TITLE

Organ Dose and Organ Dose Equivalent Rate Calculations from October 26, 2003 (Halloween Event) Solar Energetic Particle (SEP) Event using Earth-Moon-Mars Radiation Environment Module (EMMREM)

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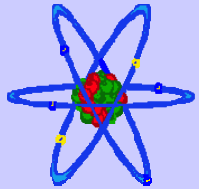
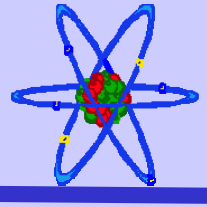
Introduction (1)



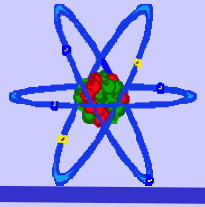
- **Risks to flight crews from Solar Energetic Particle (SEP) events and Galactic Cosmic Rays (GCR) are a major concern in planning for long-duration manned missions.**
- **The central objective of the Earth-Moon-Mars Radiation Environment Module (EMMREM) is to develop a numerical model for completely characterizing the time-dependent radiation environment in the Earth-Moon-Mars and Interplanetary space environments.**

Introduction (2)



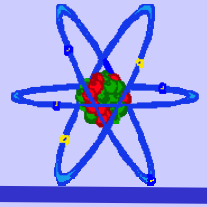
- **The Module includes a 3D energetic particle transport model (EPREM), and utilizes a version of the space radiation transport code (BRYNTRN) developed at NASA Langley Research Center.**
- **With the initial setup of the Earth-Moon-Mars Radiation Environment Module (EMMREM) framework in place, we are turning to performing realistic simulations with observations from October 26, 2003 Solar Energetic Particle event (SEP) for module testing and as an example of the module capabilities.**

Introduction (3)



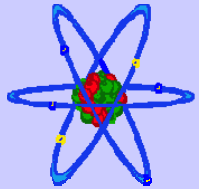
- **In this work we present and discuss the Earth-Moon-Mars Radiation Environment Module (EMMREM) predictions for the Dose Rates, Dose Equivalent Rates and accumulated Dose in space, throughout the October 26, 2003 event, for radial distance of 1 AU, with various aluminum and water shield thicknesses.**

Introduction (4)



- **These Dose and Dose Equivalent Rates data, are folded with the actual shielding distributions of a spacecraft or surface habitat, and folded with the distribution of overlying tissues providing body self-shielding for human organs, to permit us to evaluate time-dependent estimates of Organ Dose Rates and Organ Dose Equivalent Rates to determine potential exposures for human crews during long travel durations in deep space.**

Operational Overview of the current EMMREM Module (1)



The next slide is a schematic of the current EMMREM operational framework. The blue-bordered rectangles represent input or output data products for the various subsystems. The rectangles in black borders represent the different software products, which are run in series. This whole system is controlled by a number of bash shell and perl scripts. It is run in LINUX (UBUNTU V8.04) OS.

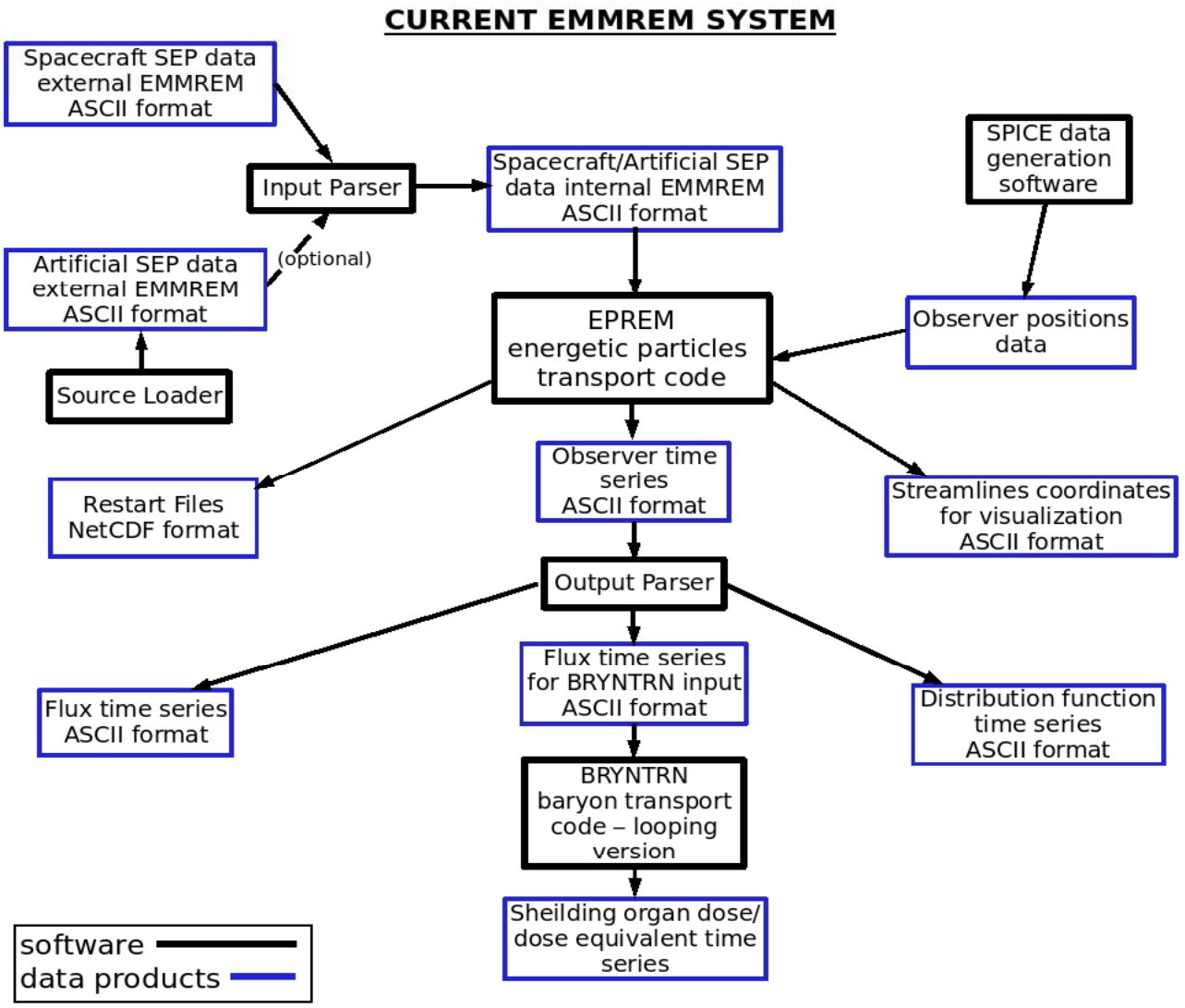
INPUT TO THE SYSTEM

On the top of the diagram. The EPREM transport code takes two types of input data

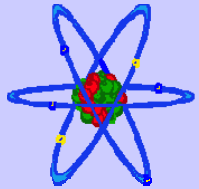
a) **Energetic particle flux time series** $\left(\frac{\#\,Particles}{cm^2 \cdot s \cdot MeV}\right)$

b) **Position of various bodies of interest in the simulation in Heliospheric Inertial Coordinates.**

Operational Overview of the current EMMREM Module (2)



Operational Overview of the current EMMREM Module (3)



THE INPUT PARSER

The external EMMREM format data (from GOES, ACE, etc) is converted into internal EMMREM format data (distribution function time series of SEPs)

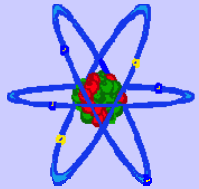
THE SPICE POSITIONS LOADER

Those are generated by utilizing the CSPICE library of the NASA SPICE Toolkit.

EPREM

The EPREM sub module is a 3-D Kinetic numerical simulation of Solar Energetic Particles transport throughout the inner Heliosphere. It is a parallelized code written in C/C++.

Operational Overview of the current EMMREM Module (4)



EPREM OUTPUT

Observer time series of distribution function spectra for various positions in the code (ASCII internal EMMREM format).

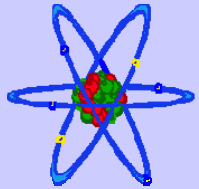
THE OUTPUT PARSER

Converts Observer outputs from distribution function time series to flux time series for several energies.

BRYNTRN

Uses output parser outputs as input. BRYNTRN is used to transport incident solar protons and their secondaries through aluminum spacecraft shielding and then through an additional quantity of water simulating human tissue.

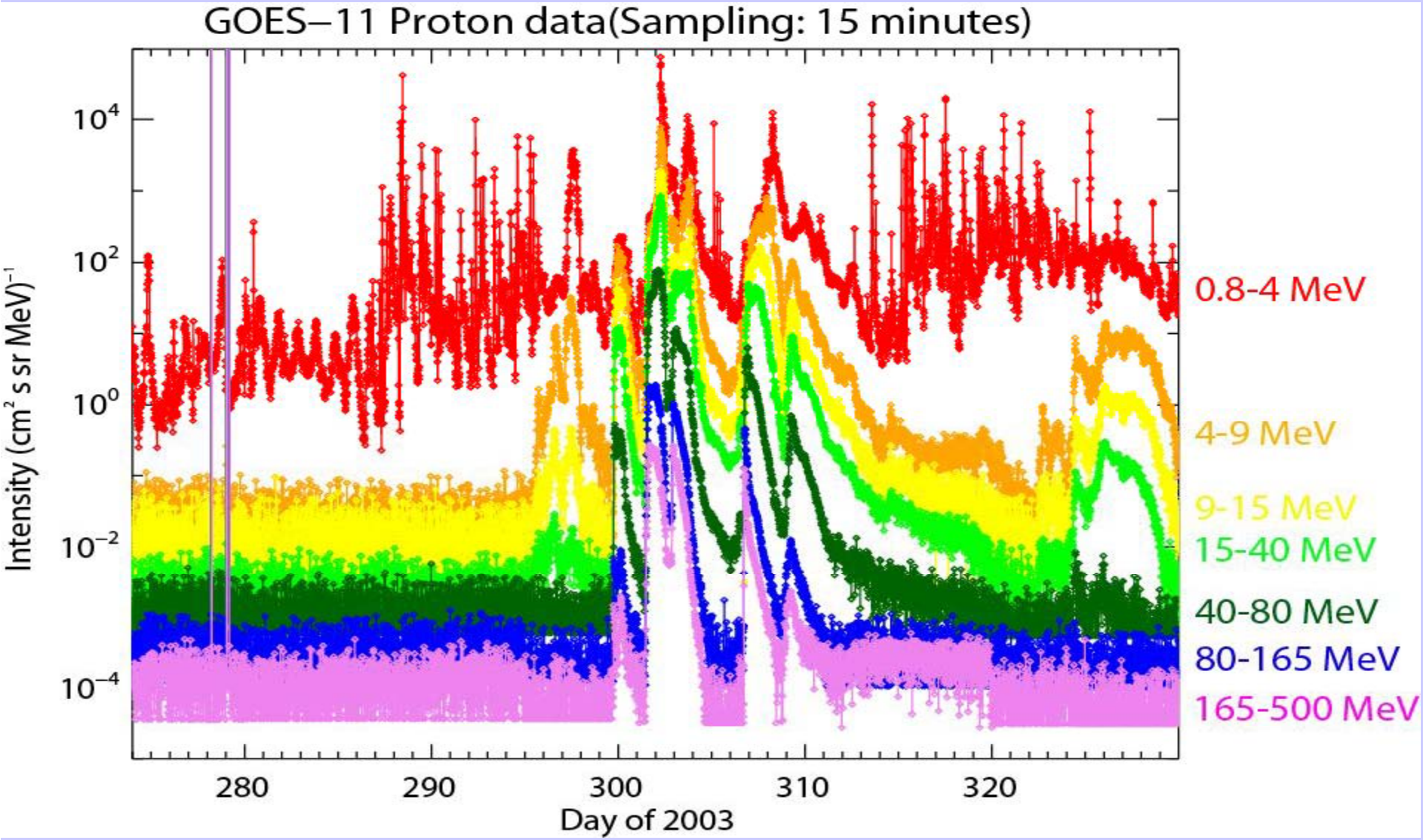
Operational Overview of the current EMMREM Module (5)



The **BRYNTRN output contains Dose and Dose Equivalent time series for different shielding depths and shielding materials. Our BRYNTRN Version is a parallelized code written in FORTRAN 77.**

The next page is the plot of the proton flux .VS. time for the October 26, 2003 SEP event.

October 26, 2003 SEP Event Proton Data



Observers results (A)

- **Plots are self descriptory.**
- **Observer results are for a radial distance of 1 AU, with Al and Water layers.**
- **Covered proton energy range is 0.1 – 500 (MeV)**
- **“d1” (in horizontal axis of plots) is start day of the event. October 26, 2003 = day 299.**
- **“Gray Equivalent Rate” = Dose Rate × RBE**

Observers results (B)

- **Aluminum shielding areal densities used simulates approximate real life scenarios.**

1.0 g/cm^2 - typical spacesuit

2.0 g/cm^2 - thin spacecraft

5.0 g/cm^2 - nominal spacecraft

10.0 g/cm^2 - SEP storm shelter

Observers results (C)

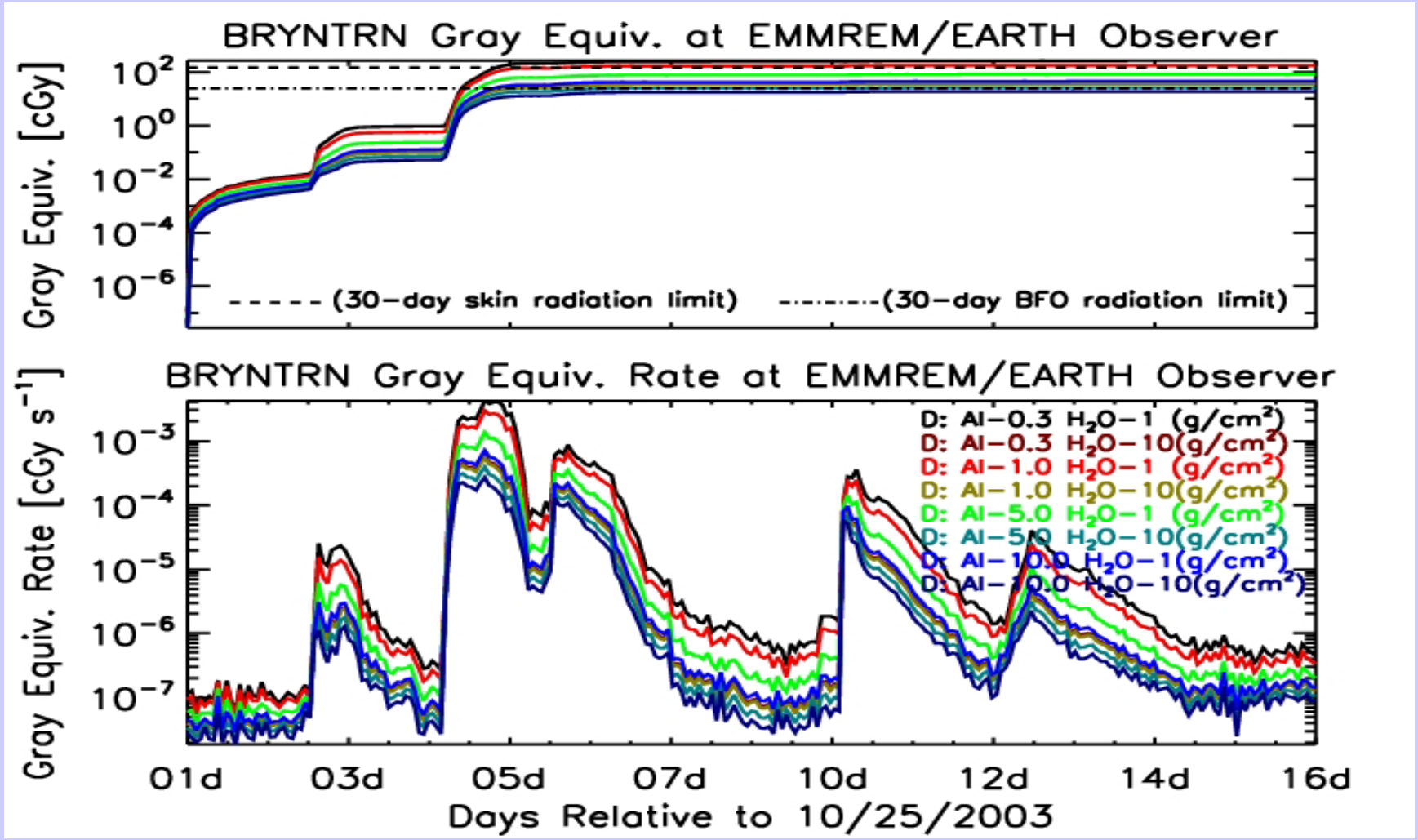
Dose limits for short-term or career non-cancer effects (in cGy-Eq. or cGy)
Note RBE's for specific risks are distinct as described below.

Organ	*30 day limit (cGy-Eq)*	*1 Year Limit (cGy-Eq)*	*Career (cGy-Eq)*
Lens*	**100**	**200**	**400**
Skin	**150**	**300**	**400**
BFO	**25**	**50**	**NA**
Heart**	**25**	**50**	**100**
CNS***	**50**	**100**	**150**
CNS* (Z≥10)**	**-**	**10**	**25**

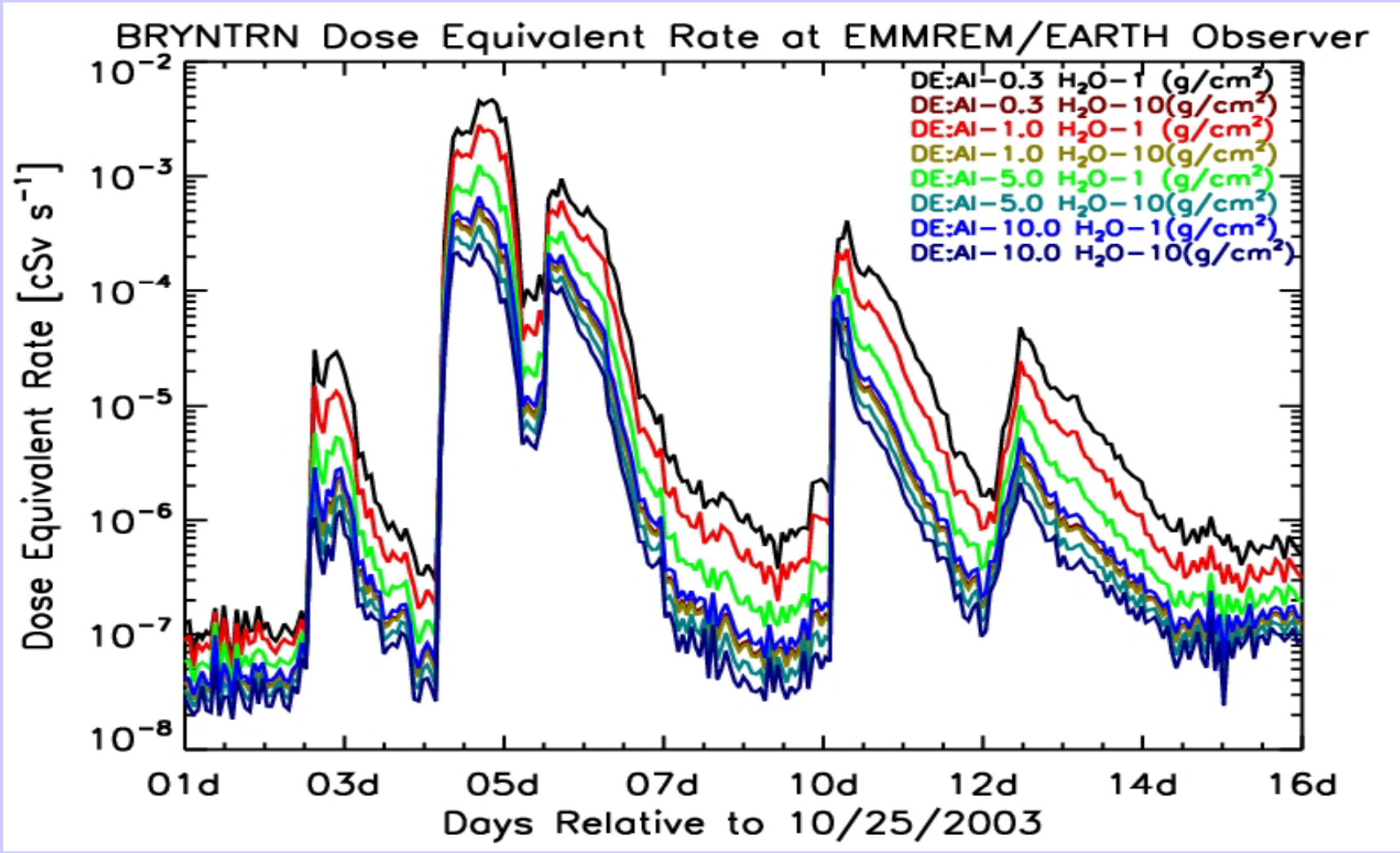
*Lens limits are intended to prevent early (< 5 yr) severe cataracts (e.g., from a solar particle event). An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (> 5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.
**Heart doses calculated as average over heart muscle and adjacent arteries.
***CNS limits should be calculated at the hippocampus.

From NASA_STD_3001_Vol 1

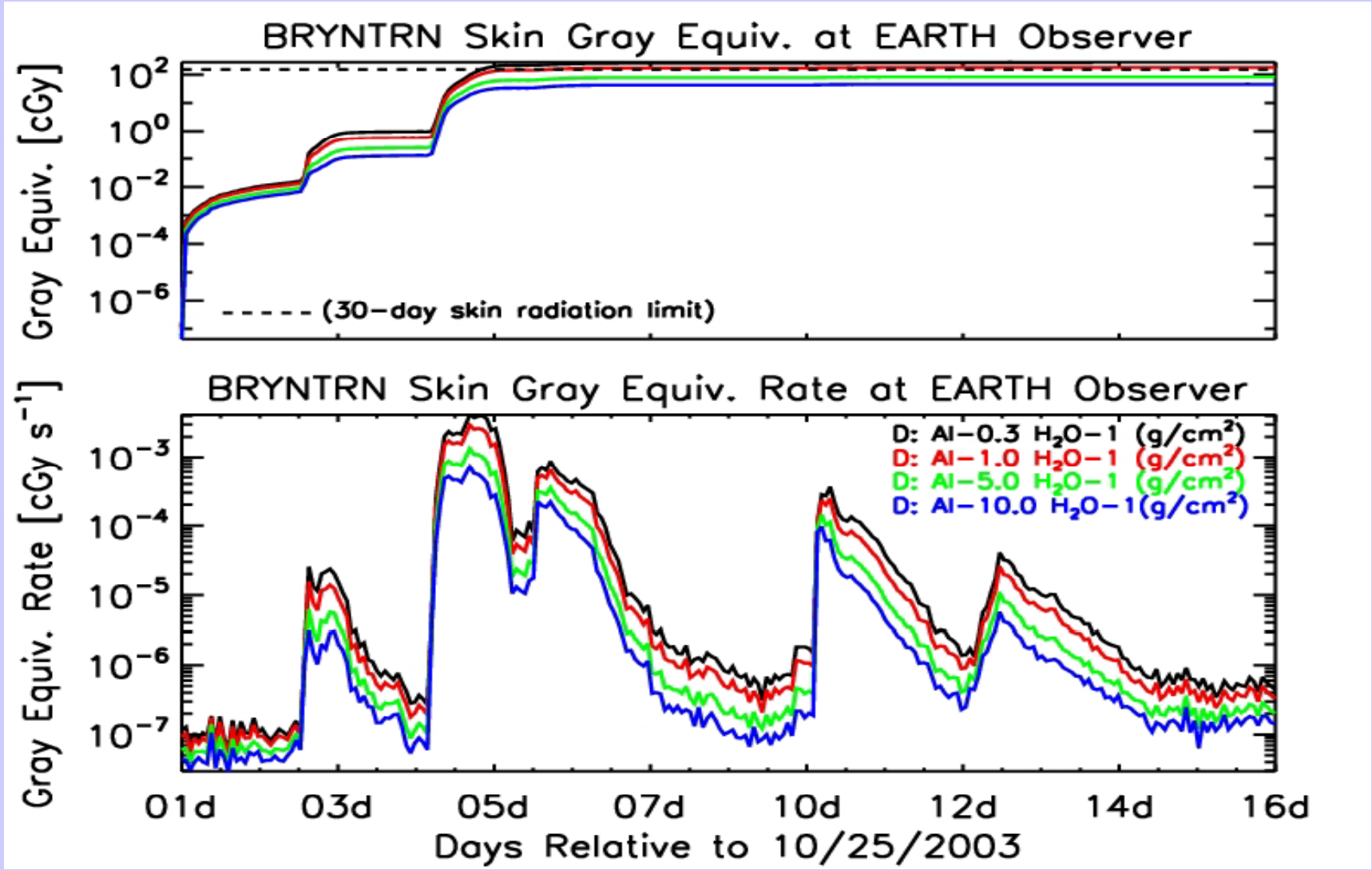
Earth Observer Results(1)



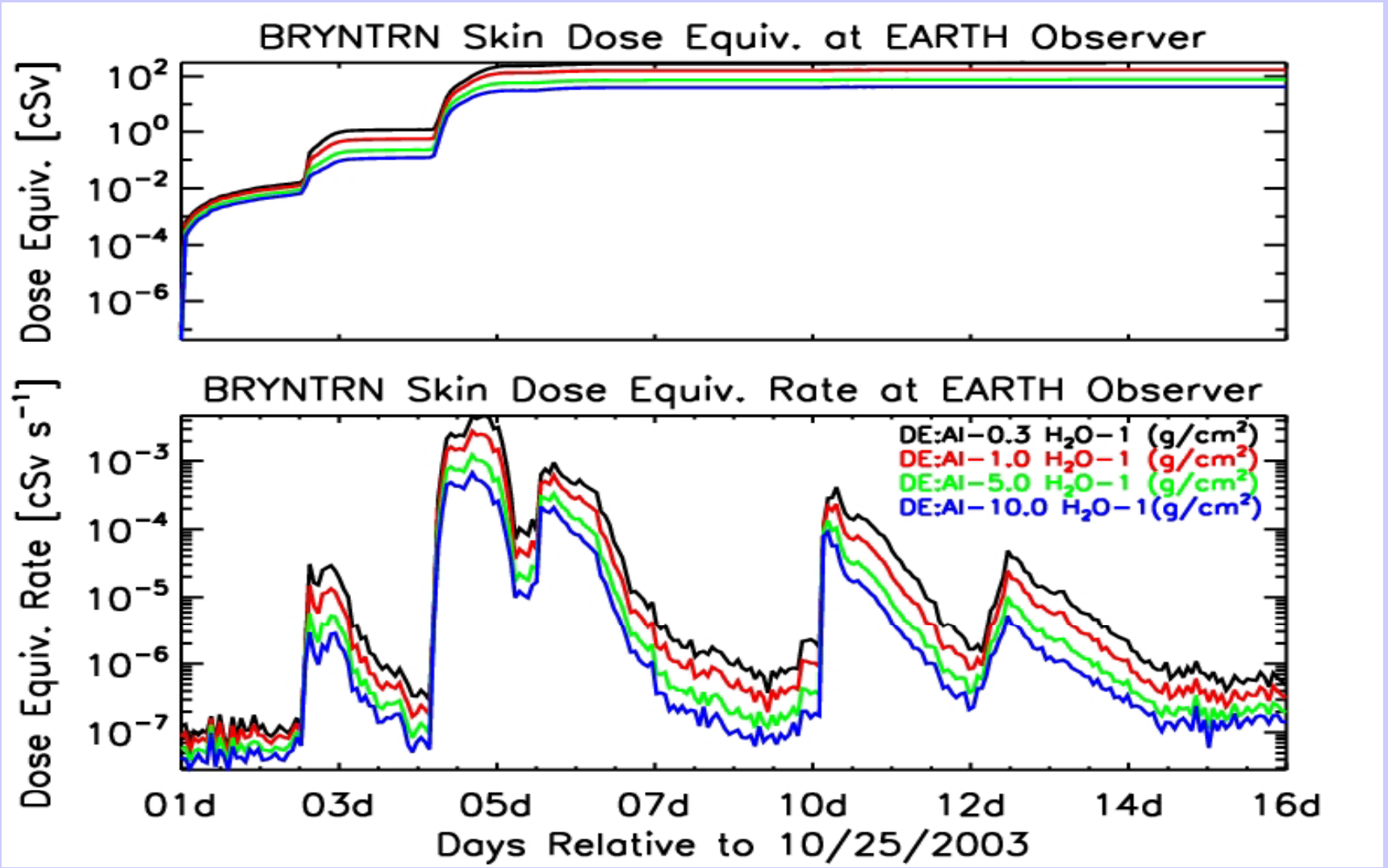
Earth Observer Results(2)



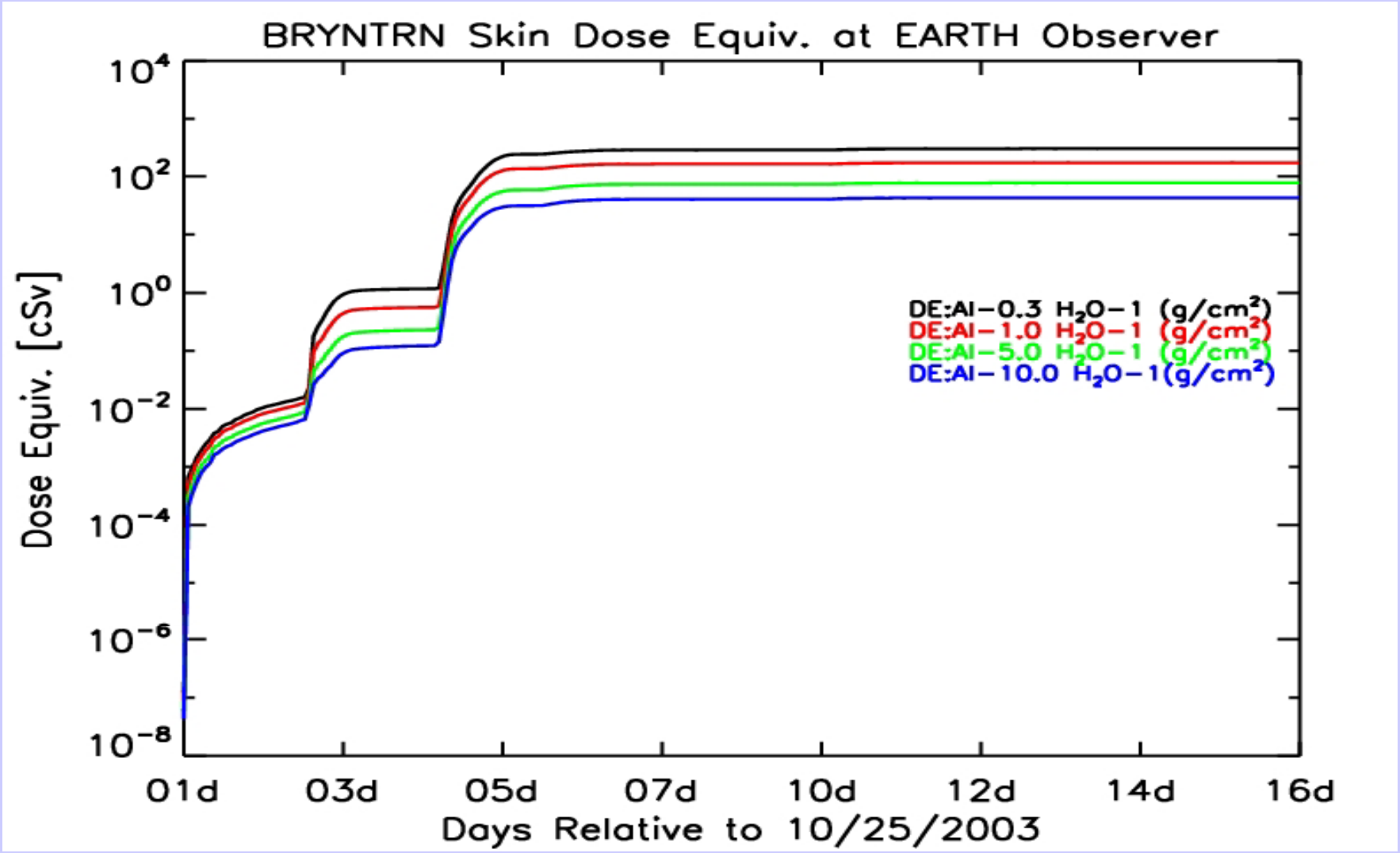
Earth Observer Results(3)



Earth Observer Results(4)



Earth Observer Results(5)



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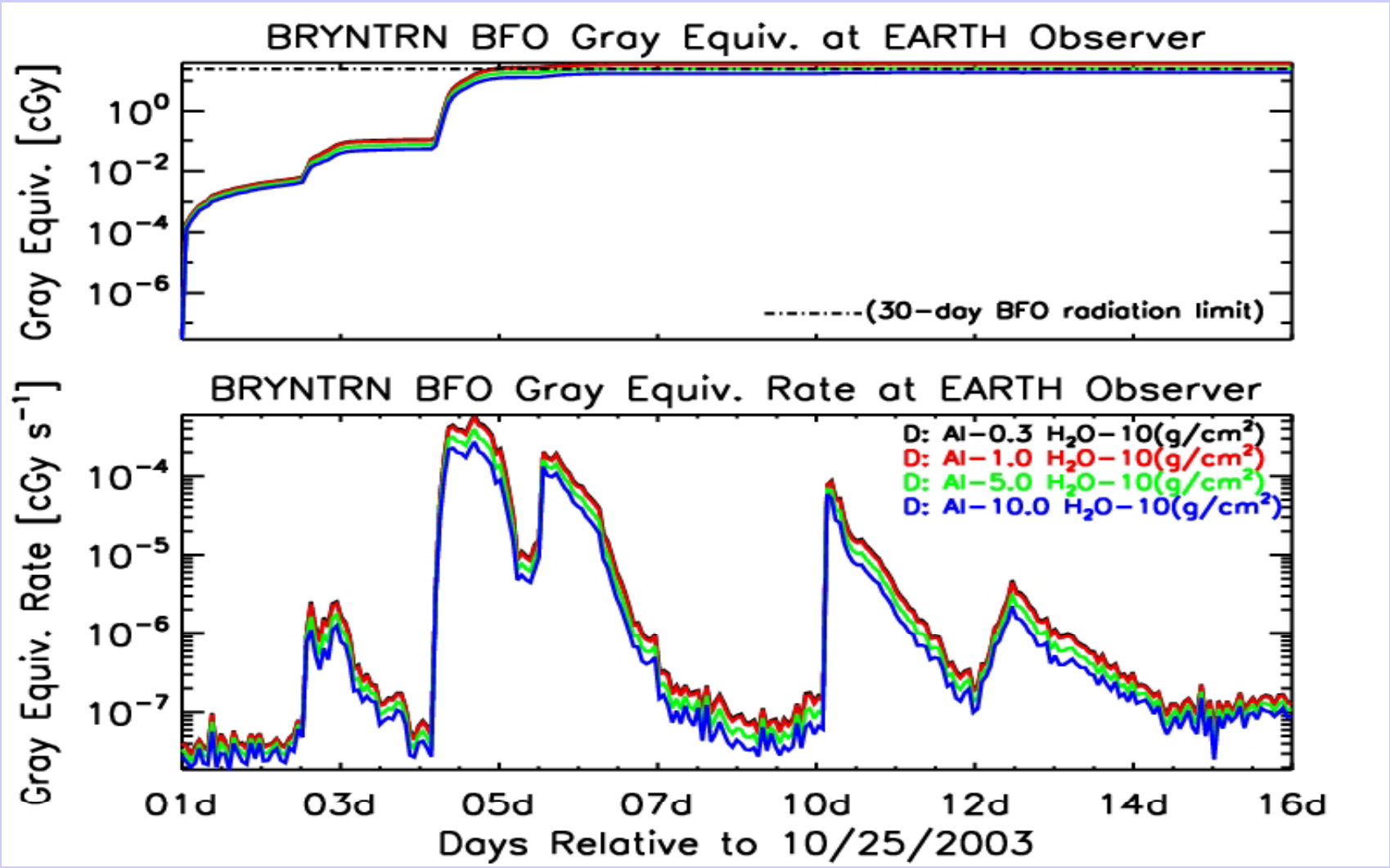
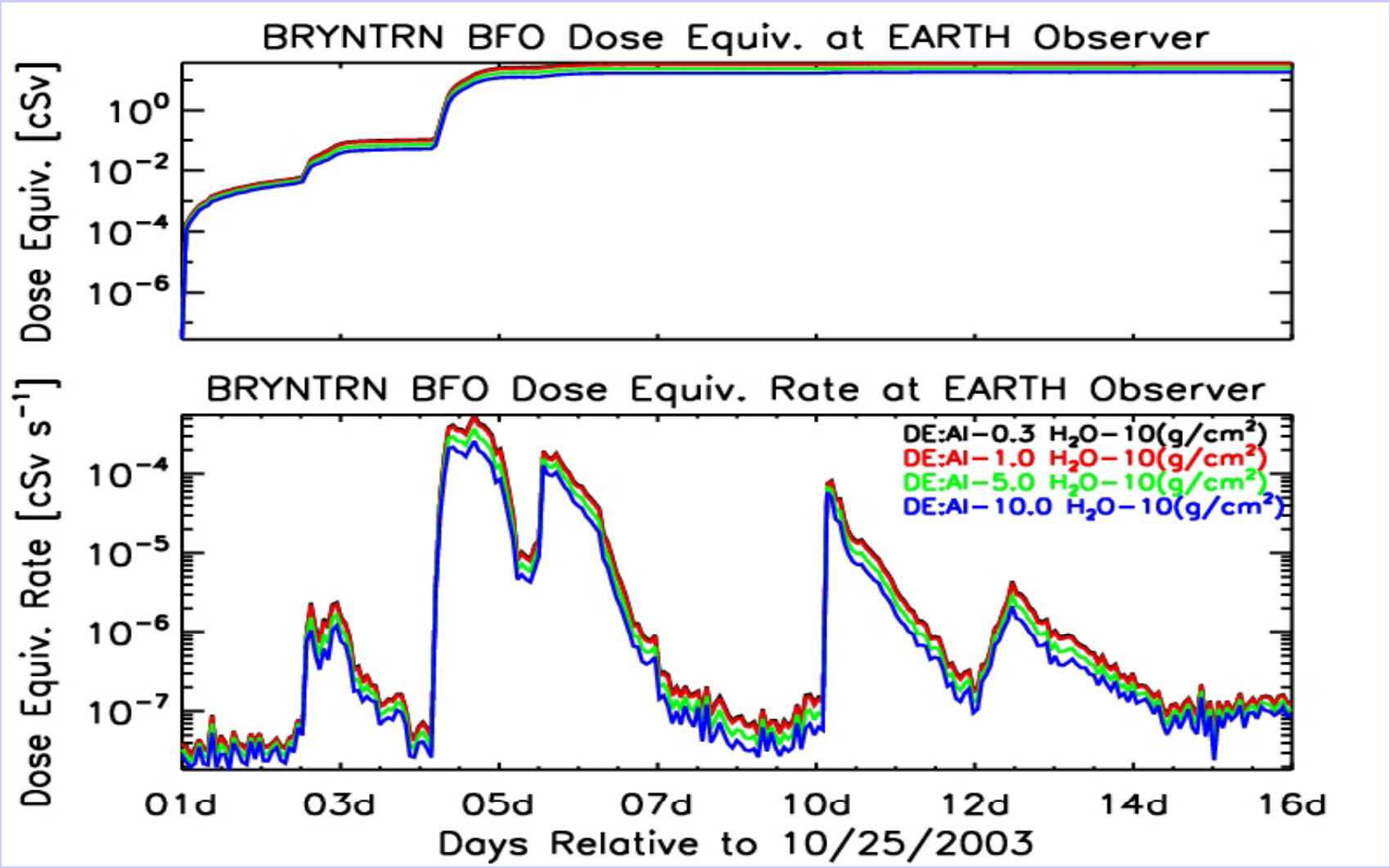


Earth Observer Results(7)



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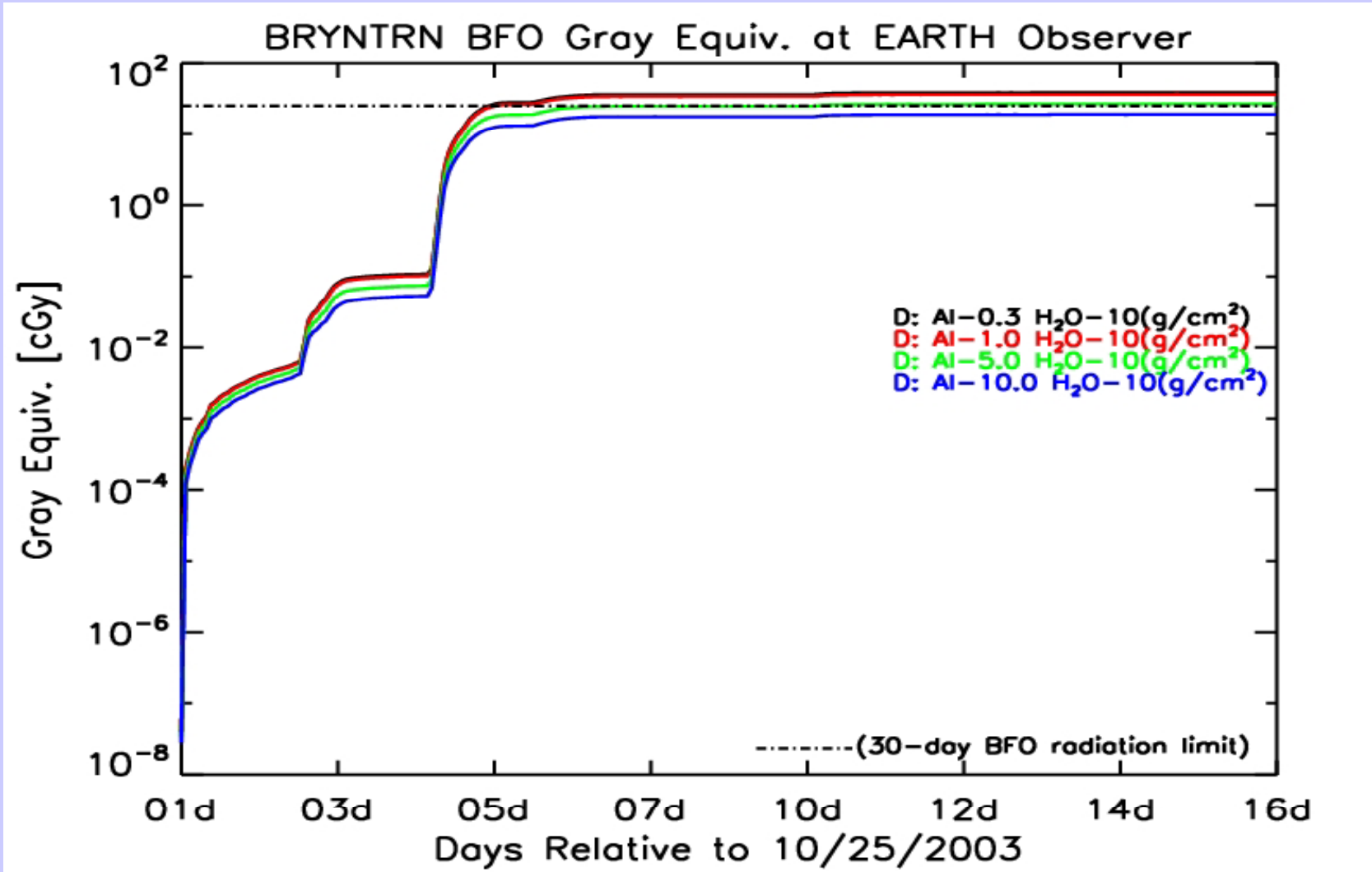
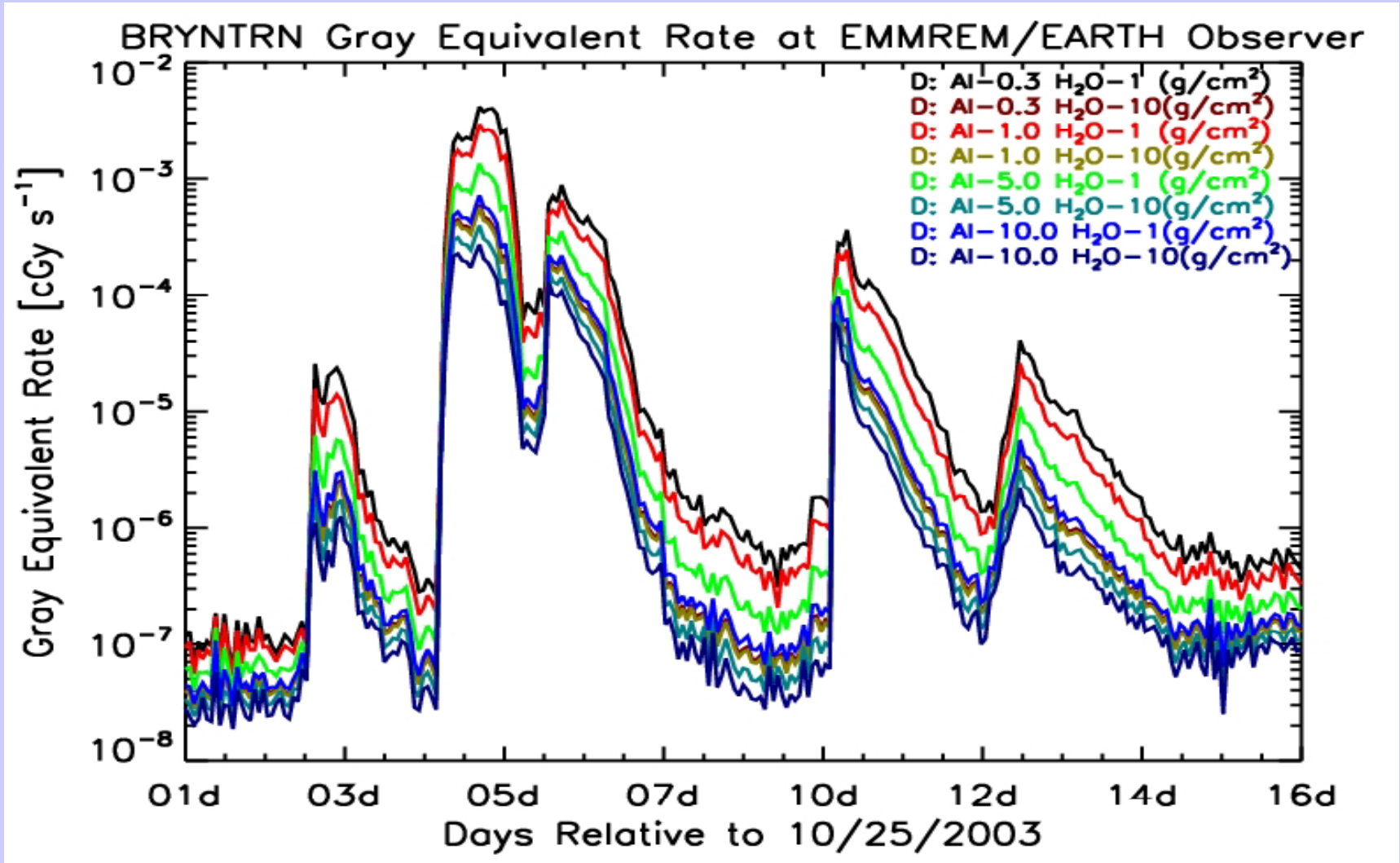


Earth Observer Results(9)



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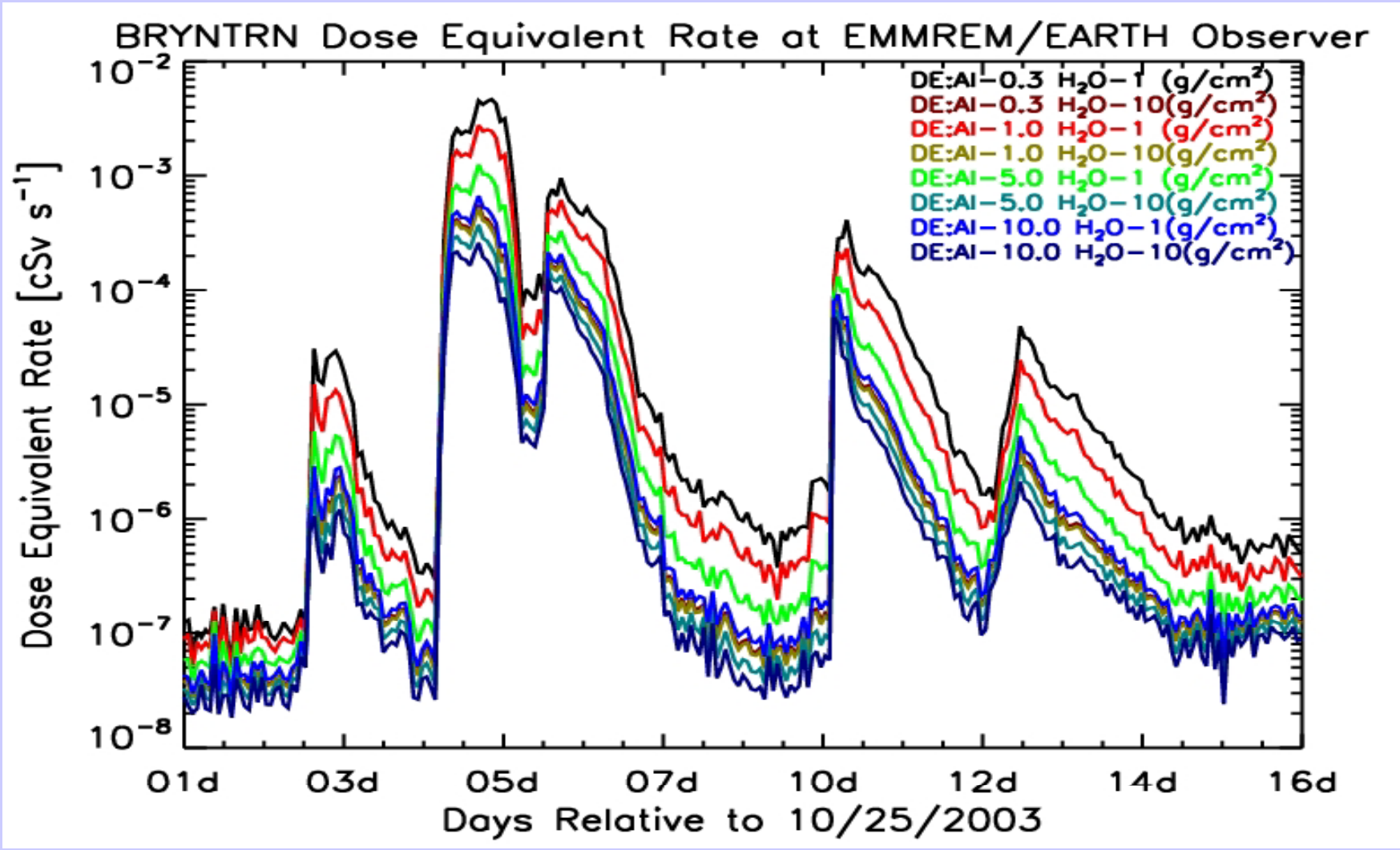
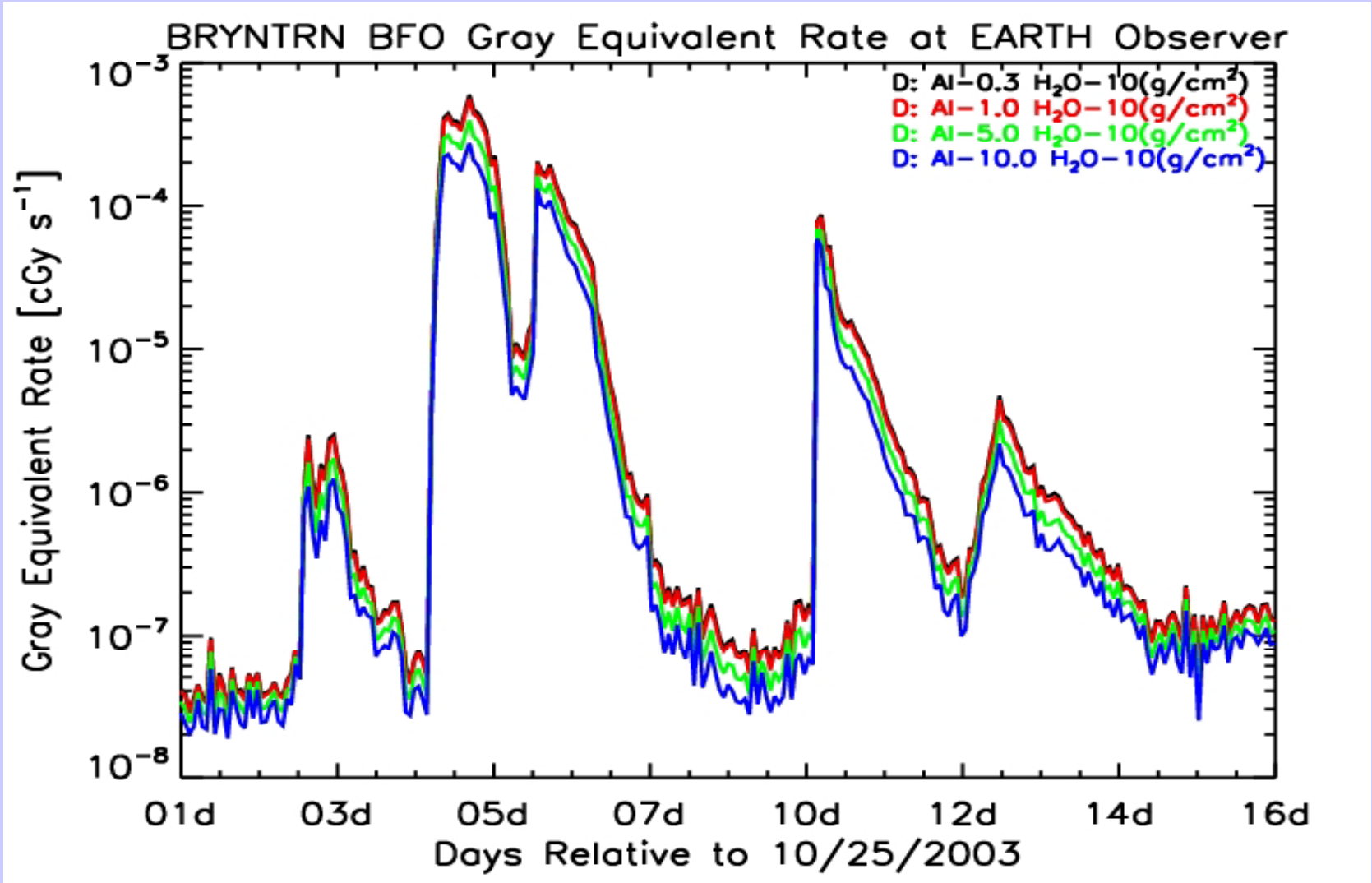
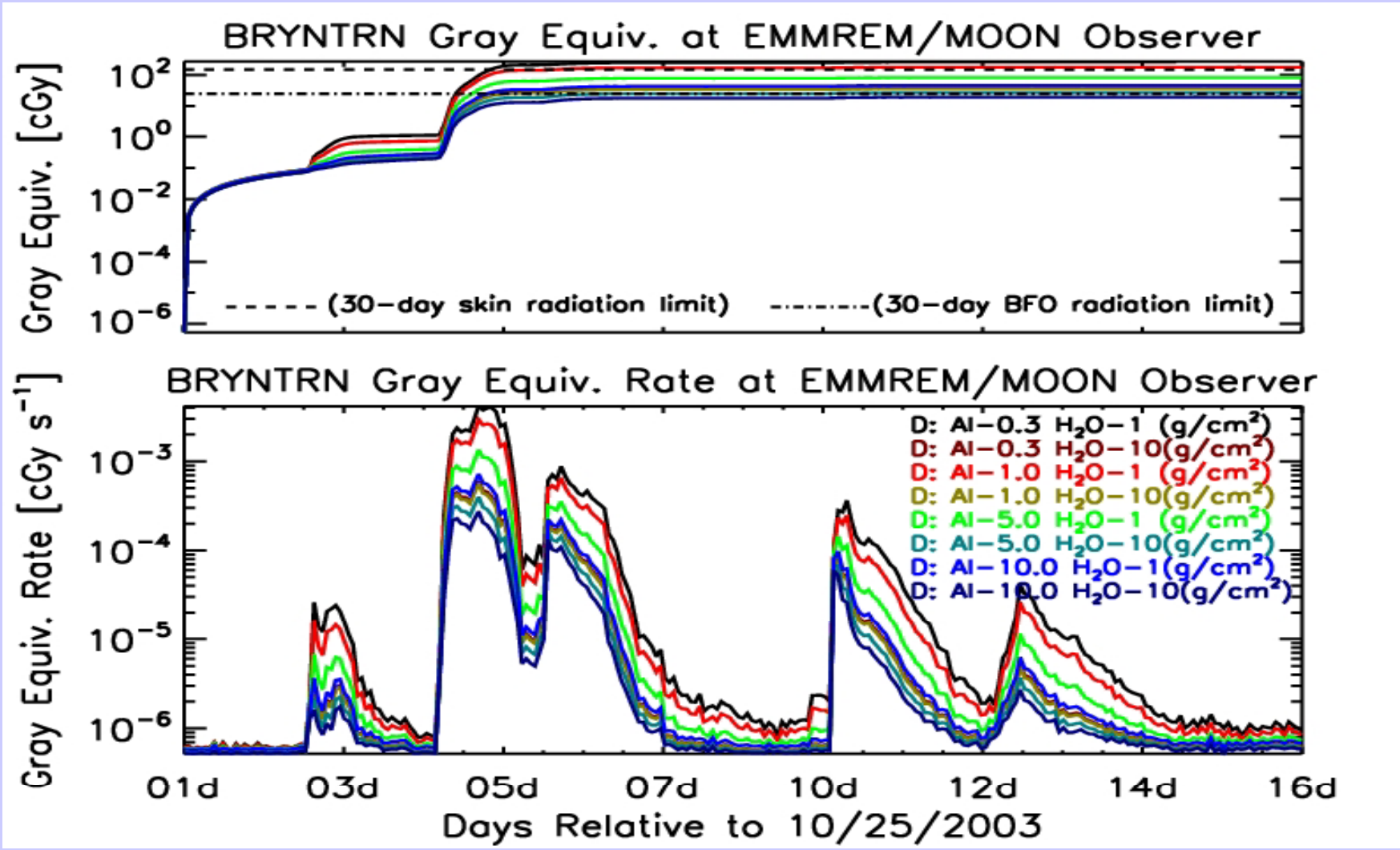


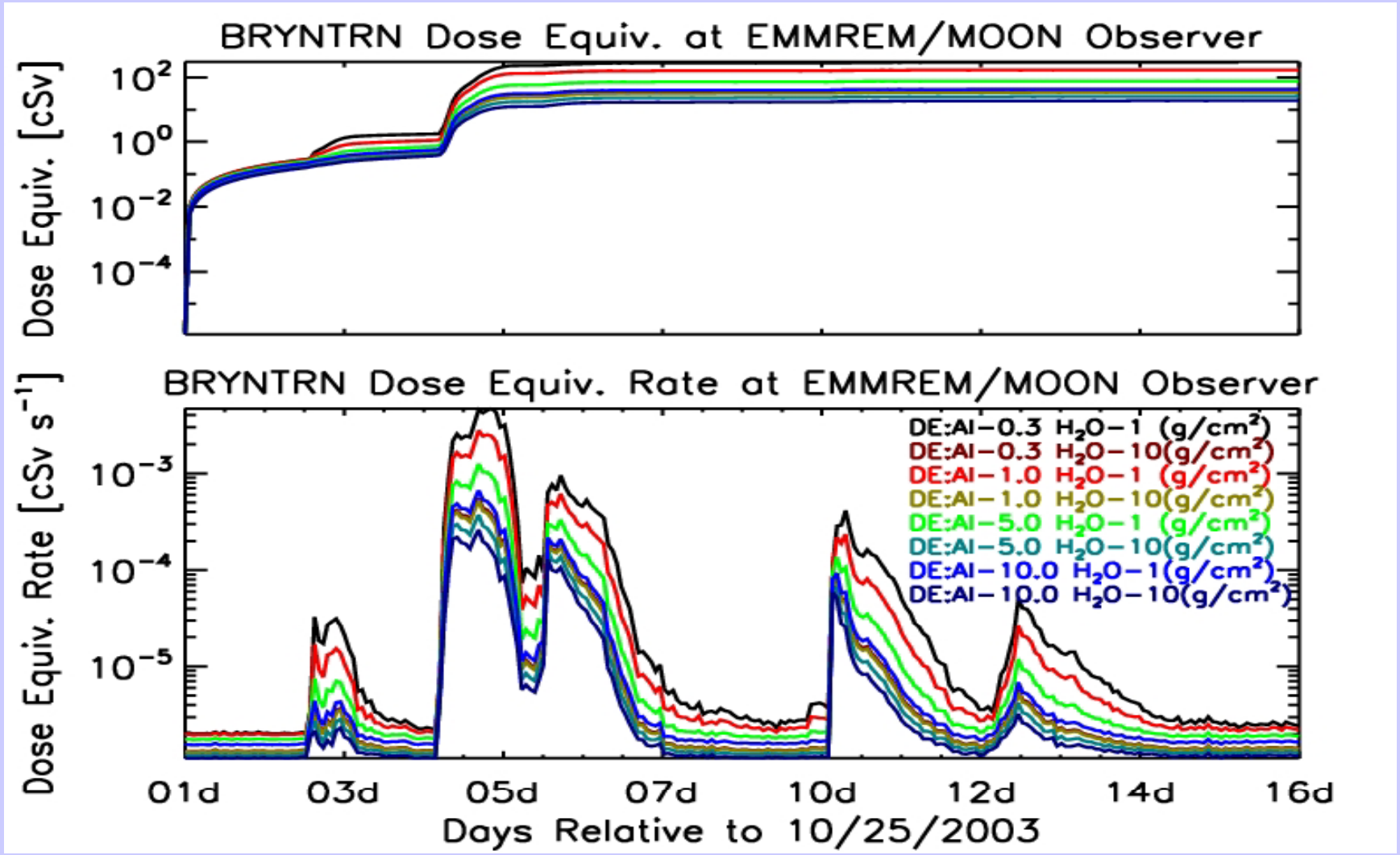
Earth Observer Results(11)



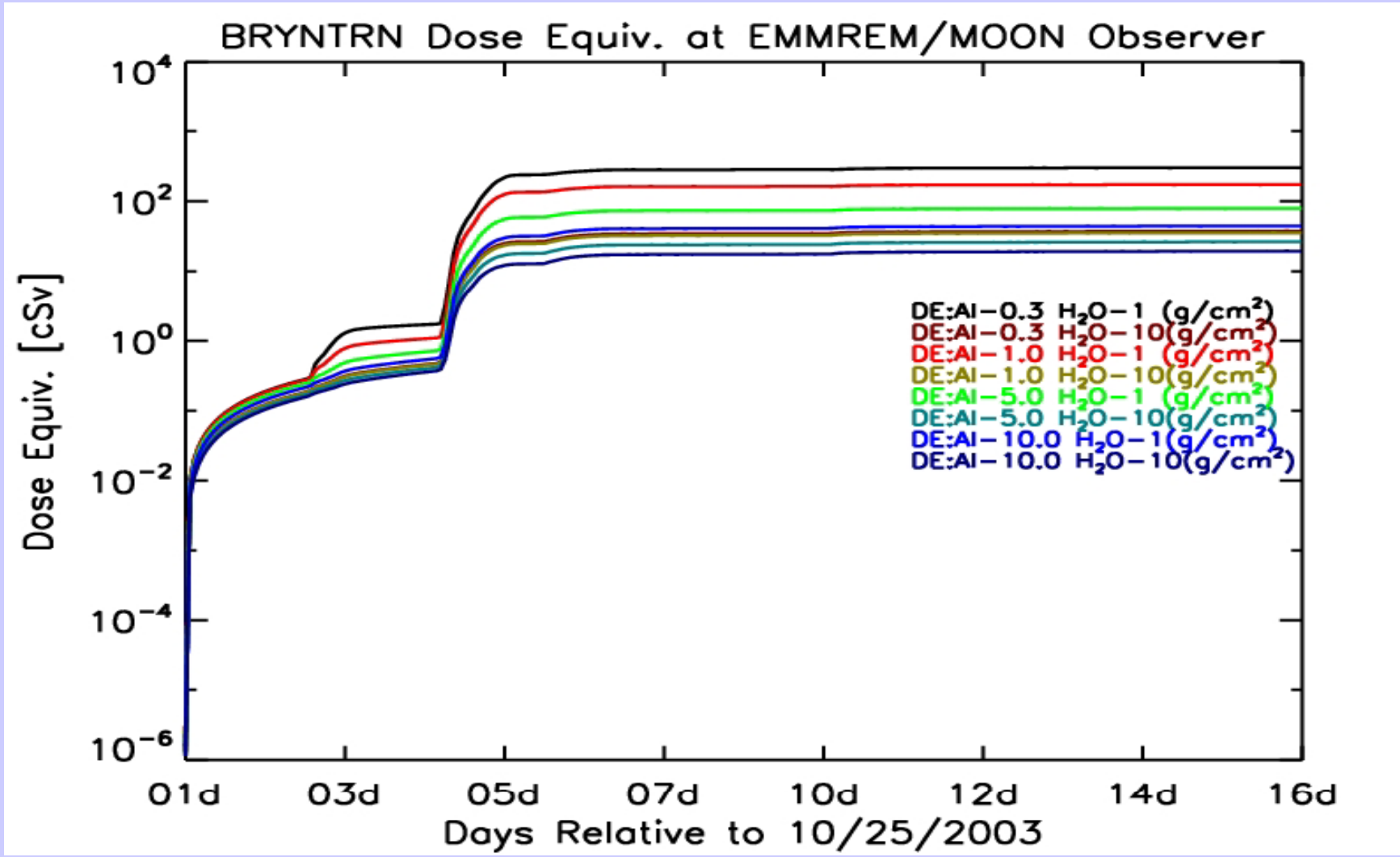
Moon Observer Results(1)



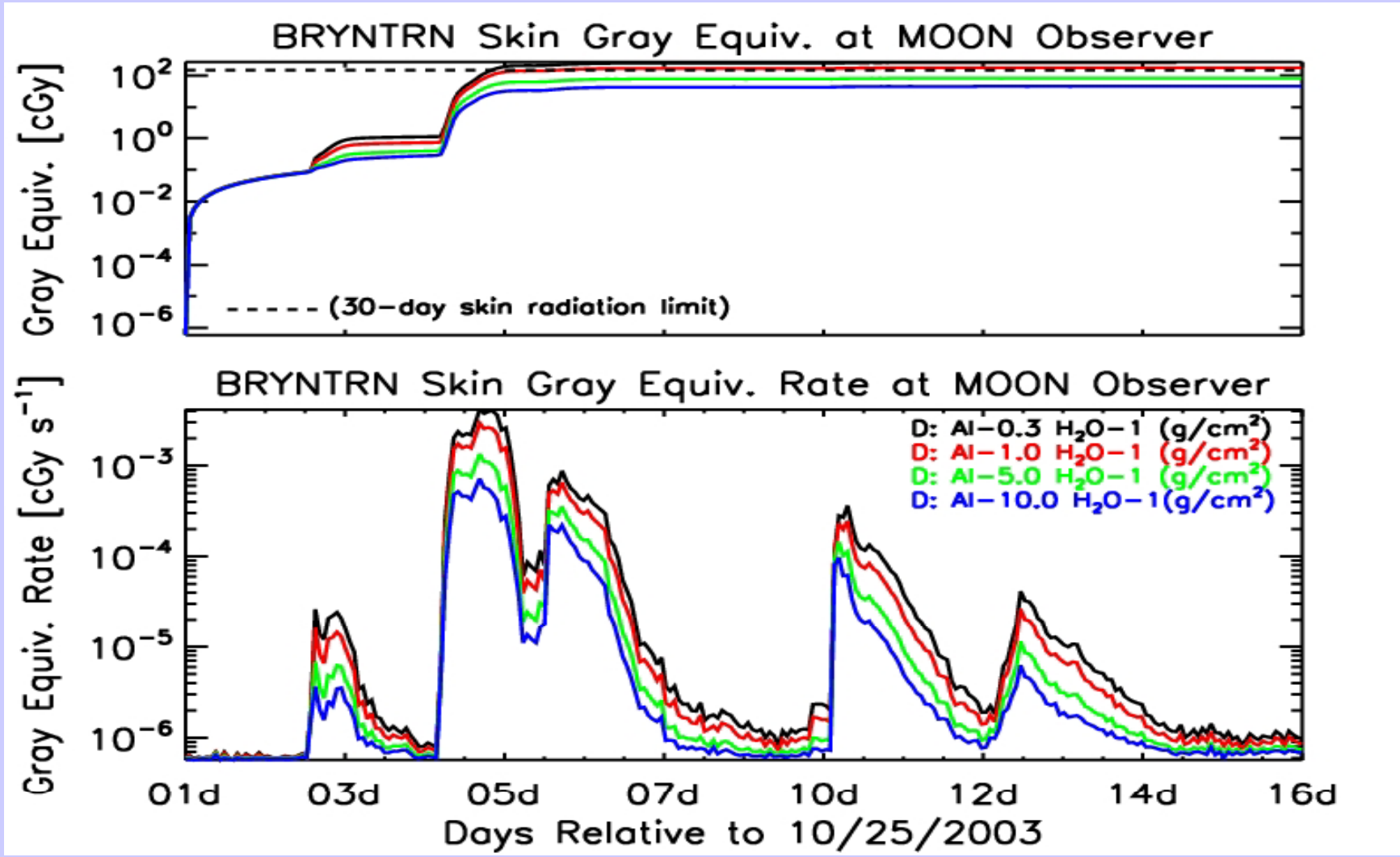
Moon Observer Results(2)



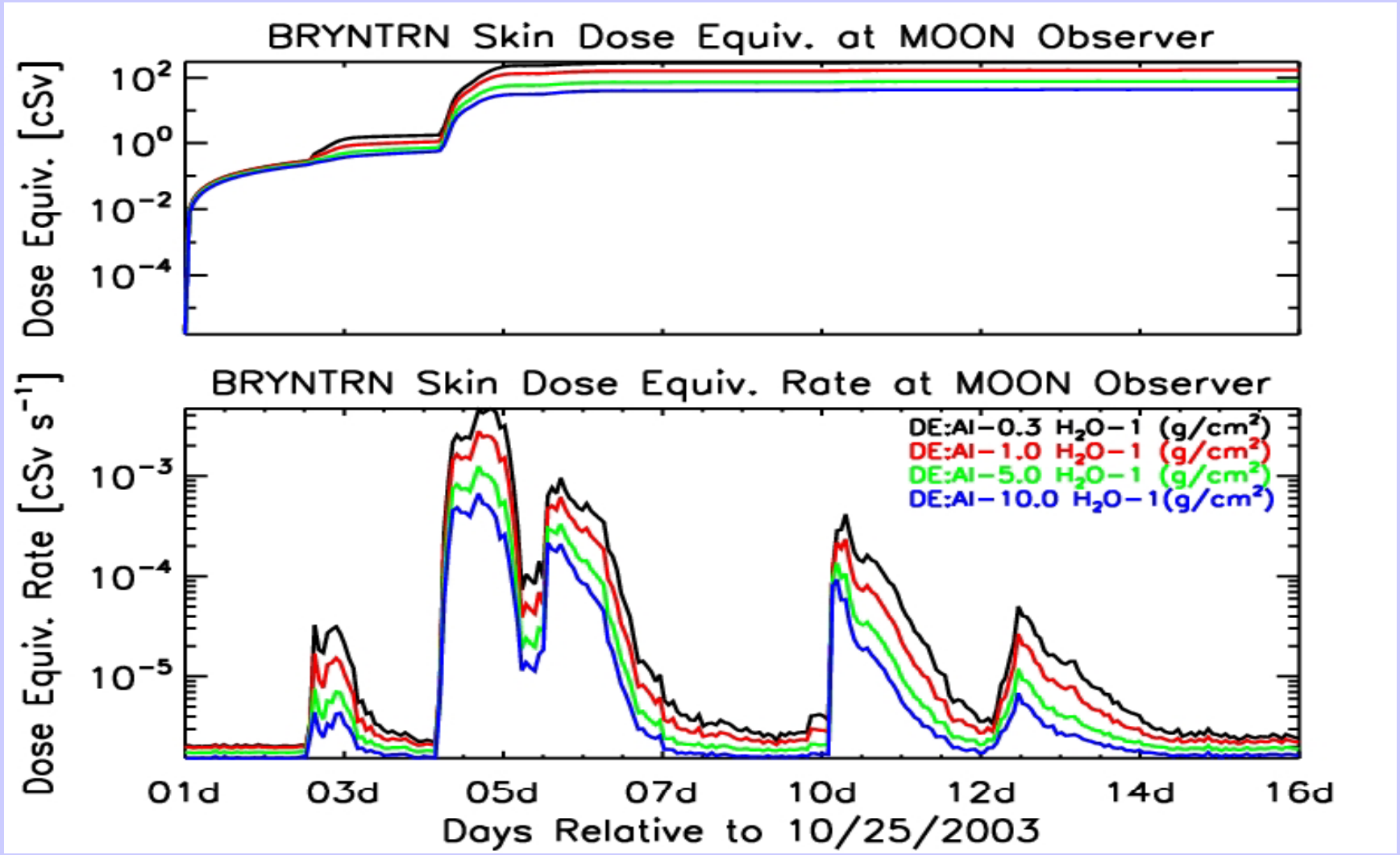
Moon Observer Results(3)



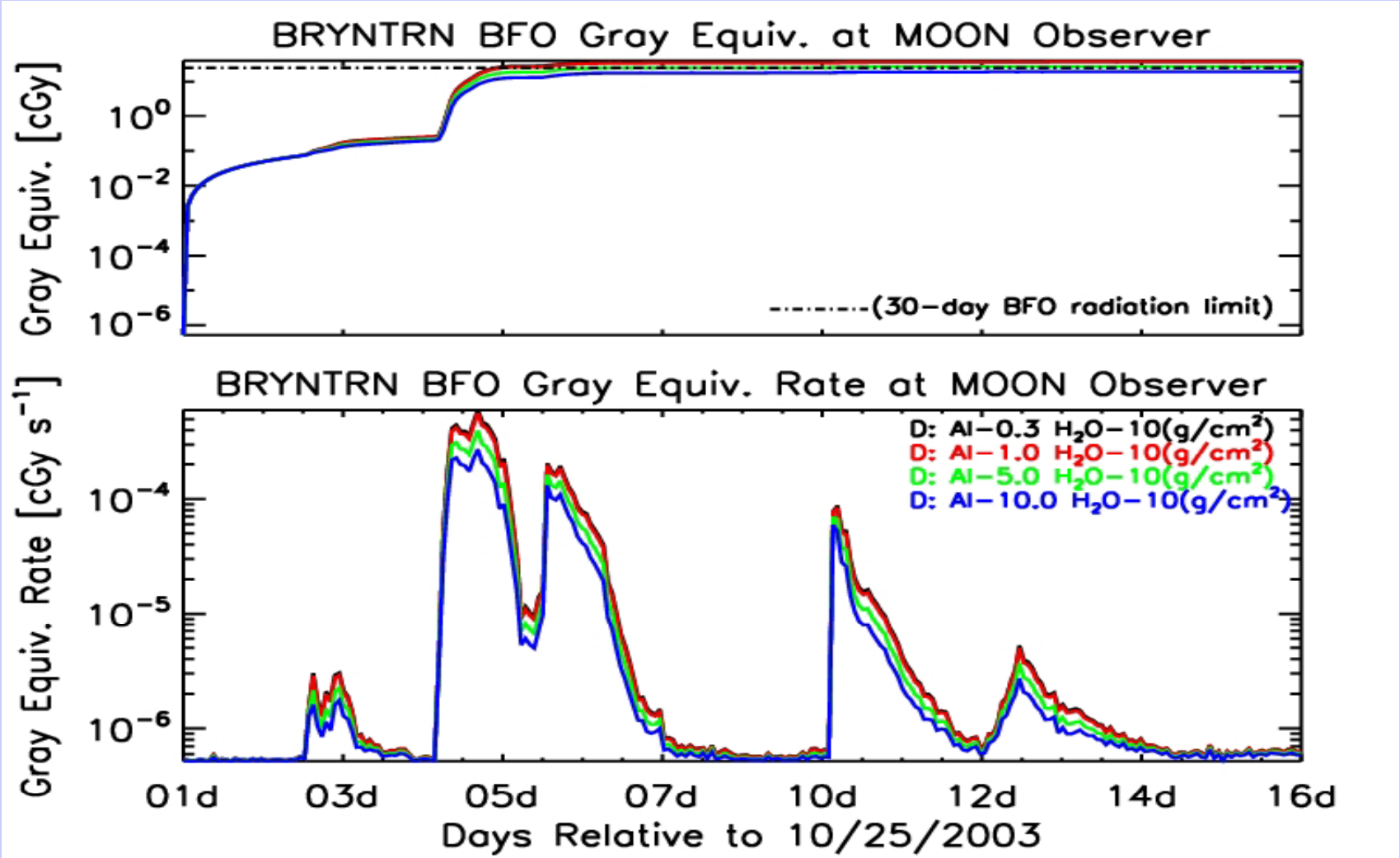
Moon Observer Results(4)



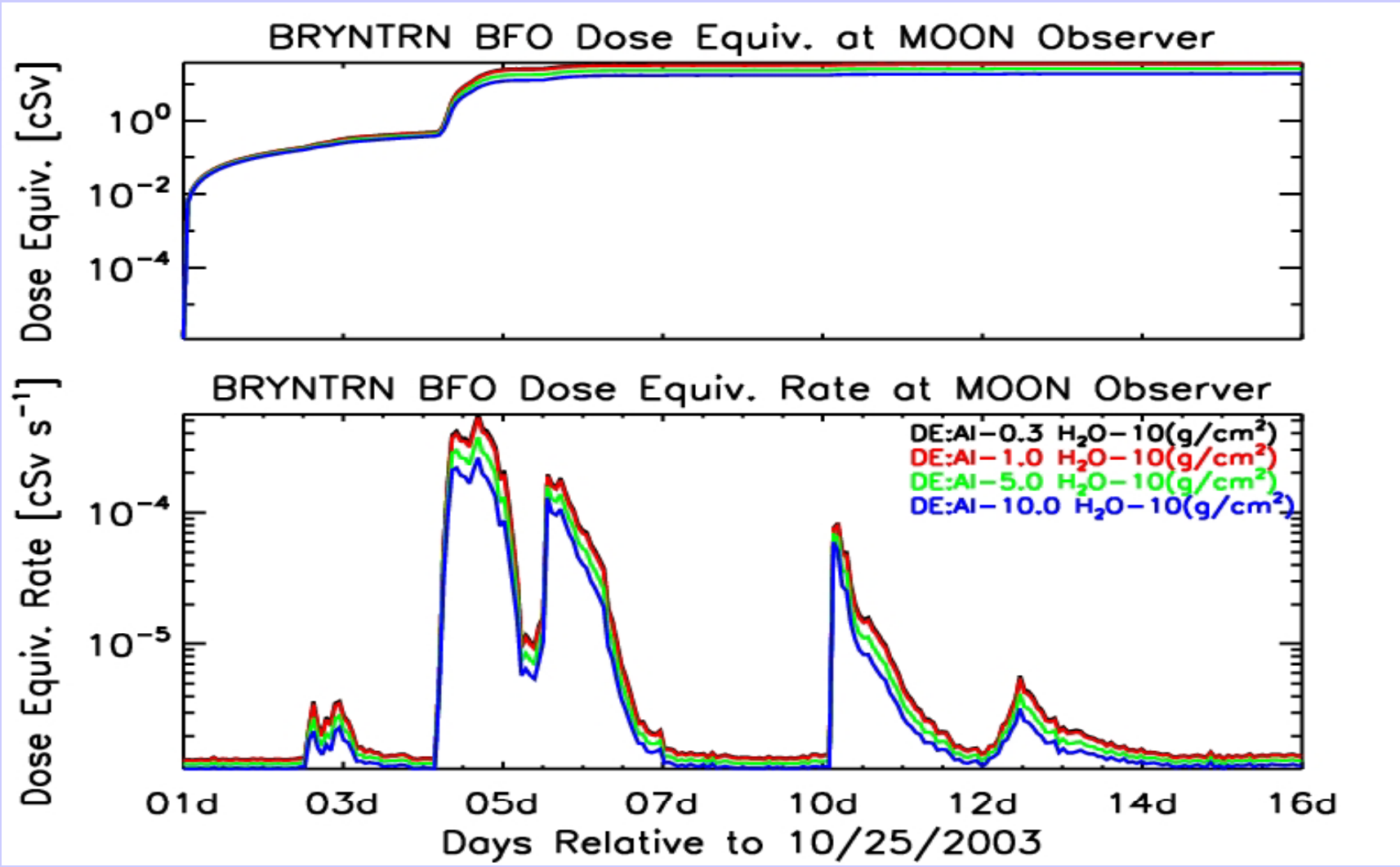
Moon Observer Results(5)



Moon Observer Results(6)



Moon Observer Results(7)



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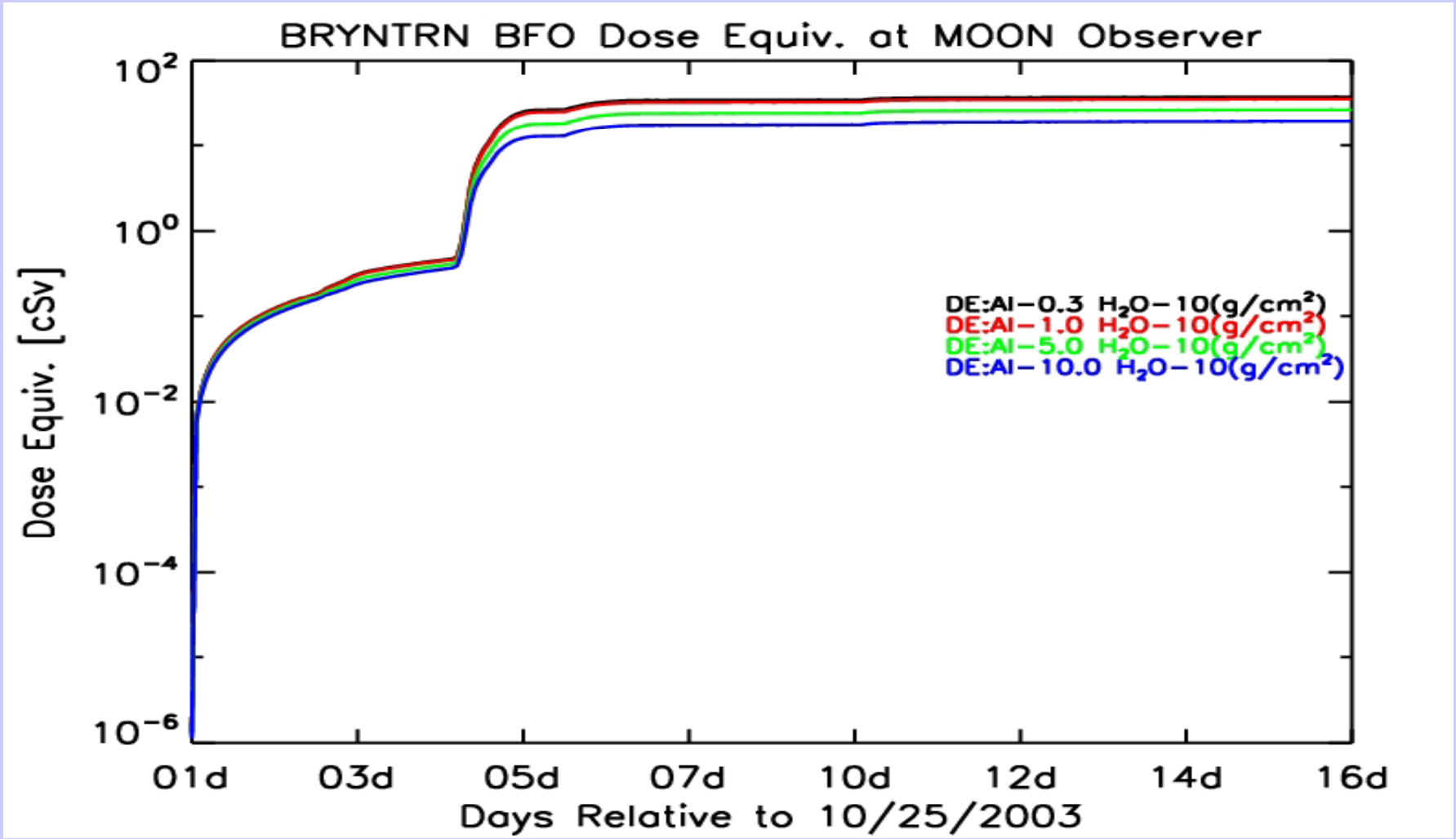
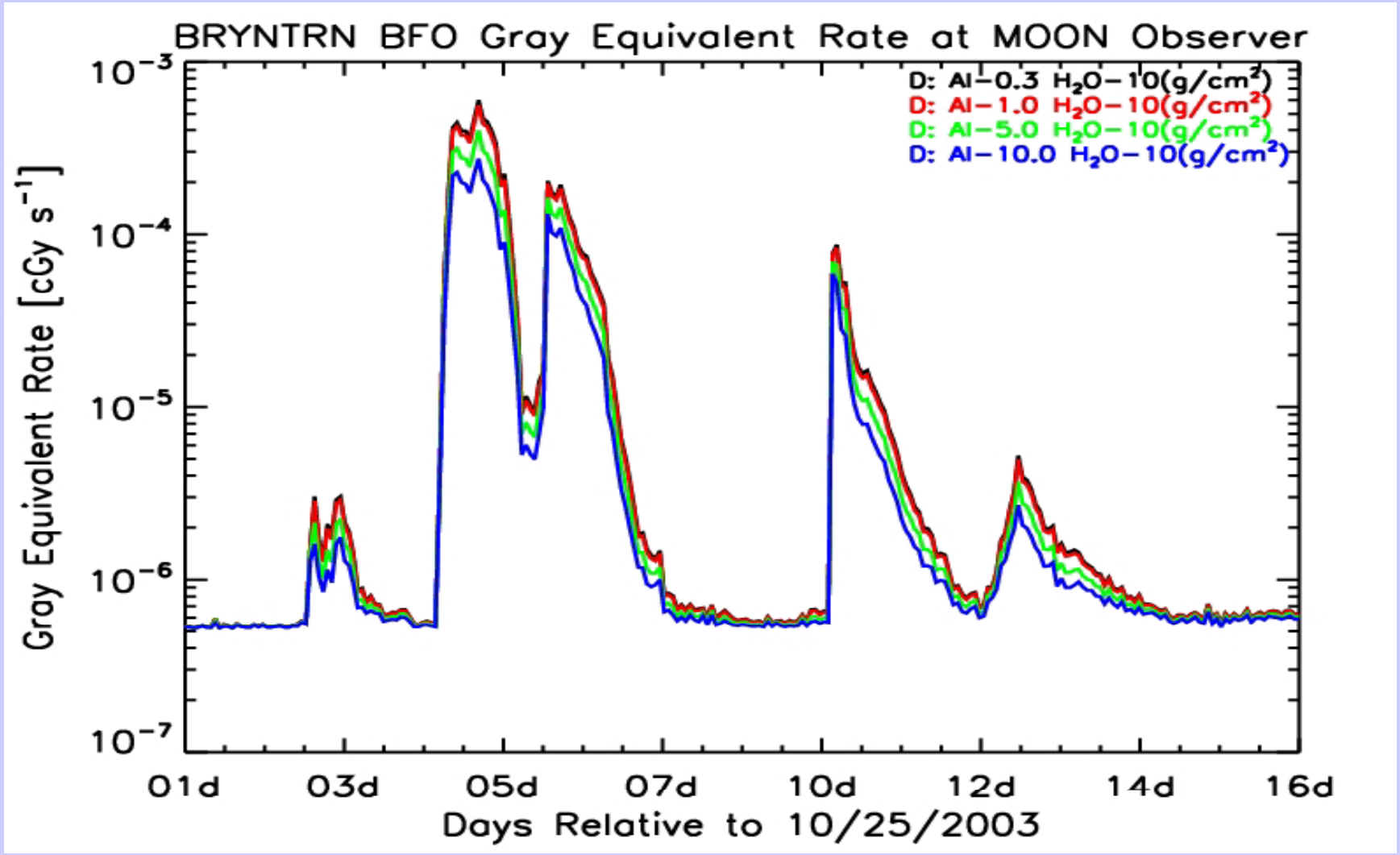


Moon Observer Results(9)



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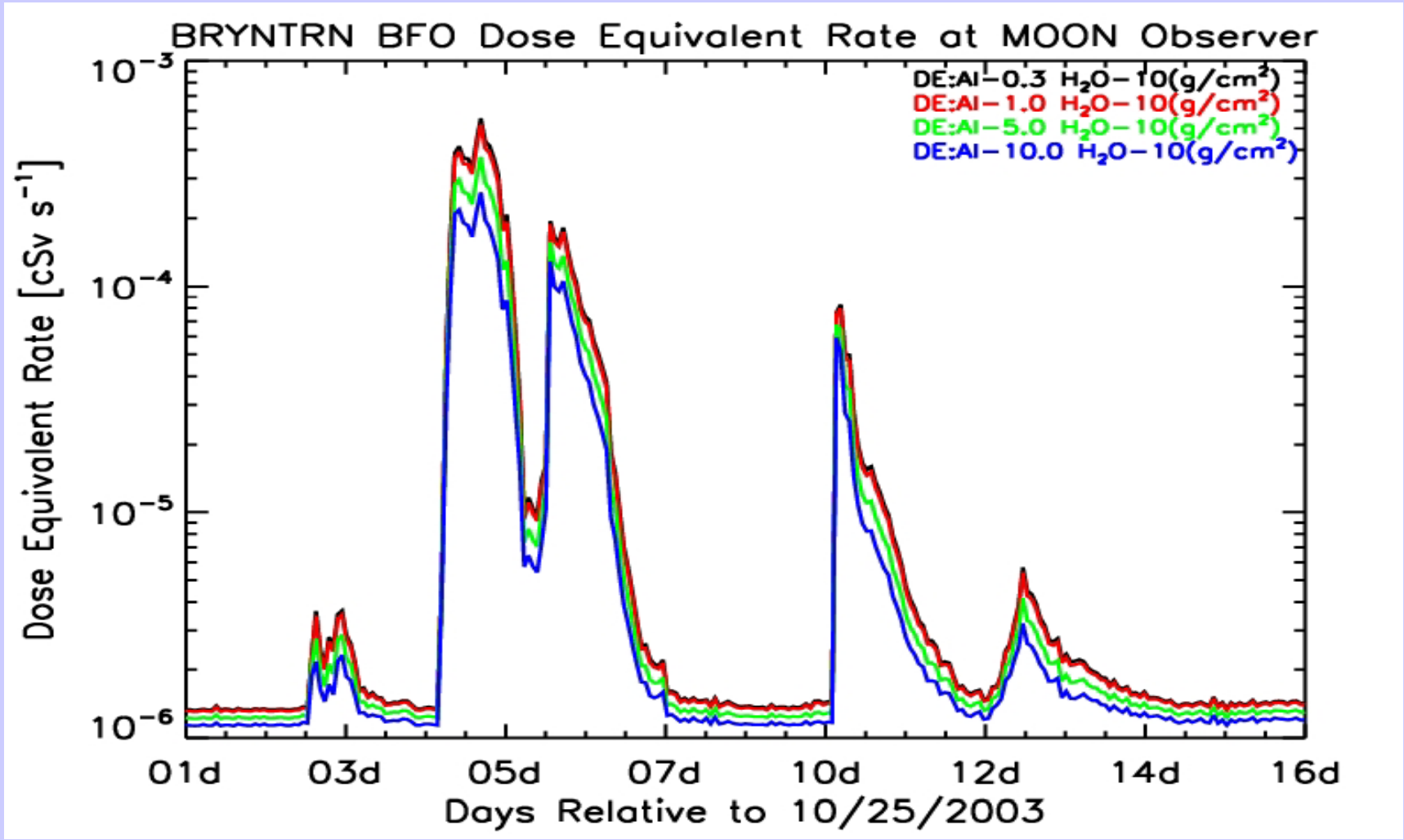
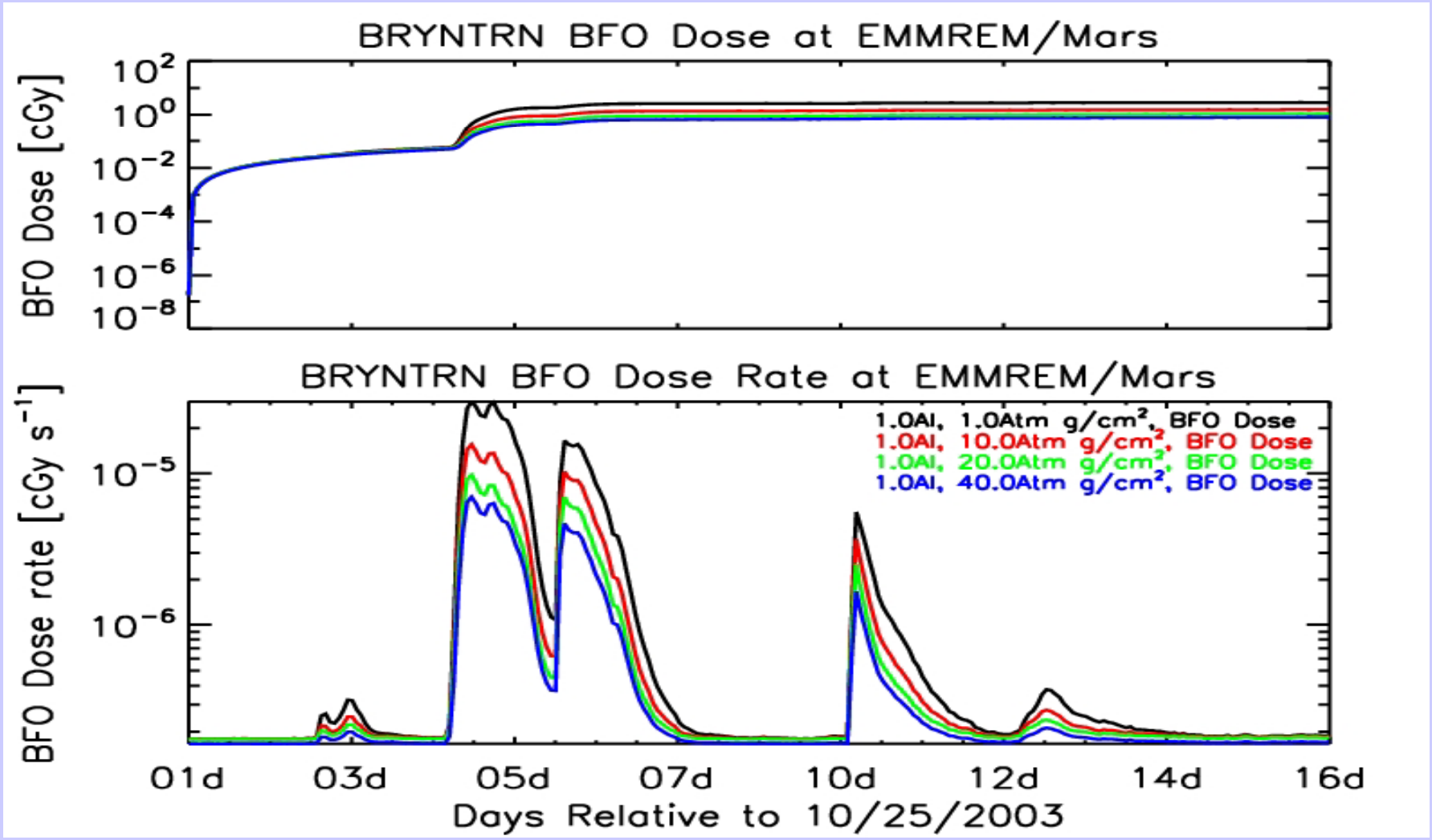


Mars Observer Results(1)



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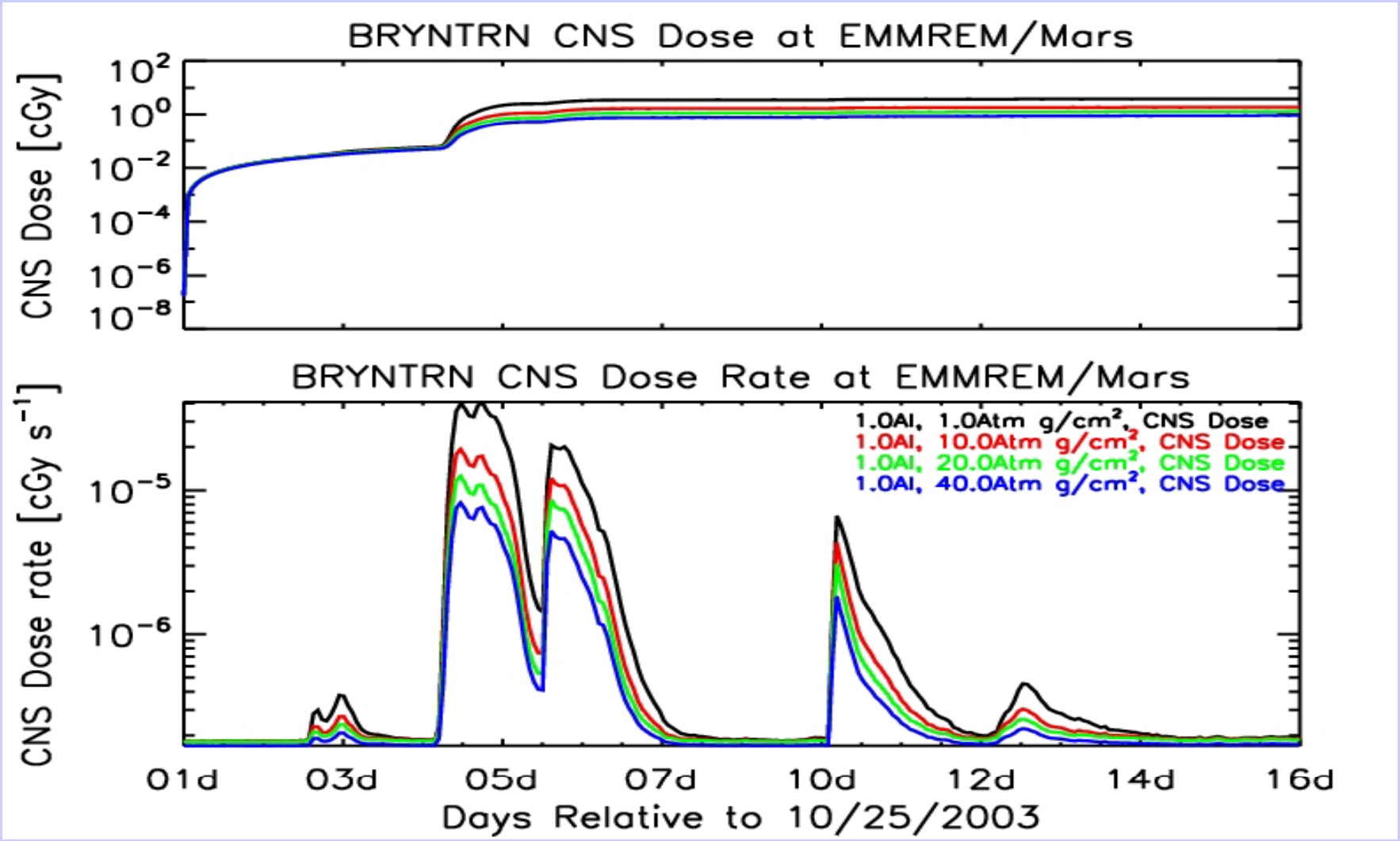
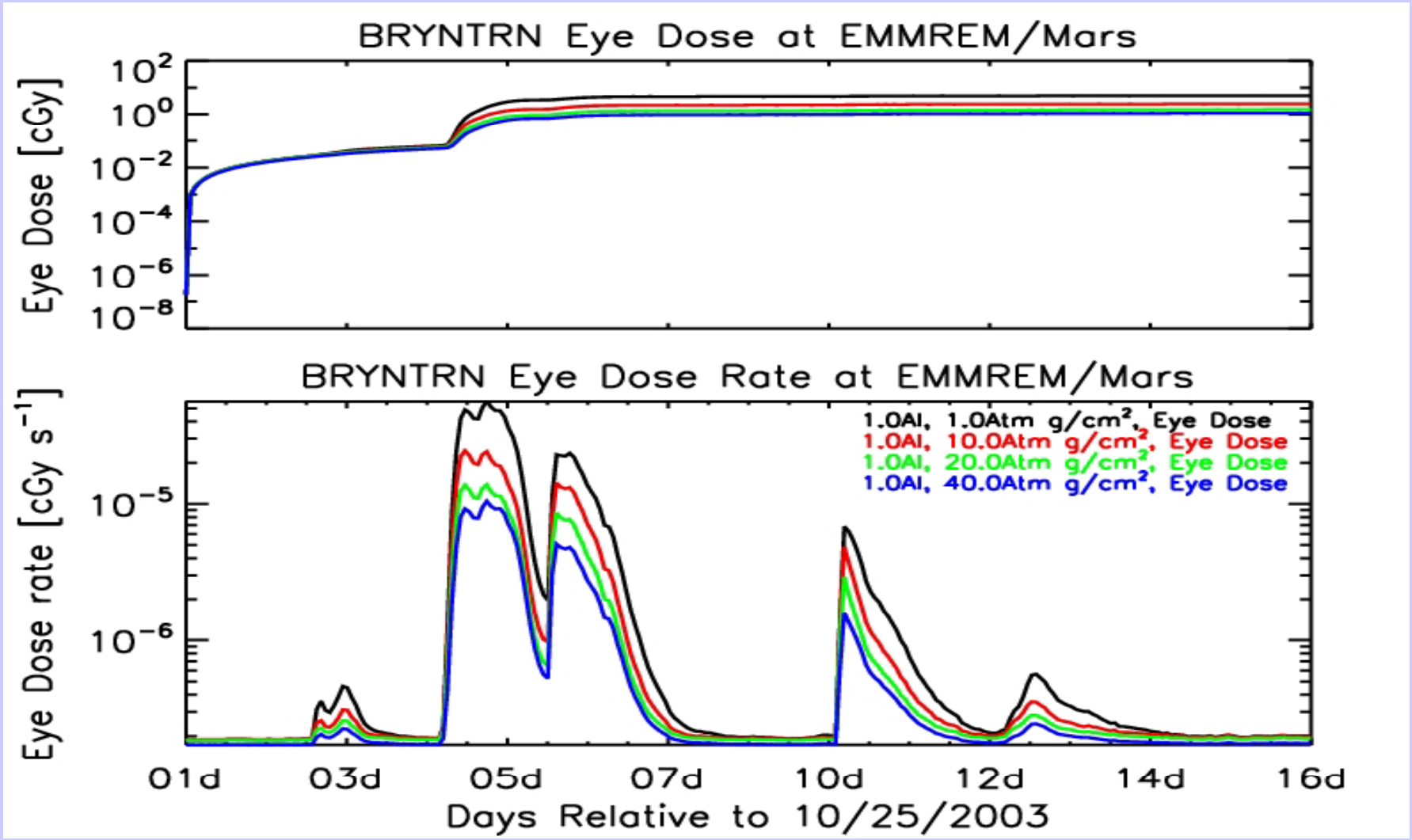
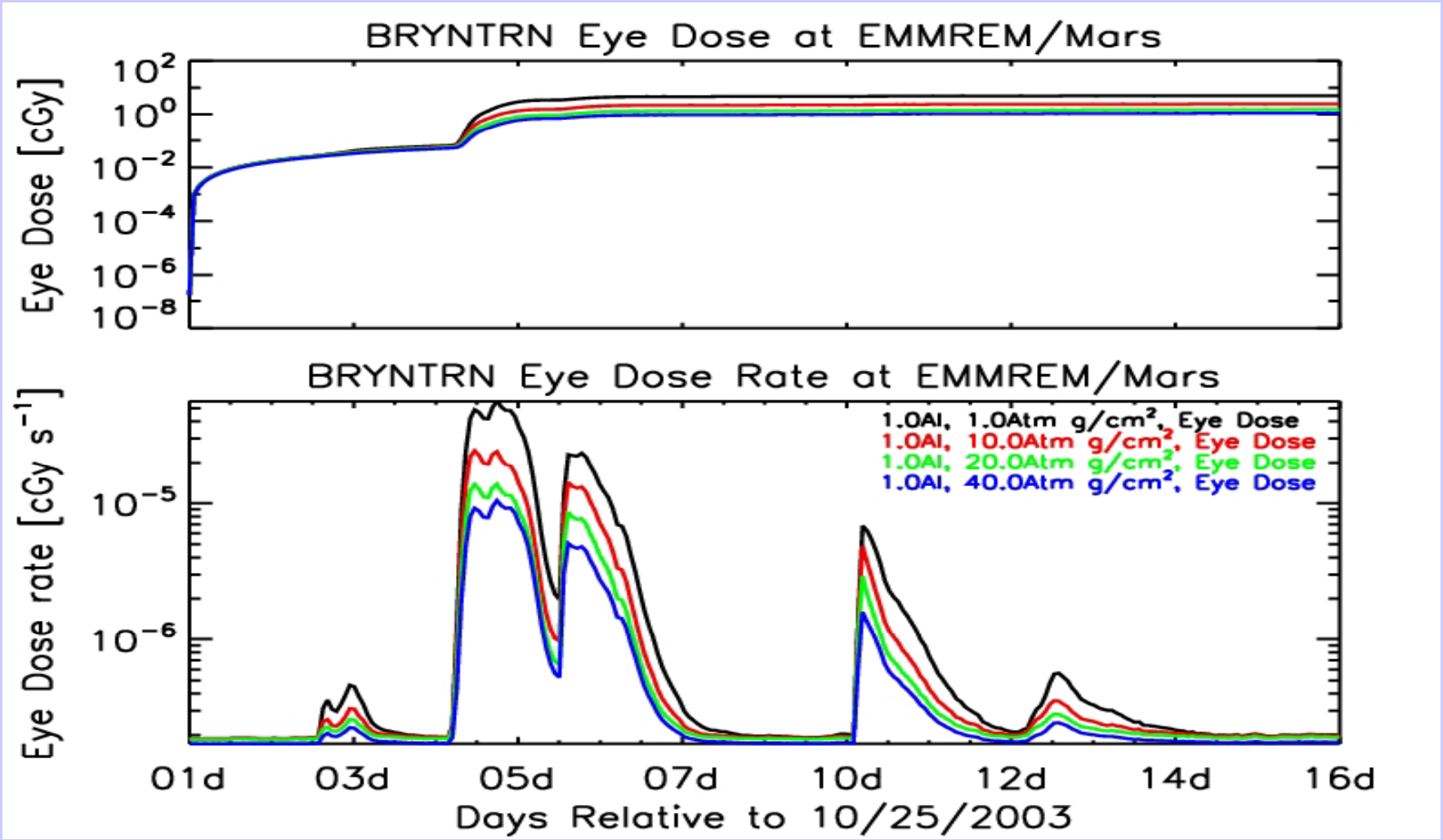


Mars Observer Results(3)



Mars Observer Results(4)



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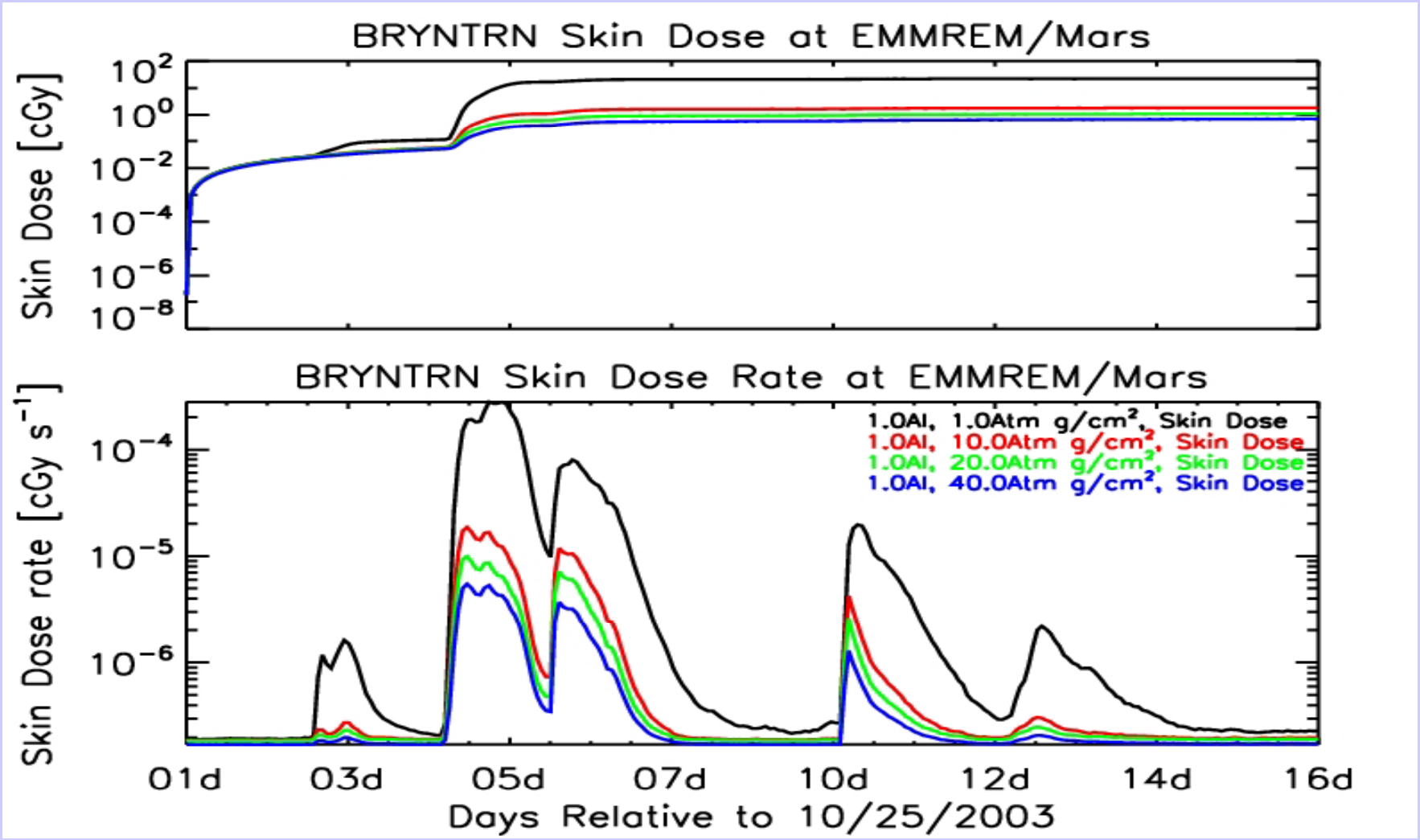

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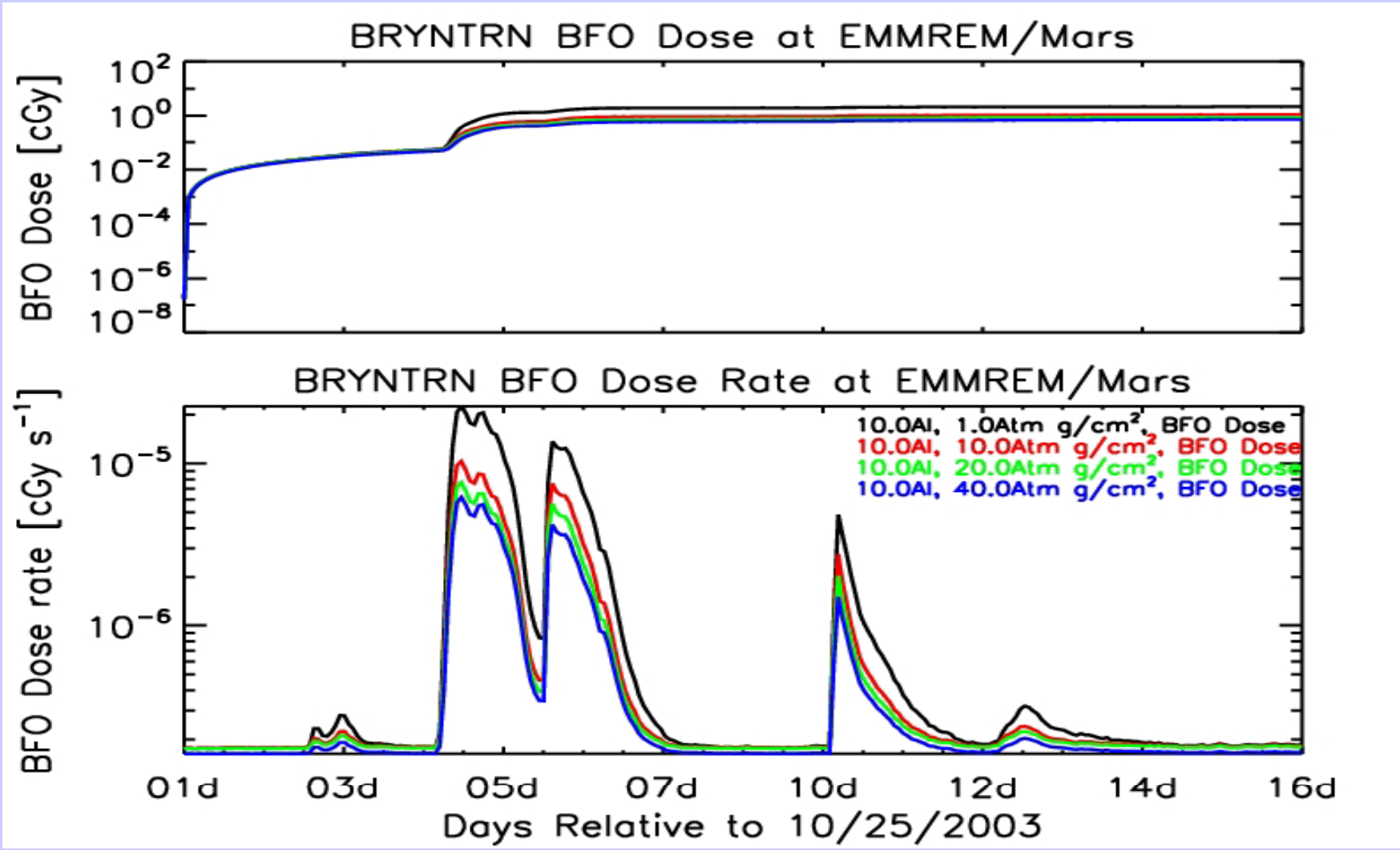
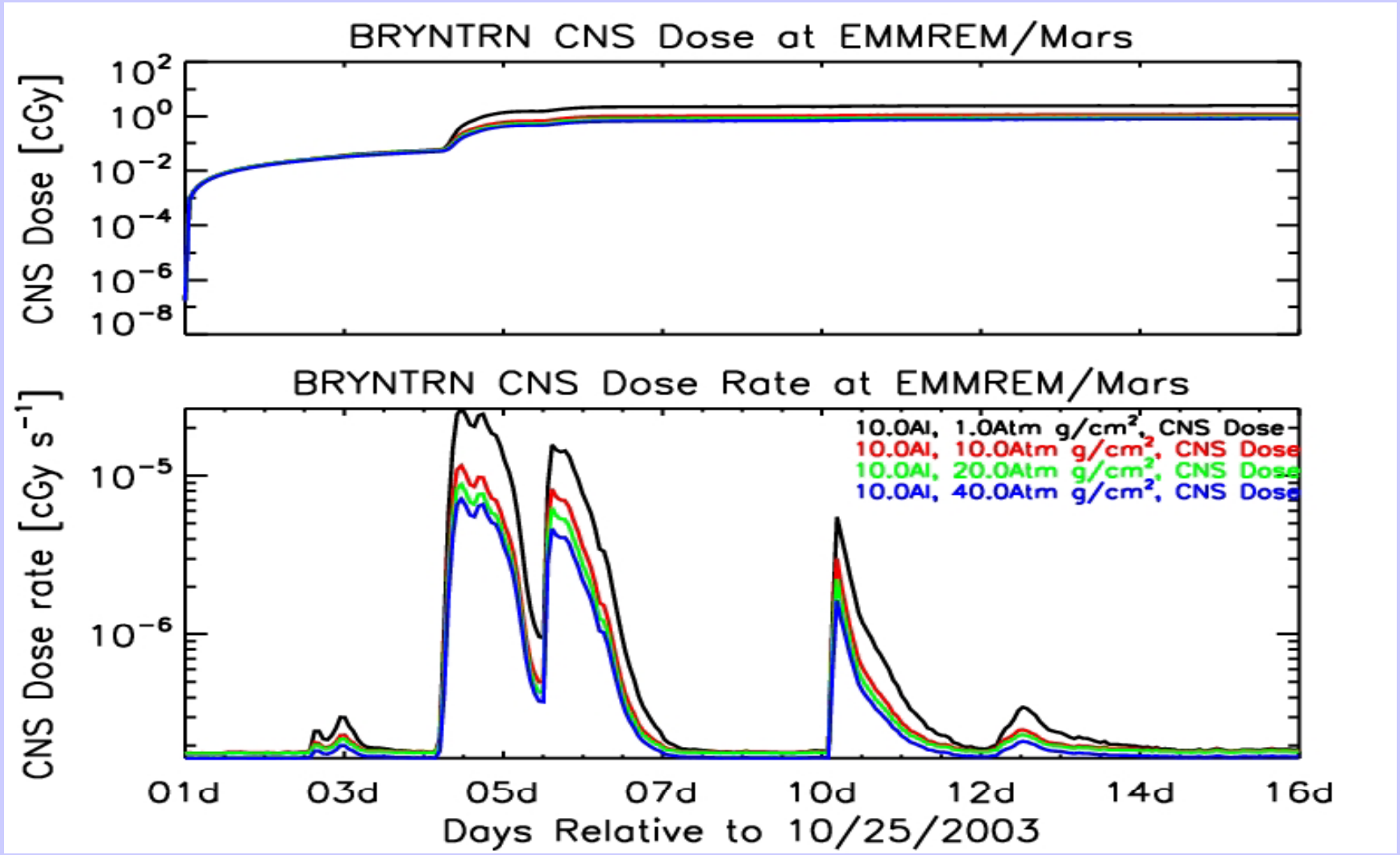
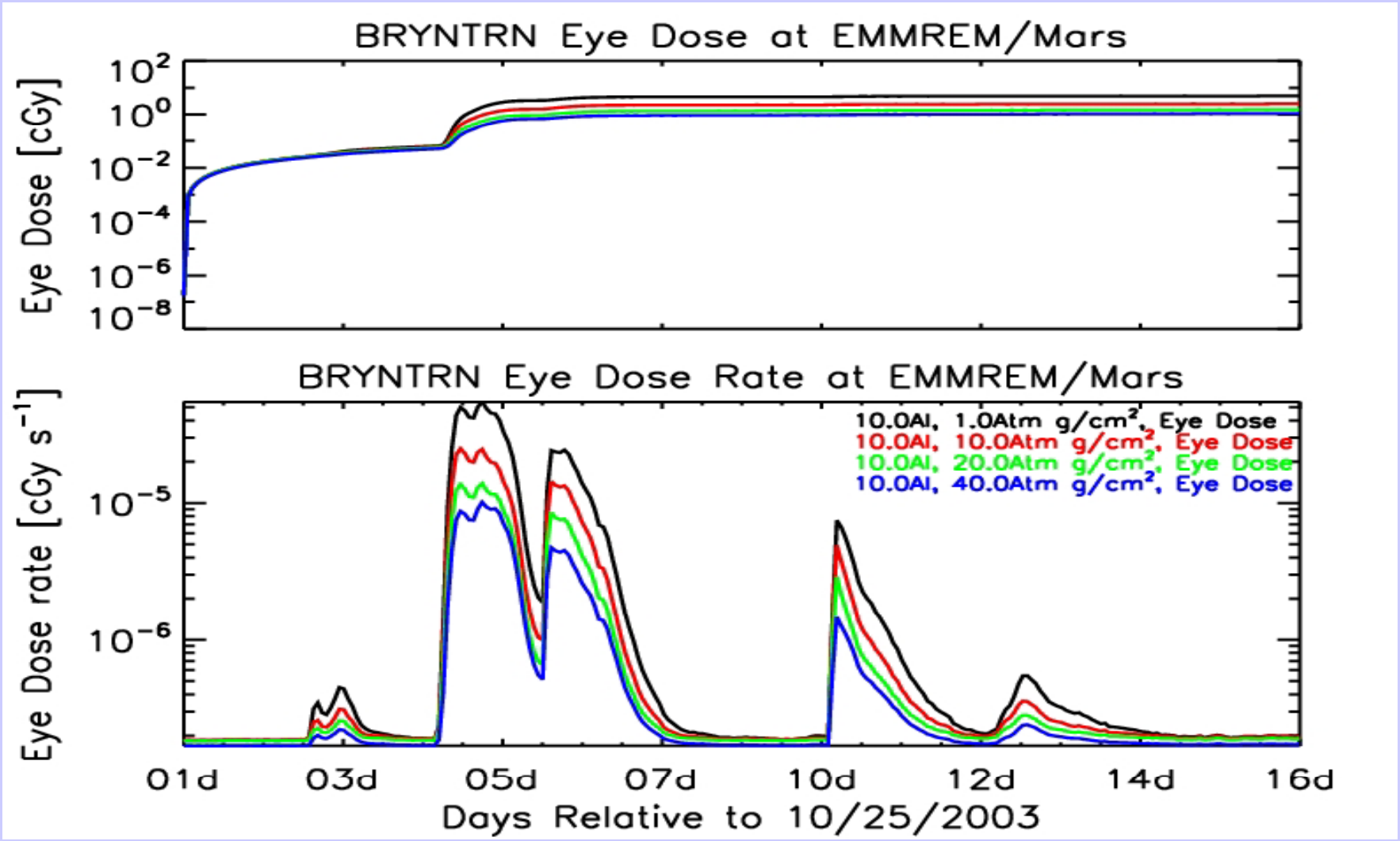


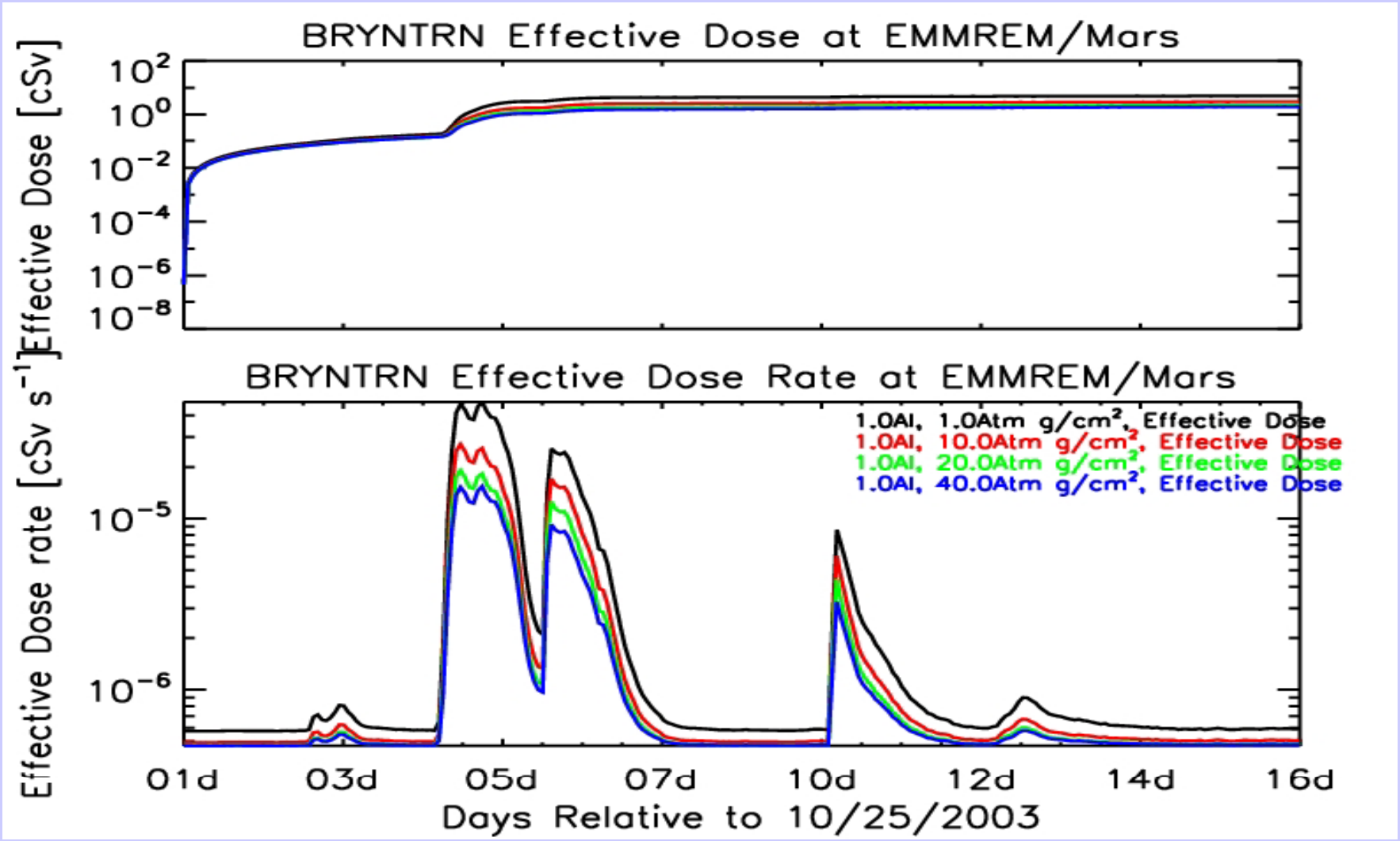
Mars Observer Results(7)



Mars Observer Results(8)



Mars Observer Results(9)



Discussion of results (1)

- **Observer results help us to determine the severity of space radiation during the event and its time dependence, based on the EPREM results at different locations in the inner Heliosphere.**
- **At radial distance of 1 AU in space, the Earth and Mars atmosphere depths are not needed.**

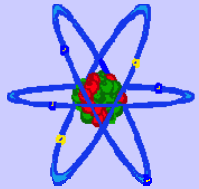
Discussion of results (2)

- **The Earth, and Moon observer's Gray Equivalent, Dose Equivalent, Skin Gray Equivalent, Skin Dose Equivalent, BFO Gray Equivalent and BFO Dose Equivalent Rates rise and fall the same as SEP flux as a function of time as expected.**
- **The thicker the aluminum shielding, the lower the exposure, as expected.**
- **The magnitude of the rates are also reasonable for the given proton energies and shielding thicknesses.**

Discussion of results (3)

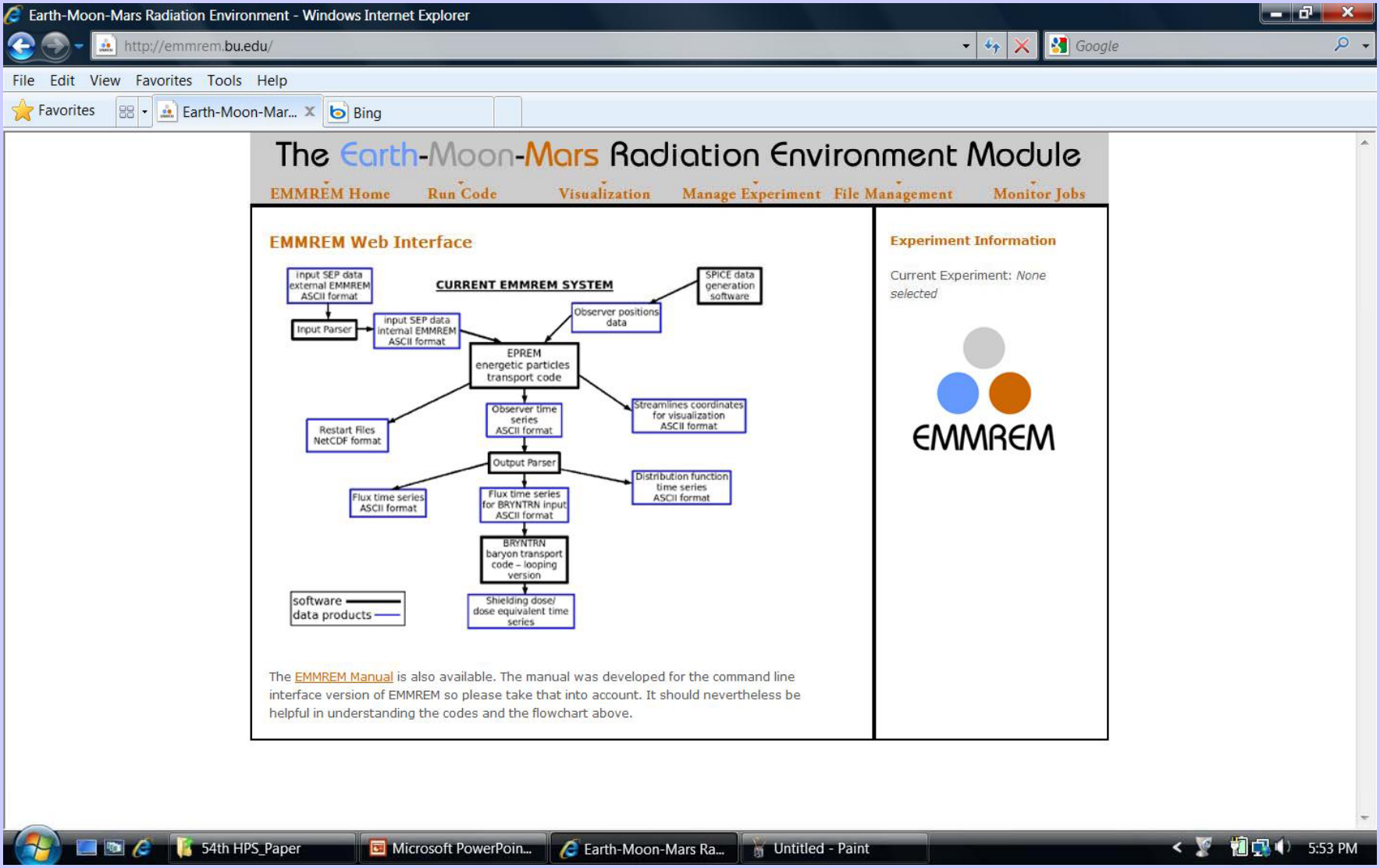
- **The 30 days dose radiation limit is less than, 150 (cGy-Eq) for skin and less than 25 (cGy-Eq) for BFO accumulated Earth and Moon observers.**
- **Mars results are for three layers. Mars Atmosphere (layer 1), Aluminum (layer 2) and Water (layer 3).**
- **To speed up EMMREM run time, look up tables were generated to evaluate the Dose and Dose Equivalent rates for Mars Observer with three layers. Look up tables were used to plot Mars Observer results.**

Conclusions

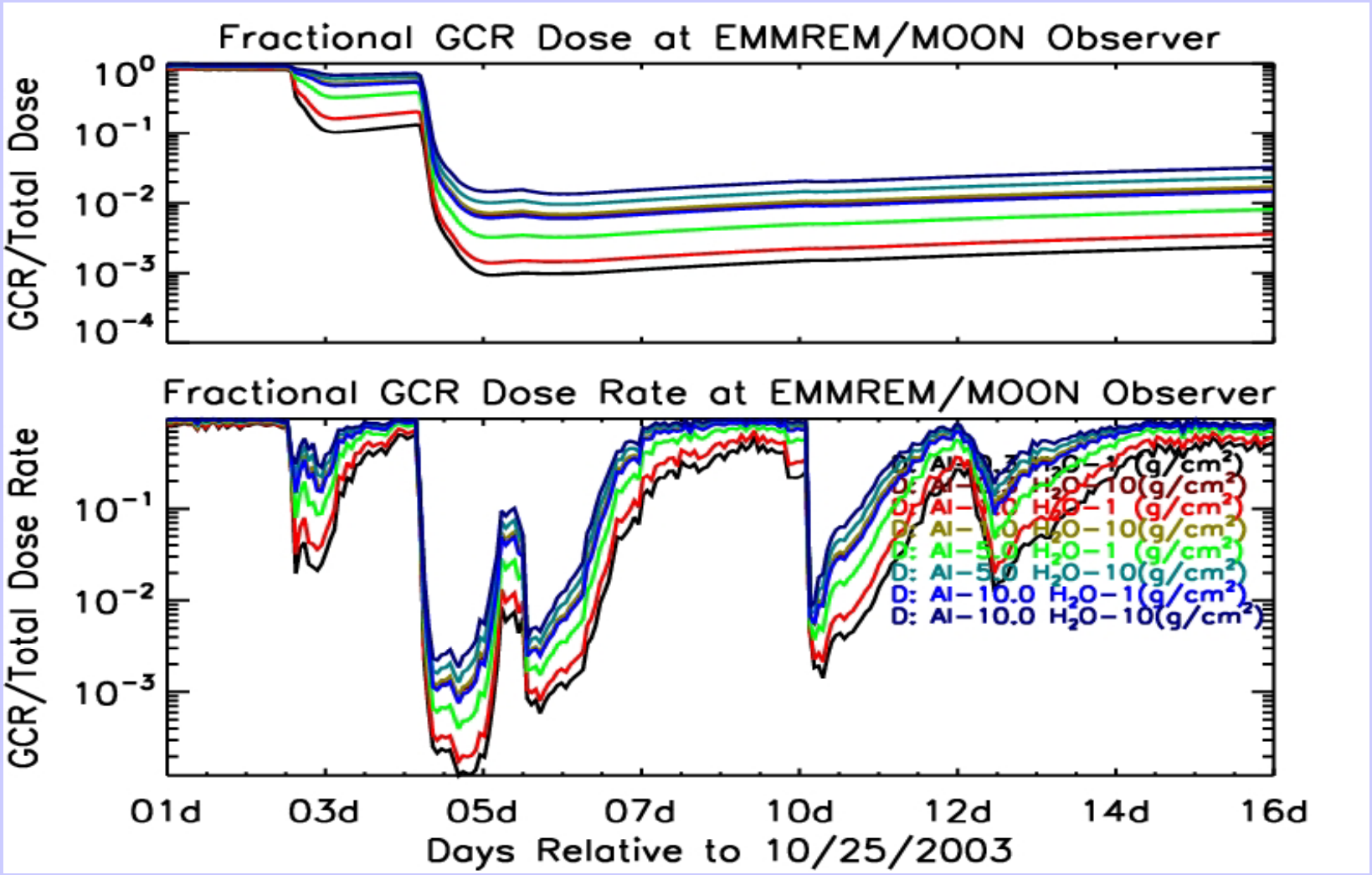


The EMMREM module is capable of characterizing the time dependent radiation calculations in the Earth, Moon, Mars, and interplanetary space environment for any SEP historical event with reasonable results. The evaluated accumulated skin and BFO Doses are less than the 30 days Dose limits for real life scenarios per NASA_STD_3001 Vol 1 guidelines.

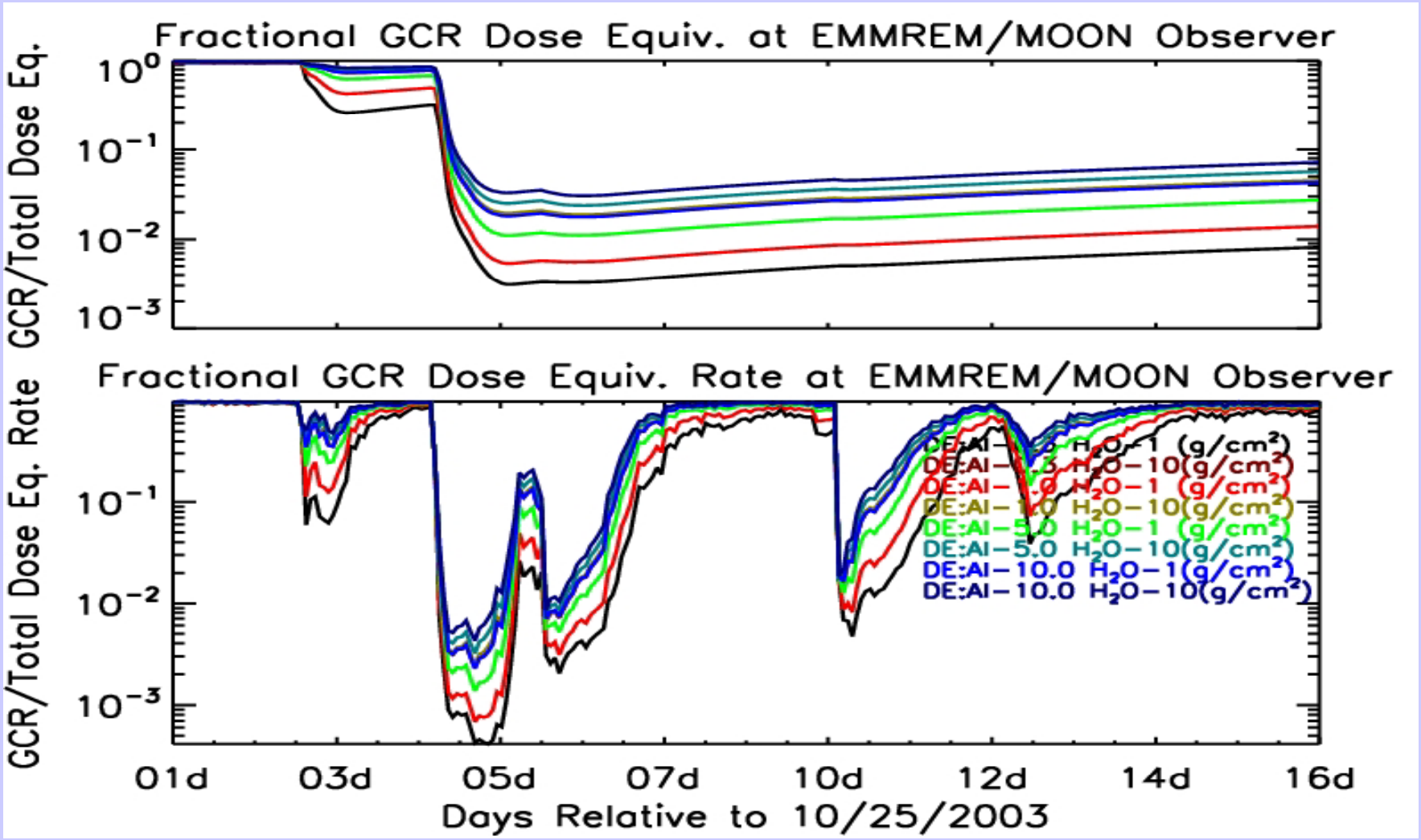
http://emmrem.bu.edu
It is not ready for public use yet.



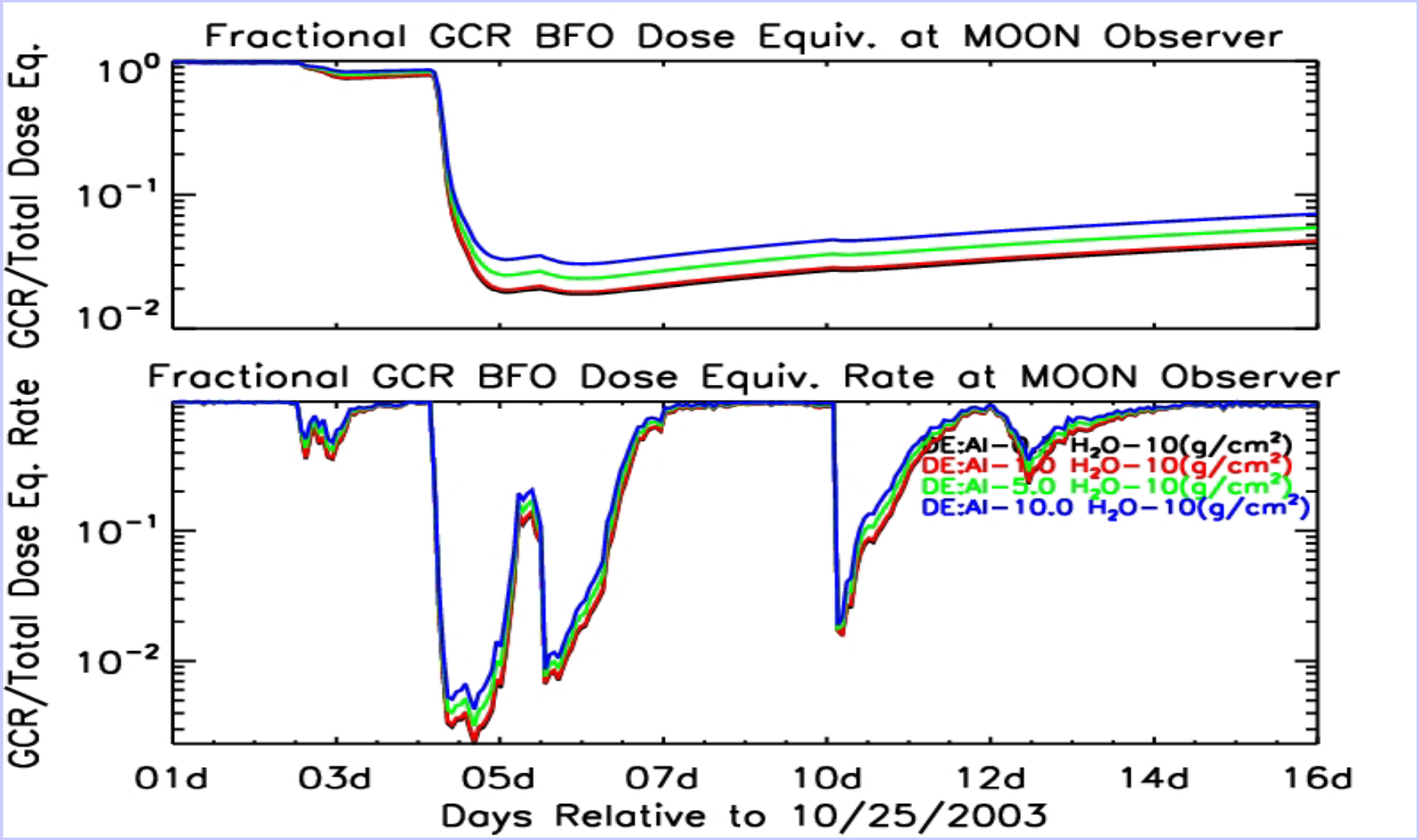
Moon Observer Results(11)



Moon Observer Results(12)



Moon Observer Results(13)



Observers results (C)

Dose limits for short-term or career non-cancer effects (in mGy-Eq. or mGy)
Note RBE's for specific risks are distinct as described below.

Organ	*30 day limit (mGy-Eq)*	*1 Year Limit (mGy-Eq)*	*Career (mGy-Eq)*
Lens*	**1000**	**2000**	**4000**
Skin	**1500**	**3000**	**4000**
BFO	**250**	**500**	**NA**
Heart**	**250**	**500**	**1000**
CNS***	**500**	**1000**	**1500**
CNS* (Z≥10)**	**-**	**100**	**250**

*Lens limits are intended to prevent early (< 5 yr) severe cataracts (e.g., from a solar particle event). An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (> 5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.
**Heart doses calculated as average over heart muscle and adjacent arteries.
***CNS limits should be calculated at the hippocampus.

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