Depth-Dependent Solar Cosmic Ray Induced Cosmogenic Production Rates

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Introduction

- Solar (SCR) and galactic cosmic rays (GCR) bombard material in the solar system with high energetic protons and α particles
- Induce spallation reactions that produce cosmogenic nuclides
- High energy particles are slowed down in the target; incident spectral shape changes with depth
- GCR penetrates deep into the material; production rates are well studied [1,2]
- SCR only penetrates the upper few g/cm^2
- This material is usually lost by ablation during atmospheric entry
- Apollo samples show SCR record
- Martian meteorites, especially Shergottites, also show SCR record

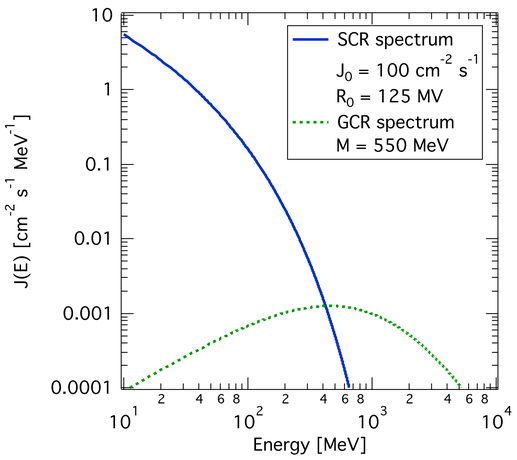

Fig. 1: Spectral shape of SCR and GCR particles in the solar system. SCRs are much more abundant than GCRs at low energies while GCRs dominate the high energy regime.

We present a model to calculate depth-dependent SCR production rates in meteorites.

Model

- Use SCR spectrum (Fig. 1) as incident spectrum
- Calculate stopping using parameterized Bethe-Bloch equation as described by [3]
- Stopping depends on chemical composition of the target material
- Calculation done for two irradiation scenarios (Fig. 2):
  1) 2π irradiation (assumes infinite disk)
  2) 4π irradiation (assumes a spherical meteoroid)
- Fig. 3 shows spectra in samples with shergottite composition [e.g., 4] for the 2π irradiation scenario
- Calculate cosmogenic production rates at given depth using the calculated spectrum and the production rate model by [5]

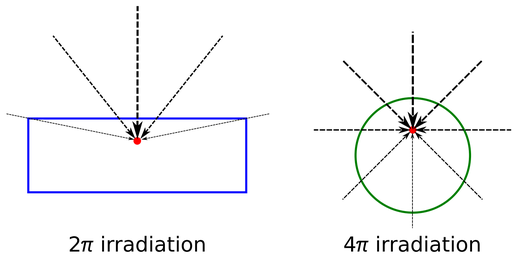

Fig. 2: The two considered irradiation scenarios. Thick arrow indicate little stopping. In the 2π scenario, no SCR particles penetrate from the back of the meteoroid.

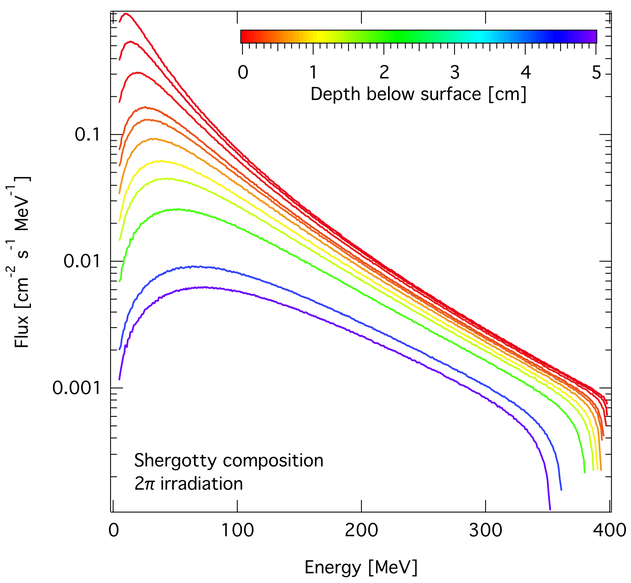

Fig. 3: SCR spectra at different depths in a meteoroid with shergottite composition. The modelled range goes from 0.05 cm (upper curve) to 5 cm depth (lower curve).

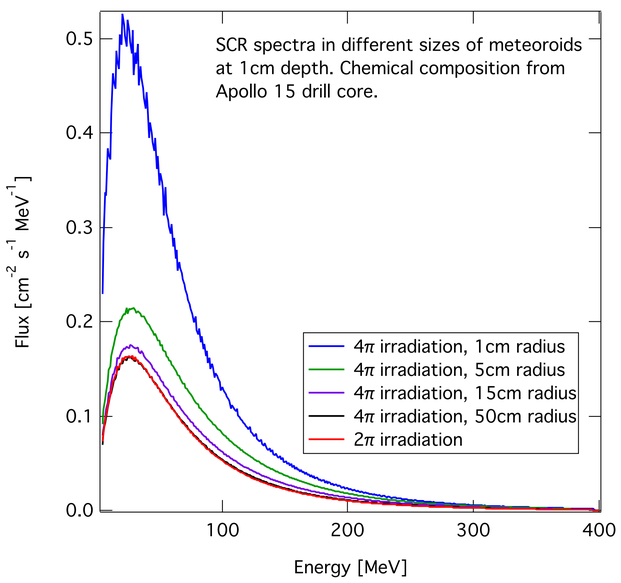

Fig. 4: Flux denities modelled for 2π and 4π irradiations of a meteoroid with the same composition as the Apollo 15 drill core at 1 cm depth. The 4π model converges nicely and is for large meteoroids identical to the 2π model (red and black curve).

Results

- New production rates for Apollo 15 drill core [6] agree well with production rates by [7] (Fig. 5)
- Our model uses state-of-the-art stopping calculations and the best knowlege of nuclear cross sections
- Fig. 6 and Fig. 7 show depth-dependent cosmogenic production rates for noble gases in lunar and martian samples
- Considering two rigidities - the higher the rigidity the more energetic particles are in the spectrum
- Production rates at larger shielding depth are higher for higher rigidities

The results of the new production rate model agree well with literature value and can be used to calculate depth-dependent cosmogenic production rates.

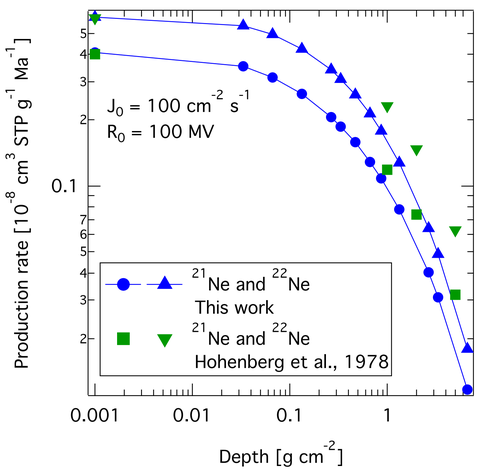

Fig. 5: Comparison of our production rates with literature values [7].

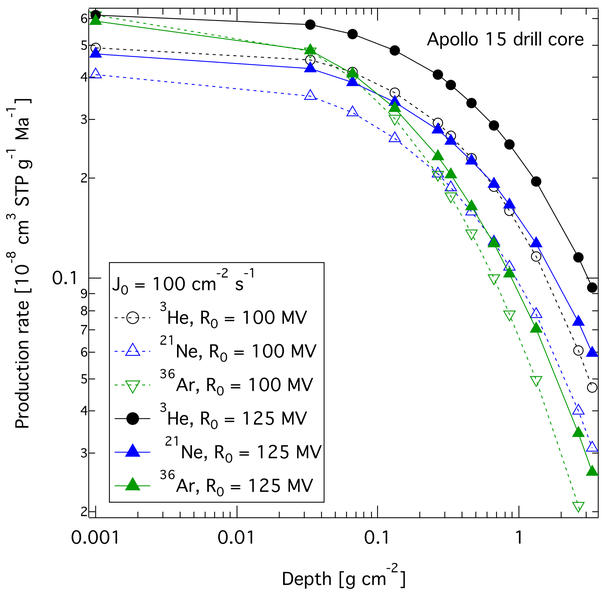

Fig. 6: Noble gas production rates in Apollo 15 drill core composition for two different rigidities and for the 2π irradiation scenario.

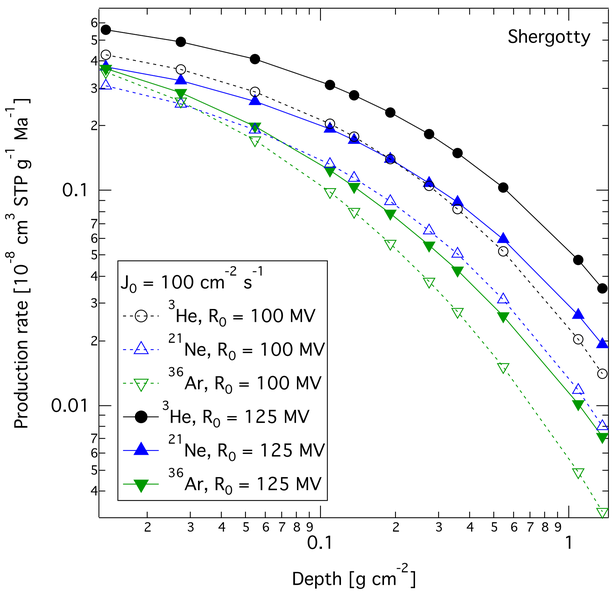

Fig. 7: Noble gas production rates in a meteoroid having shergottite chemical composition for two different rigidities and for the 2π irradiation scenario.

Discussion

- ^{21}Ne/^{22}Ne ratio in lunar samples have the opposite trend at depth <1 cm than martian meteorites (Fig. 8)
- Difference is due to Na content
- Na ~5 times higher in shergottites compared to lunar material

- Measured cosmogenic Ne in Shergotties shows low ^{21}Ne/^{22}Ne ratios, much lower than by GCR irradiation
- See previous / next poster [8] and literature [9]
- SCR induced ^{21}Ne/^{22}Ne is between 0.58 and 0.68 for a spectrum with a rigidity of 125 MV (Fig. 8)
- This is significantly lower than the GCR ratio (~0.85)
- Shergottites have ^{21}Ne/^{22}Ne as low as 0.7 (measured data)
- Can be explained as a combination of SCR and GCR
- Question remains why these meteoroids did not loose their upper few g/cm^2 while passing through the Earth's atmosphere

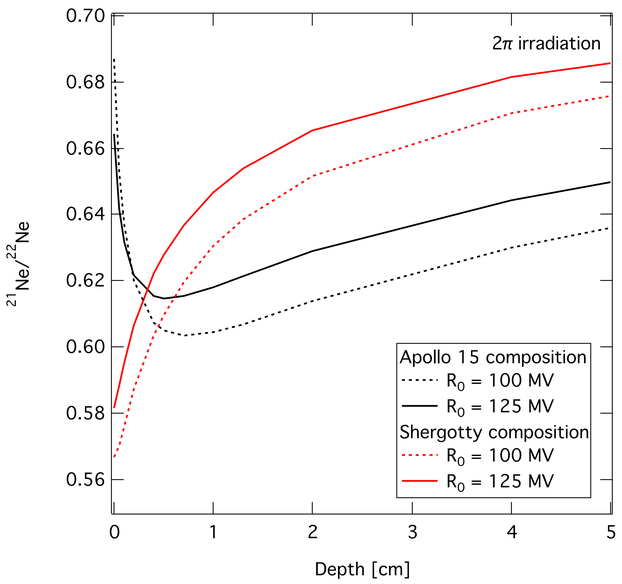

Fig. 8: Ratio of cosmogenic ^{21}Ne/^{22}Ne at different depths in samples with the chemical composition of Apollo 15 drill core and Shergotty. The difference between the shapes of the curves is mainly due to different amount of Na. 2π irradiation scenario.

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References
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