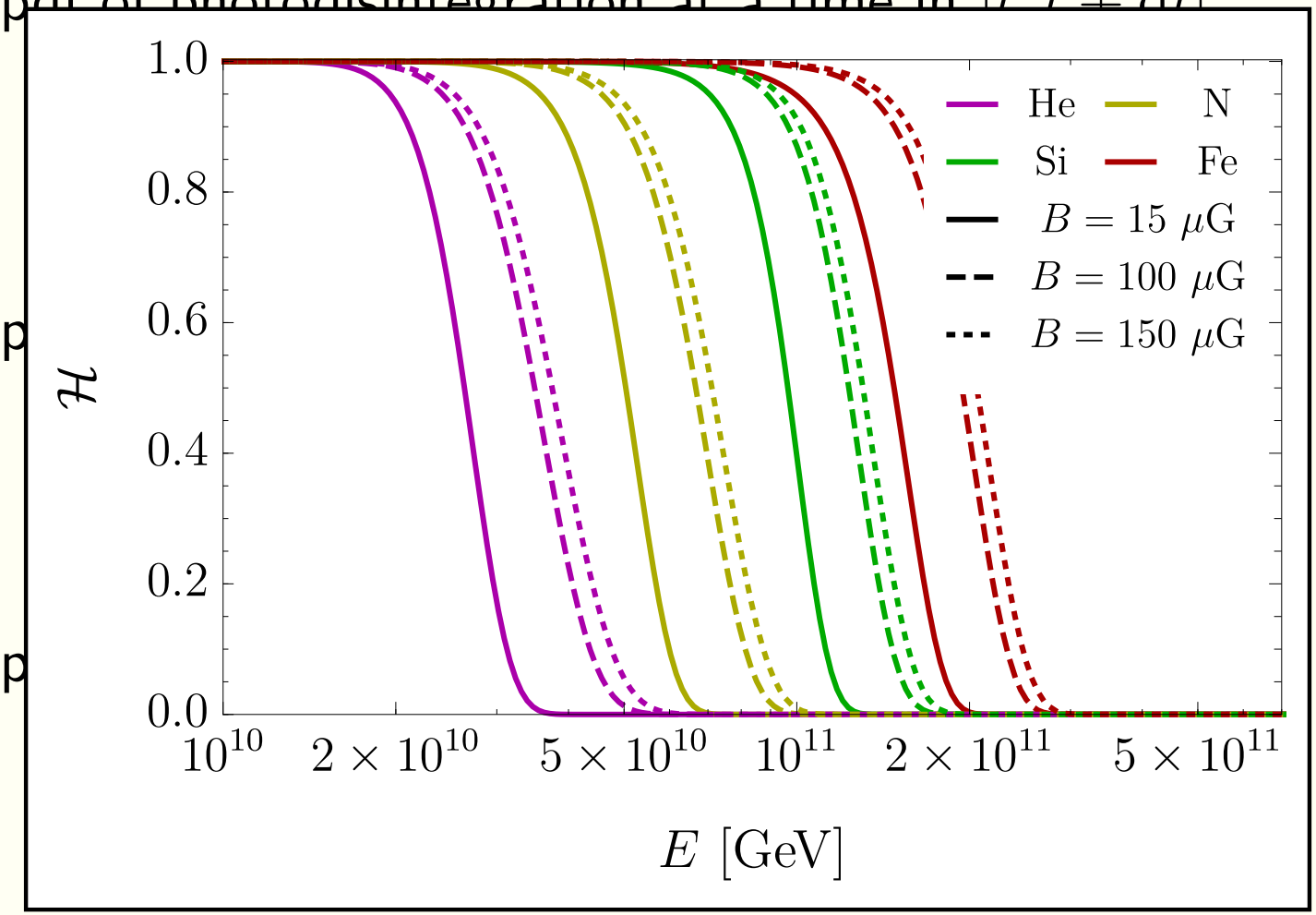

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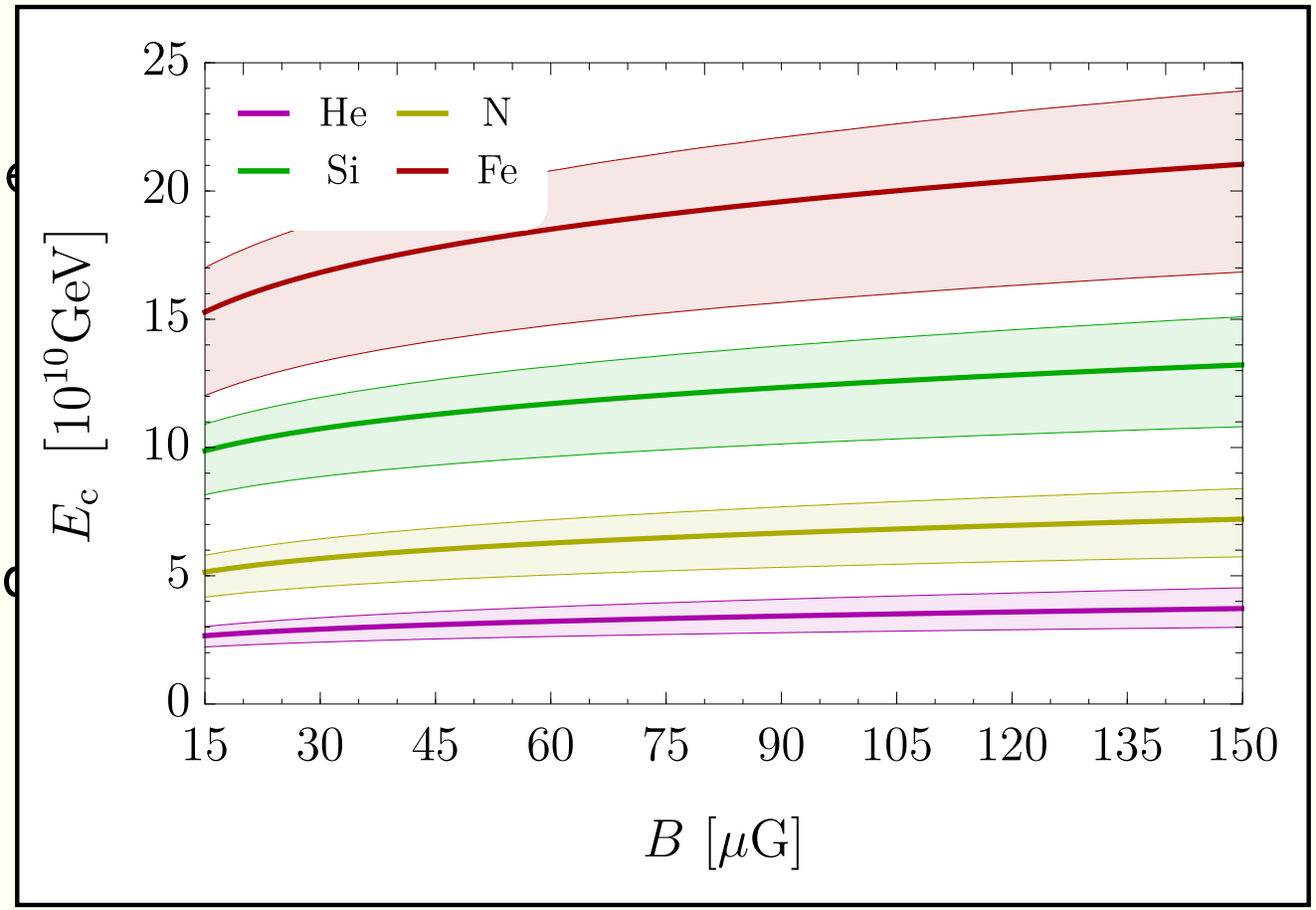
- wide distribution $\rightarrow$ dispersion in maximum energy

Energy cutoff

- ene
- wic



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  - impossible

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  -
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  -
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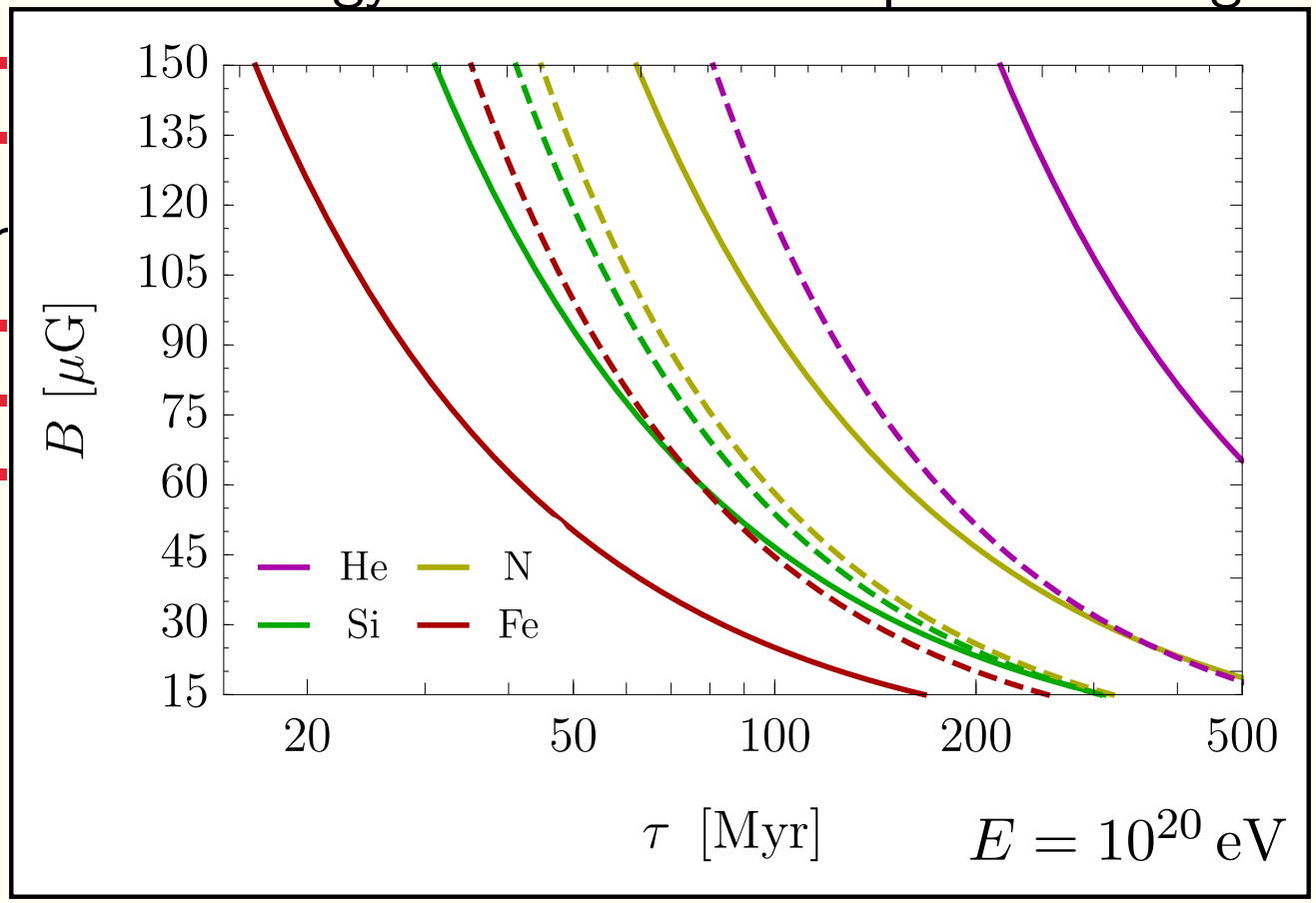
  -



Current work

- tune the composition ratios to find the all particle spectrum
- calculate the spectral index
- understand and solve the transport equation at the wave front with CMB absorption for a single species
- couple the equations for different species

Thank you