Impact of GLE Events on the Earth's Atmosphere Electrical Properties and the Subsequent Effect on Dust Particles Transport

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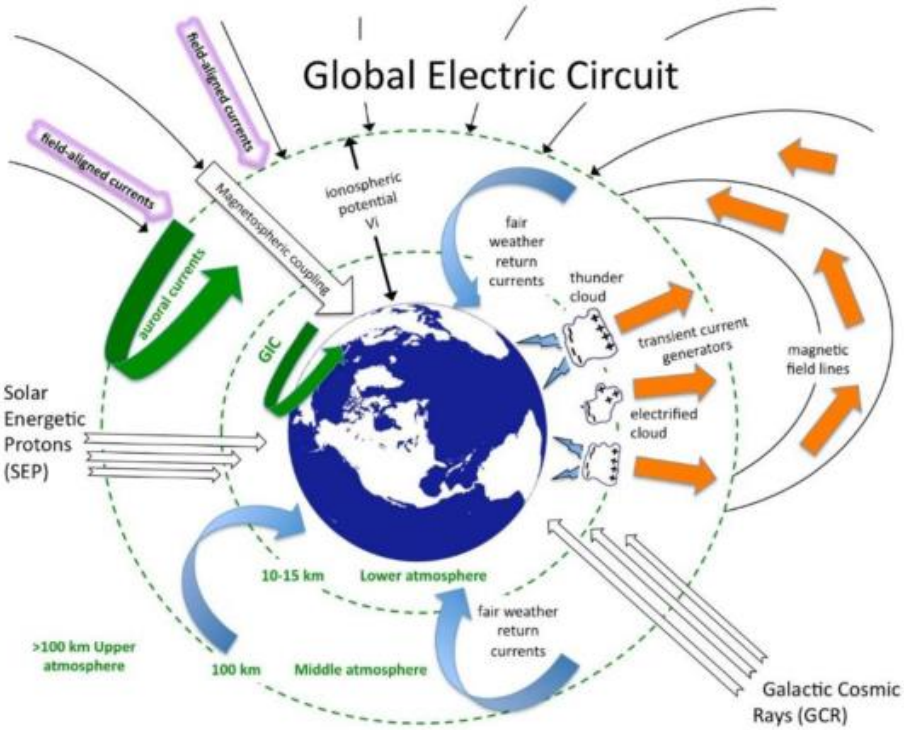
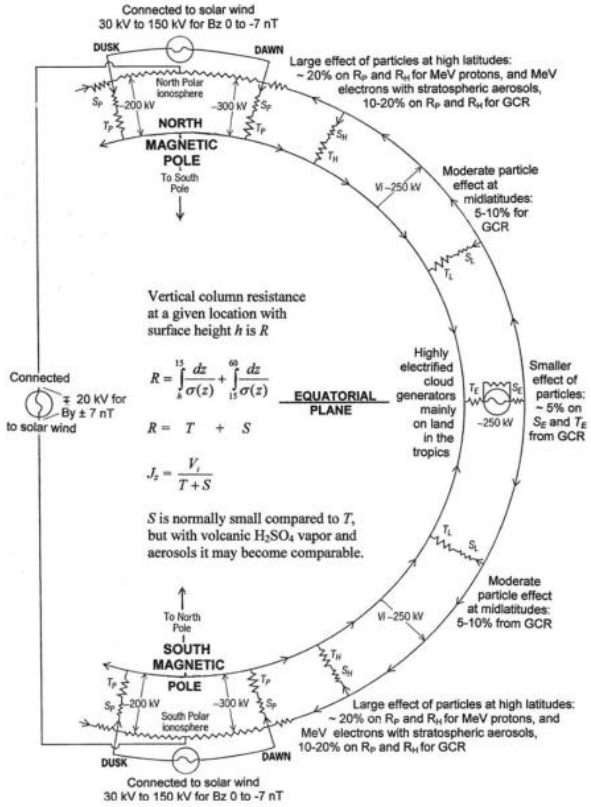
Background

Global Electric Circuit (GEC)



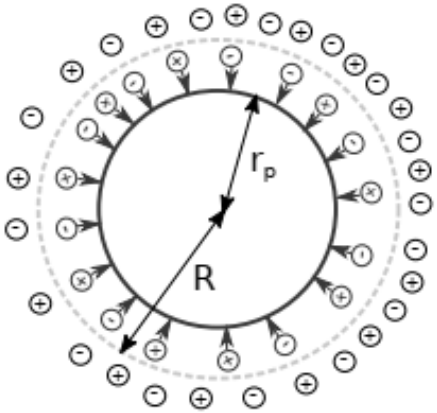
> Phenomena that drive the **GEC**. [Courtesy of NSF]

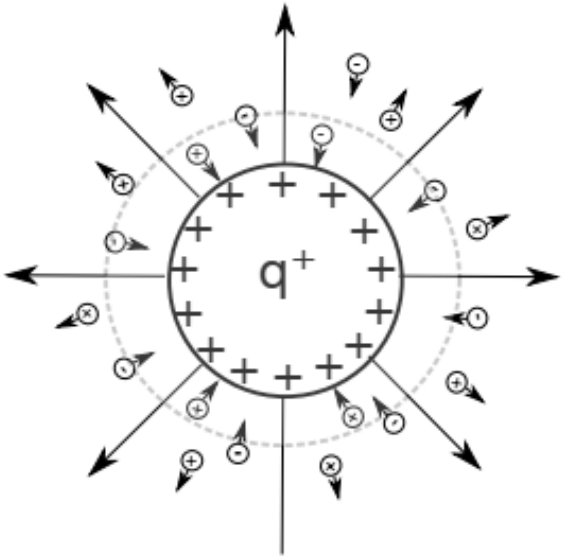


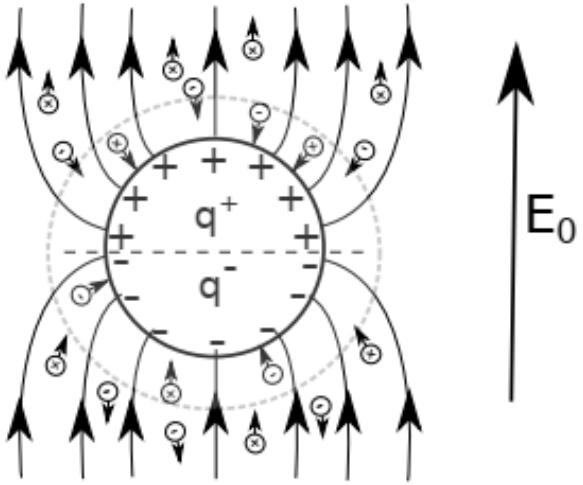
> Schematic of a section through the **global atmospheric electric circuit** in the dawn–dusk magnetic meridian. [see Tinsley BA, Rep. Prog. Phys. 71(2008), doi:10.1088/0034-4885/71/6/066801)]

Modeling

Dust particle electrification due to ion attachment







> **Uncharged particle**
No external electric field
(Diffusion Mechanism)

> **Charged particle**
No external electric field
(Electrical Attraction Mechanism)

> **Uncharged particle**
External electric field
(Polarization Mechanism)

Modeling

Model formulation

Discretization bins of dust particles

i	Bin_i start (μm)	Bin_i end (μm)	r_i (μm)	$N_{0,i}$ (m^{-3})
1	0.05	0.49754	0.11009	1.129286×10^{8}
2	0.49754	0.5025	0.5	7.29383×10^{4}
3	0.5025	0.9952	0.67089	2.088442×10^{6}
4	0.9952	1.005	1	2.196567×10^{4}
5	1.005	2.4877	1.4363	1.176378×10^{6}
6	2.4877	2.5125	2.5	4.171284×10^{3}
7	2.5125	4.976	3.4757	2.029122×10^{5}
8	4.976	5.025	5	2.045581×10^{3}
9	5.025	9.952	6.6764	8.080773×10^{4}
10	9.952	10.05	10	4.882423×10^{2}
11	10.05	24.878	13.132	1.42718×10^{4}
12	24.878	25.125	25	1.6105×10^{1}
13	25.125	49.756	30.175	3.065036×10^{2}
14	49.756	50.25	50	3.805×10^{1}
15	50.25	74.635	57.013	5.401142
16	74.635	75.375	75	2.673747×10^{-2}
17	75.375	99.514	83.132	3.160056×10^{-1}
18	99.514	100.5	100	3.303402×10^{-3}
19	100.5	150	112.55	3.96402×10^{-2}

> A **full description of the model** can be found in:

Mallios et al., 2021, Front. Earth Sci. 9, doi:10.3389/feart.2021.709890

- Ion dynamics:

$$\frac{dn^{\pm}}{dt} = -\vec{\nabla}\cdot\left[\underbrace{\pm n^{\pm}\mu^{\pm}\vec{E}}_{\text{Advection}} - \underbrace{D^{\pm}_{\text{ion}}\vec{\nabla}n^{\pm}}_{\text{Diffusion}}\right] + \underbrace{q}_{\text{Ionization}} - \underbrace{an^{+}n^{-}}_{\text{Ion-ion recombination}} - \underbrace{n^{\pm}\sum_i \beta_i^{\pm}}_{\text{Ion attachment}}$$

- Dust particles dynamics:

$$\underbrace{\frac{d\rho_{\mathrm{p},i}}{dt}}_{\text{Charge density dynamics}} = -\vec{\nabla}\cdot\left[\underbrace{\rho_{\mathrm{p},i}\vec{v}_{\mathrm{p},i}}_{\text{Adevction}} - \underbrace{D_{\mathrm{p},i}\vec{\nabla}\rho_{\mathrm{p},i}}_{\text{Diffusion}}\right] + \underbrace{q_{\mathrm{e}}\left(\beta_i^{+}n^{+} - \beta_i^{-}n^{-}\right)}_{\text{Charging due to ion attachment}}$$

$$\underbrace{\frac{dN_{\mathrm{p},i}}{dt}}_{\text{Number density dynamics}} = -\vec{\nabla}\cdot\left[\underbrace{N_{\mathrm{p},i}\vec{v}_{\mathrm{p},i}}_{\text{Advection}} - \underbrace{D_{\mathrm{p},i}\vec{\nabla}N_{\mathrm{p},i}}_{\text{Diffusion}}\right]$$

- Gauss law:

$$\vec{\nabla}\cdot\vec{E} = \frac{\rho_{\mathrm{tot}}}{\varepsilon_0} = \frac{\sum_i \rho_{\mathrm{p},i} + q_{\mathrm{e}}\left(n^{+} - n^{-}\right)}{\varepsilon_0}$$

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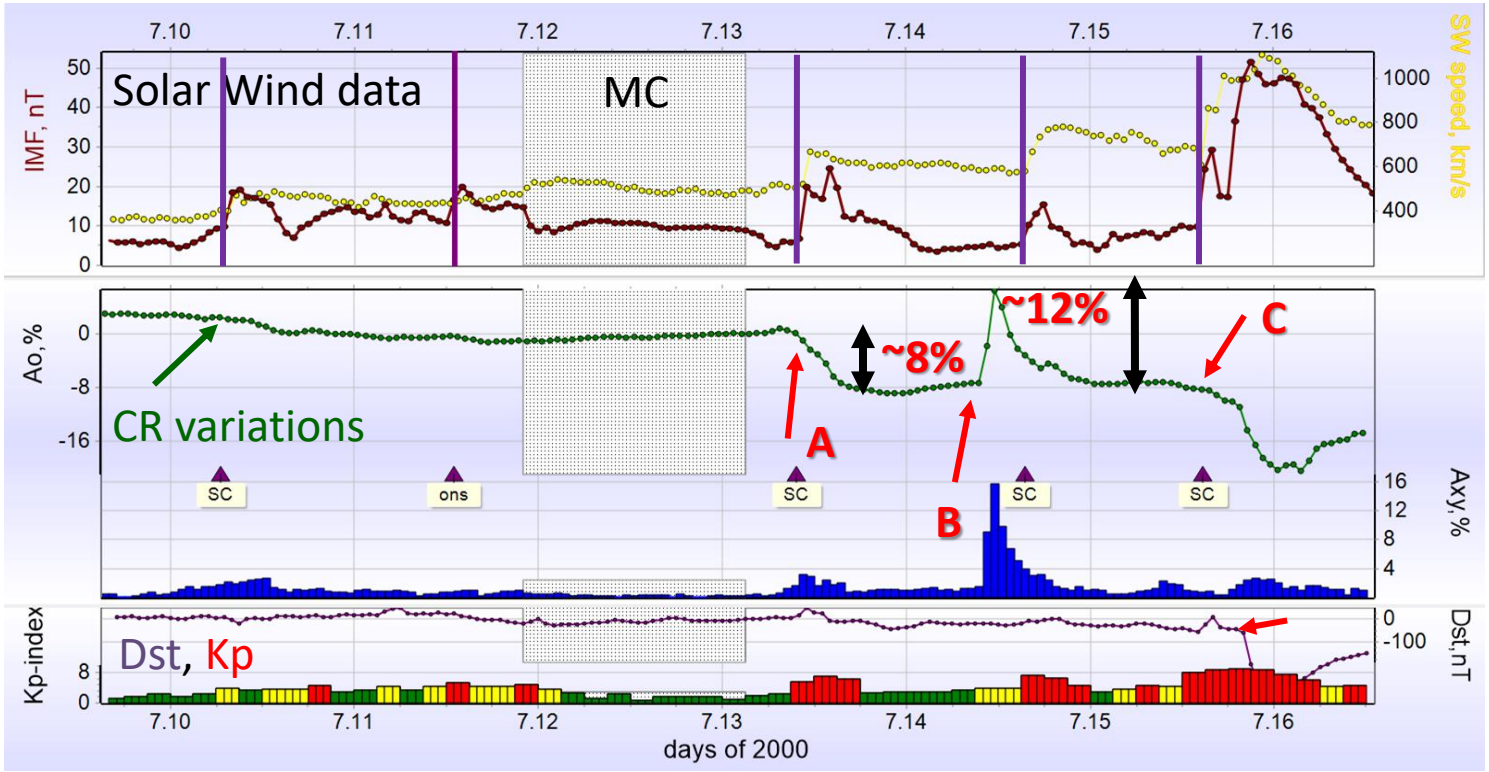
Event under investigation

Cosmic rays @ Earth & GLE59 (on 14.07.2000)



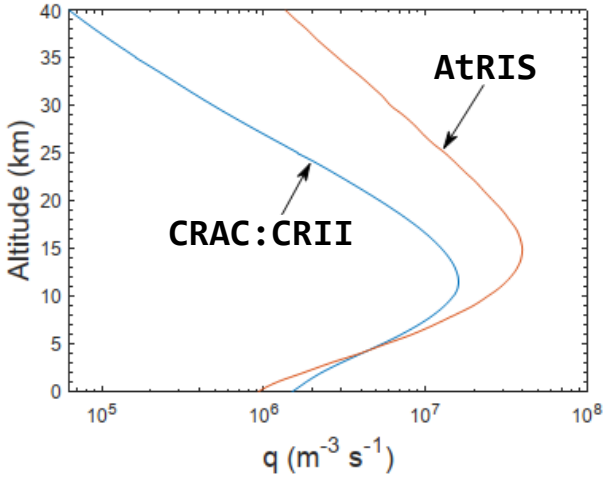
> **A**: The interplanetary counterparts of a CME reaches Earth and a *sudden* ***Forbush decrease*** of **~ 8%** at a rigidity of 10 GV is recorded

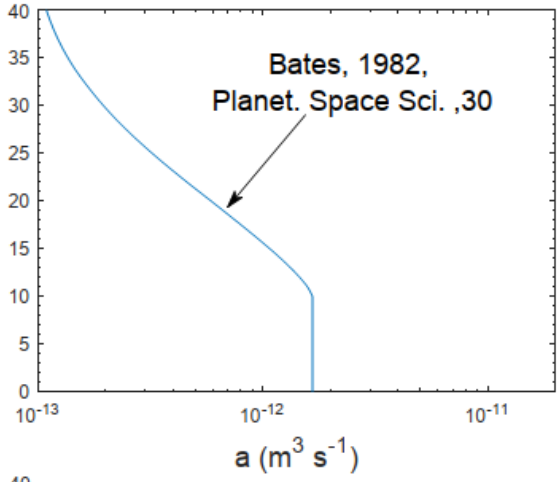
> **B:** A *CME occurs at the Sun*. It accelerates particles to relativistic energies that reach Earth a few minutes later. A *sudden increase of ~ 12% at 10 GV is recorded in CR variations*. The **Ground Level Enhancement (GLE) 59**.

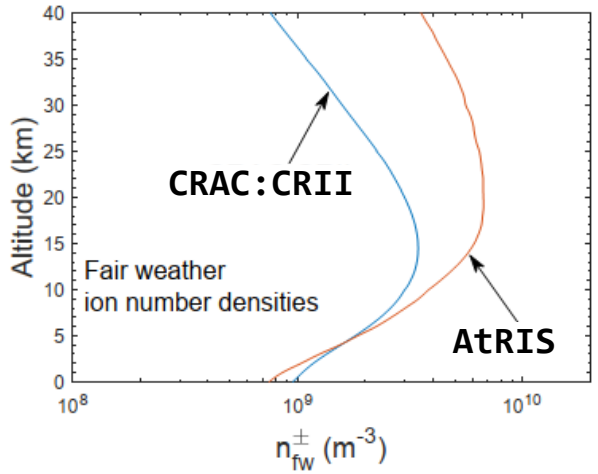
> **C:** The *CME arrives at Earth*, another ***Forbush decrease*** is recorded. In conjunction to a significant geomagentic storm.

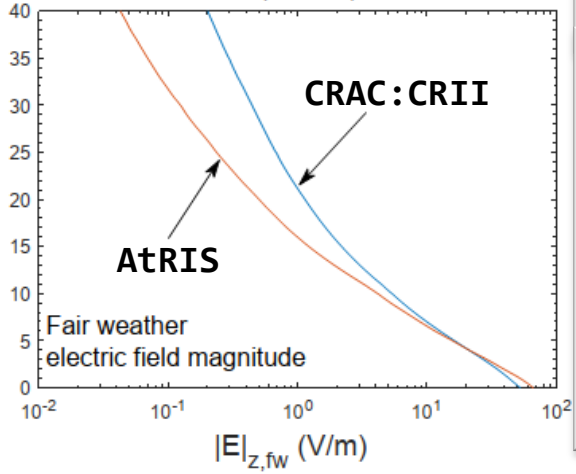
Results

Initial – Fair weather conditions







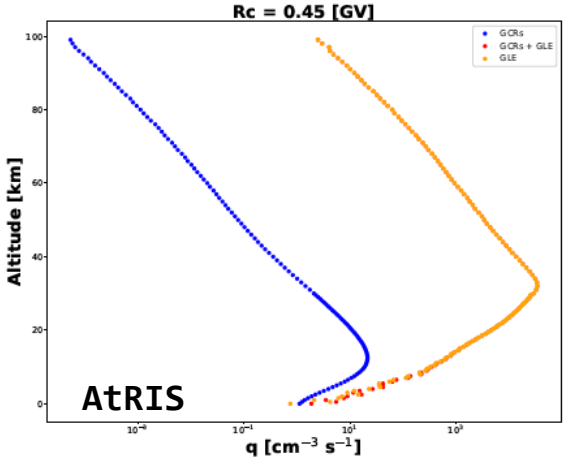


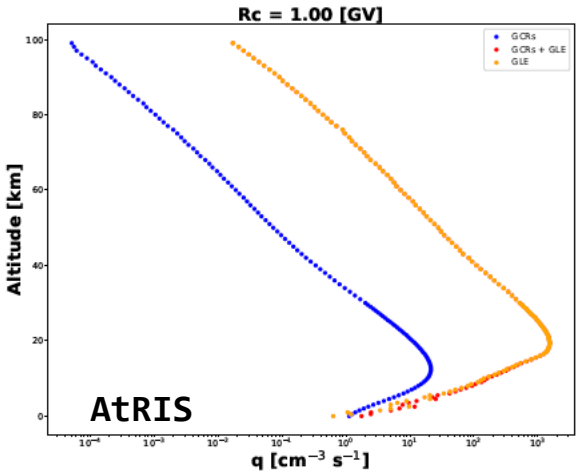
> **Mauritania** (24.32, -10.96) has been chosen as the *location for the study*, since it is *close to* the **dust particles emission source**, and to the **dust particle size distribution measurement location**.

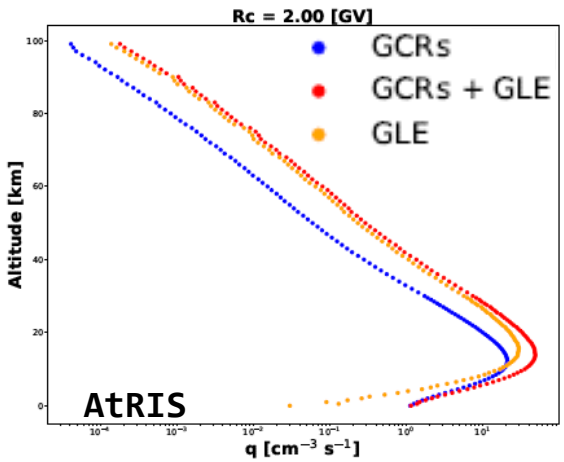
> Two simulation codes: **CRII** & **AtRIS** provided the **Galactic Cosmic Ray** (**GCR**) ionization rate (**q**) profile and were used as *input* to the model.

Results

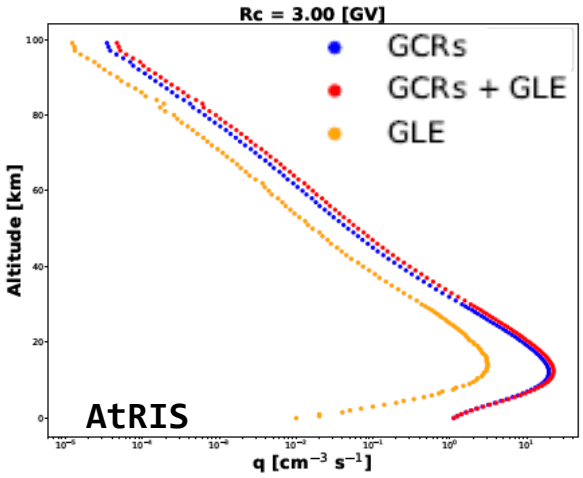
Evolution of *q* | GCRs *vs* SCRs in the GLE

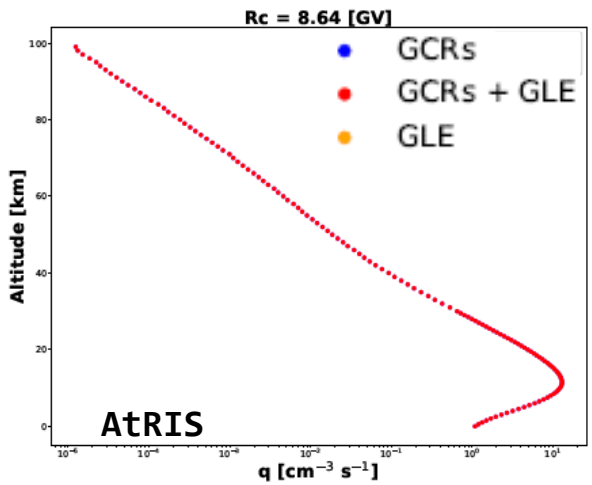






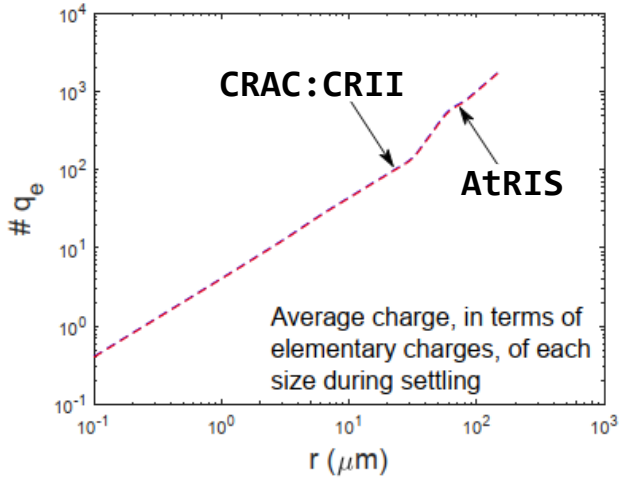
> AtRIS was used to simulate **q** for **GCRs** and **Solar Cosmic Rays** (**SCRs**) during the **GLE** at *a set of rigidities* (energies).

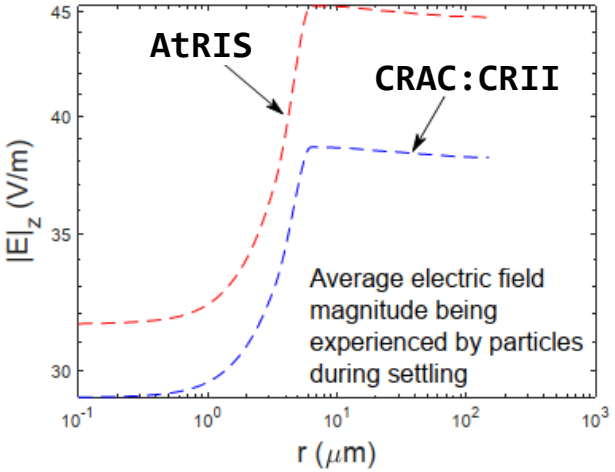




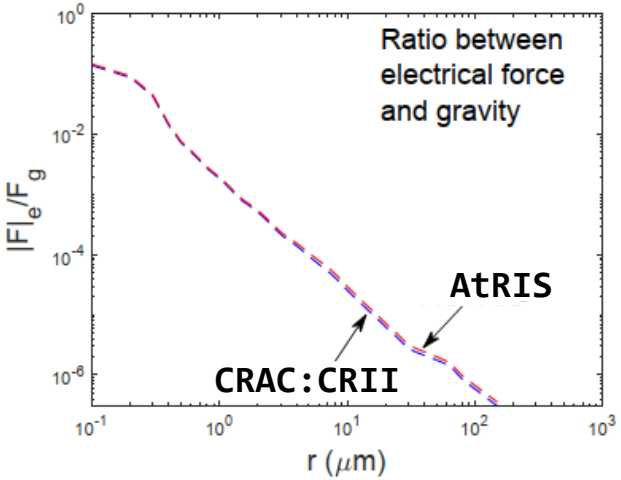
Results

Dust particles electrical properties for GCRs





> Both codes: **CRII** & **AtRIS** lead to comparable **average charge (q_E)**and **ratio** between the electrical force and gravity ($|F|_e/F_g$)



> A difference arises in the obtained average electric field ($|E|_z$)

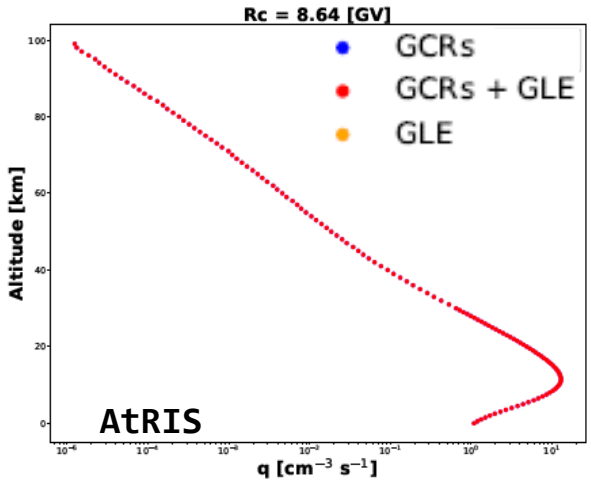
Next steps

Dust particles electrical properties for both GCRs + SCRs

> **Mauritania** (24.32, -10.96) **has a cut-off** at ***Rc = 8.64 GV***. This means that the ionization rate (**q**) is **dominated** by **GCRs** alone in this area.

> Our parametric study *discretized* the **Rc** (see previous slide) for **several simulated cut-offs** for the **Mauritania** region.

> Hence our immediate next steps include the ***dust particle electrical properties*** for both **GCRs** + **SCRs** (GLE) for each of the **simulated Rc** in an attempt to *quantify* how **average charge (q_E)**and **ratio** between the electrical force and gravity ($|F|_e/F_g$) and average electric field ($|E|_z$) would *respond* to the addition of **SCRs**.



Thank you for your interest !

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