Gamma-Ray Line Production by Heavy-Heavy Interactions

direct reactions: accelerated p and α
inverse reactions: accelerated heavy

$$p + {}^{24}Mg \rightarrow p + {}^{24}Mg^{*1.37}$$

$$\alpha + {}^{24}Mg \rightarrow \alpha + {}^{24}Mg^{*1.37}$$

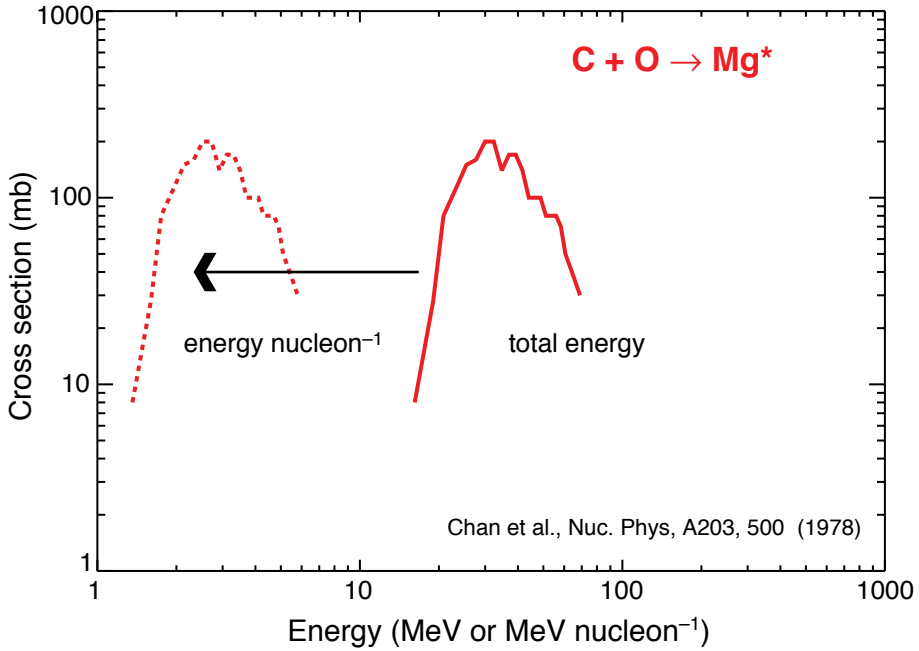
heavy-heavy reactions:

$${}^{16}O + {}^{12}C \rightarrow {}^{4}He + {}^{24}Mg^{*1.37}$$

Potential advantages:

- large cross section compared to p and α reactions
  (certainly true for the *total* cross section)

- when expressed as energy nucleon^{-1} the cross section shifts to lower energies which has an advantage for steep spectra



Disdvantages:

- much smaller abundances

  $[p]\bullet[C] = (1.0)^*(3 \times 10^{-4}) = 3 \times 10^{-4}$

  $[O]\bullet[C] = (1 \times 10^{-2})^*(3 \times 10^{-4}) = 3 \times 10^{-6}$

- in a thick target, larger coulomb energy losses $\propto Z^2/A$

- greater loss due to nuclear destruction

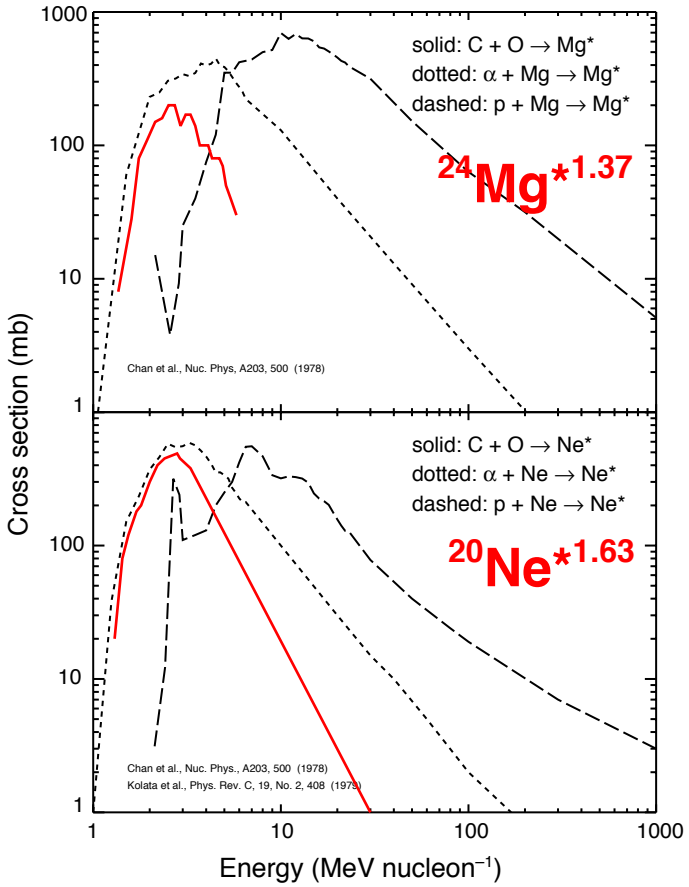
- because of the heavy projectile mass, the line will be broader than the "narrow" line and should not add to the measured narrow line yield

- the cross sections generally have higher threshold energies compared to p and α reactions due to the larger coulomb barrier ($\propto Z_1Z_2/A^{1/3}$) although this may be compensated for when expressed as energy nucleon^{-1}

Examples

Reactions of O and C are most favorable because:

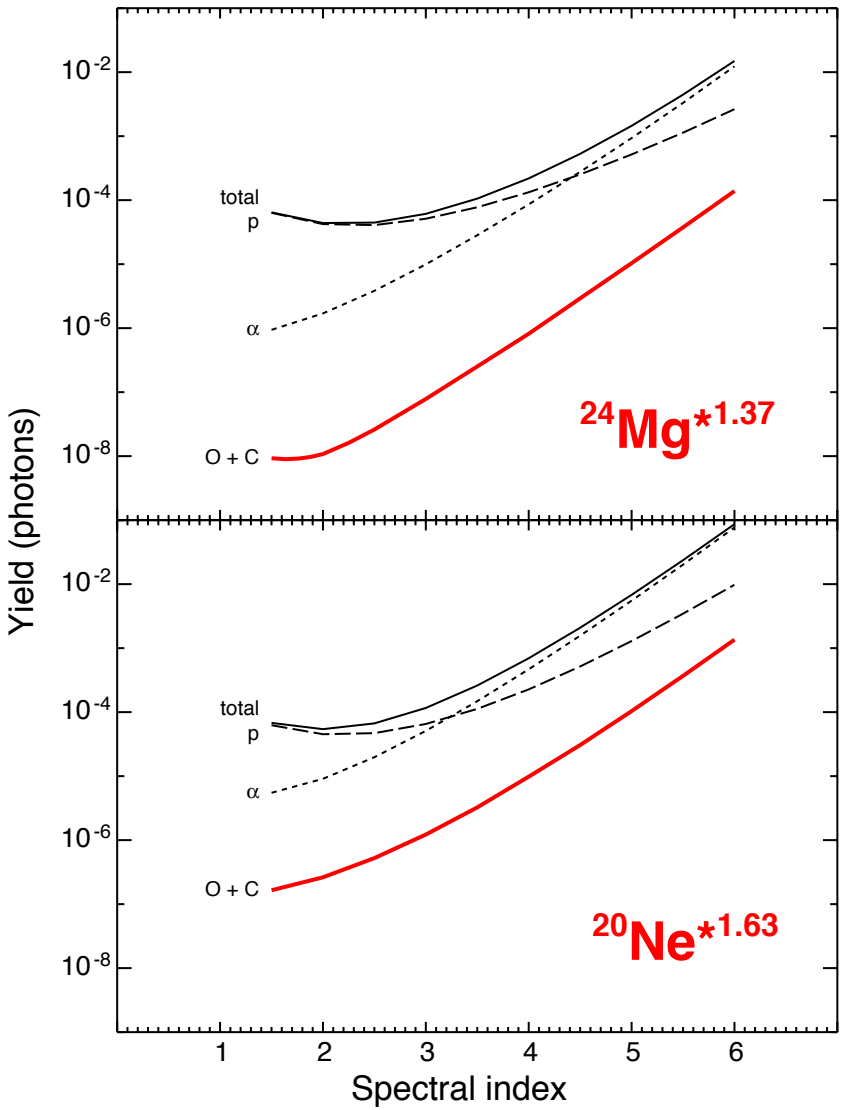
1. abundances
2. lowest coulomb losses
3. lowest nuclear destruction



The cross sections are **not** larger

The energy nucleon nucleon^{-1} advantage does not completely compensate for the coulomb barrier disadvantage when compared to the α reaction

Yield calculation



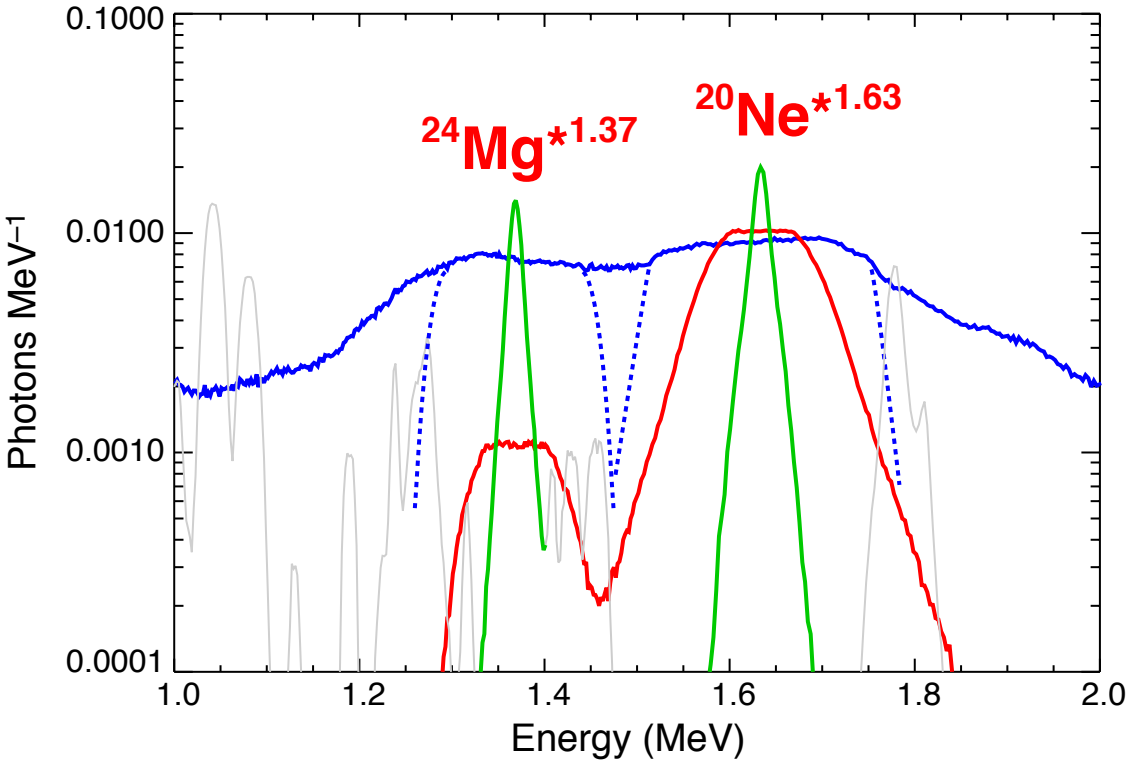
Thick target yield:

$$Q = n \int_0^\infty dE_0 \frac{dN}{dE}(E_0) \int_0^{E_0} dE \frac{\sigma(E)}{dE/dl(E)} P(E_0, E)$$

$$P(E_0, E) = exp\left[-n \int_E^{E_0} \frac{\sigma_N(E')}{dE/dl(E')} dE'\right]$$

The heavy-heavy interaction is never more than a few percent of the total yield

Line shapes



direct (narrow)

inverse (broad)

heavy-heavy (× 500)

fractional FWHM

direct:	1–2%
inverse:	~16%
heavy-heavy:	~9%