ELECTROMAGNETIC DISSOCIATION CROSS SECTIONS FOR HIGH LET FRAGMENTS

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2:15 - 2:30 pm (15 mins.)
INTRODUCTION

ELECTROMAGNETIC DISSOCIATION (EMD)

RESULTS

CONCLUSIONS
Galactic cosmic rays (GCR) & solar particle events (SPE) are radiation hazards in space for humans & electronic components
- GCR contain all nuclei in periodic table
- Energies hundreds of GeV/nucleon (n) & beyond

Focus on GCR interactions
- Nuclei broken into lighter fragments upon interaction with target nuclei

Target nuclei represent nuclei making up
- Spacecraft shielding, human body, electronic components, etc.
- Example: $^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + n + \text{Al}$
**Introduction: Strong vs. Electromagnetic (EM)**

\[ ^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + \text{n} + \text{Al} \]

Short range strong interaction when projectile & target nuclei overlap.
Introduction: Strong vs. Electromagnetic (EM)

$^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + \text{n} + \text{Al}$

Short range strong interaction when projectile & target nuclei overlap.

Long range EM interaction when projectile & target nuclei miss each other.
**Electromagnetic Dissociation**

$$\sigma_{\text{EMD}} = \int dE_\gamma N(E_\gamma) \sigma(E_\gamma)$$

Photonuclear cross section $\sigma(E_\gamma)$ shown by red curve, plotted against photon energy $E_\gamma$. Green & blue curves show virtual photon spectra $N(E_\gamma)$ for low & high energy projectiles.

Previously, EMD models (e.g. within NUCFRG3) calculate single proton (p) production, single neutron (n) or light ion production
- Light ion ≡ isotope of hydrogen (H) or helium (He)
- Deuteron (d ≡ ²H), triton (t ≡ ³H), helion (h ≡ ³He), alpha (α ≡ ⁴He)

New model EMDFRG accounts for multiple nucleon production
- 2p, 2n, 1p1n, 2p1n, 3p1α, 2p2t, ... (in addition to single light ions)

Such processes important:
- Consider reaction \( {^{56}}Fe + Al \rightarrow {^{52}}Cr + X + Al \) high LET \( {^{52}}Cr \)
- Most probable EMD particles representing X are 2p2n or \( {^{4}}He \)
- \( {^{56}}Fe + Al \rightarrow {^{52}}Cr + {^{4}}He \) + Al \( \rightarrow {^{52}}Cr + 2p2n + Al \) EMDFRG & NUCFRG3
- \( \sigma({^{52}}Cr) = \sigma(2p2n) + \sigma({^{4}}He) \)
- Production of high LET \( {^{52}}Cr \), must include both multiple nucleon production of 2p2n plus light ion production of \( {^{4}}He \)
Compare:

EMDFRG ——— with photonuclear parameterization for $\sigma(E_\gamma)$
EMDFRG - - - - - with photonuclear data for $\sigma(E_\gamma)$
NUCFRG2 - - - - -
NUCFRG3 .......

Focus on EMDFRG ——— and NUCFRG3 .........
Excellent agreement for EMDFRG —— Poor agreement for NUCFRG3 • • • • •
Excellent agreement for EMDFRG —— Worse agreement for NUCFRG3 • • • • •
Similar agreement for EMDFRG —— and NUCFRG3 • • • • •

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Galactic Cosmic Ray Environment

January 28, 2016 10 / 25
**RESULTS - SINGLE NUCLEON**

Good agreement for EMDFRG —— Poor agreement for NUCFRG3 • • • • •
Similar agreement for EMDFRG —— and NUCFRG3 • • • • •
Excellent agreement for EMDFRG
Large Hadron Collider (LHC)

4,056.44 TeV/n: $^{208}$Pb + Target $\rightarrow$ 1n

Excellent agreement for EMDFRG
RESULTS - DOUBLE NUCLEON

EMDFRG —— DATA ——

1700 MeV/n : $^{18}$O + Target → $^{16}$O (2n)

$\sigma$ (mb)

Z target

1700 MeV/n : $^{18}$O + Target → $^{16}$N (1p1n)

$\sigma$ (mb)

Z target

Good agreement for EMDFRG

$\sigma_{\text{NUCFRG3}} = 0$
**RESULTS - DOUBLE NUCLEON**

**EMDFRG**

**DATA***—— MMM***

13.7 GeV/n: $^{28}$Si + Target → $^{26}$Al + 1p1n

Excellent agreement for EMDFRG ———

$\sigma_{\text{NUCFRG3}} = 0$

13.7 GeV/n: $^{28}$Si + Target $\rightarrow$ $^{26}$Mg + 2p (f=0.18)

Poor agreement for EMDFRG ——— (fit = - - -)

$\sigma_{\text{NUCFRG3}} = 0$

13.7 GeV/n: $^{28}$Si + Target $\rightarrow$ $^{26}$Si + 2n (f=0.05)
Good agreement for **EMDFRG**

\[ \sigma_{\text{NUCFRG3}} = 0 \]

**RESULTS - DOUBLE NUCLEON**

1260 MeV/n: \(^{59}\text{Co} + \text{Target} \rightarrow ^{57}\text{Co} \ (2n)\)

1700 MeV/n: \(^{59}\text{Co} + \text{Target} \rightarrow ^{57}\text{Co} \ (2n)\)

2100 MeV/n: \(^{59}\text{Co} + \text{Target} \rightarrow ^{57}\text{Co} \ (2n)\)

1000 MeV/n: \(^{197}\text{Au} + \text{Target} \rightarrow ^{195}\text{Au} \ (2n)\)
Reasonable agreement for \textit{EMDFRG} ——– $\sigma\text{NUCFRG3} = 0$
RESULTS - TRIPLE NUCLEON

Excellent agreement for EMDFRG ——– $\sigma_{\text{NUCFRG3}} = 0$

Poor agreement for EMDFRG ——– (fit = - - -) $\sigma_{\text{NUCFRG3}} = 0$
**RESULTS - TRIPLE NUCLEON**

1000 MeV/n: $^{197}$Au + Target → $^{194}$Au (3n)

1700 MeV/n: $^{197}$Au + Target → $^{194}$Au (3n)

Mixed agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
**Results - Many Nucleon**

13.7 GeV/n: $^{28}$Si + Target → $^{24}$Mg + 2p2n

- Good agreement for EMDFRG  
  $\sigma_\text{NUCFRG3} = 0$

13.7 GeV/n: $^{28}$Si + Target → $^{23}$Na + 3p2n

- Poor agreement for EMDFRG  
  (fit = - - -)  
  $\sigma_\text{NUCFRG3} = 0$

13.7 GeV/n: $^{28}$Si + Target → $^{24}$Na + 3p1n  
  (f=0.27)
13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{24}\text{Mg} + \alpha$

Excellent agreement for EMDFRG

Poor agreement for NUCFRG3

Results - Alpha

(Another reason for developing EMDFRG)
Excellent agreement for EMDFRG  

\[ \sigma_{\text{NUCFRG3}} = 0 \]
CONCLUSIONS

- New EMDFRG model for single & multiple nucleon & light ion
- Calculations are compared to complete set of experimental data
- Agreement with data is excellent for all cases relevant for space radiation
- Single, double & triple nucleon removal data agrees very well over the whole range of energies, projectiles and targets
- Alpha production data agrees very well for $^{28}\text{Si}$ projectiles, including alpha production in coincidence with single nucleons
- Some discrepancies, but not important for space radiation, because cross sections are quite small
  - Exception is for double nucleon removal from $^{28}\text{Si}$