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An investigation of the possibility of detecting gamma-ray flashes originating from the atmosphere of Venus

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The Runaway Electrons Avalanche Model Monte Carlo simulations is used to study the propagation of runaway electrons and gamma-ray flashes originating from the atmosphere of Venus, and the possibility of detecting these high-energy gamma rays at low-Venus orbit is also investigated. Relativistic Runaway Electron Avalanche (RREA) lengths and energy spectra at the Venus middle cloud levels have similar values to those of Earth at sea level, with a similar RREA threshold electric field (~286 kV/m). If electrified clouds in Venus make similar numbers of gamma rays as are made by thunderstorms on Earth during Terrestrial Gamma-ray Flashes (TGFs), then the calculated gamma-ray fluences at low-Venus orbit (~550 km) have an approximate range of 10^{-3} $photons/cm^2$ to 4 $photons/cm^2$ for the source altitude between 58 km and 70 km. These gamma-ray fluences are similar to those measured by spacecraft in low-Earth orbit from TGFs. Therefore, if TGF-like events initiate in the middle and upper clouds of Venus, they would be detectable by spacecrafts at low-Venus orbit.

Venus' Atmosphere Composition

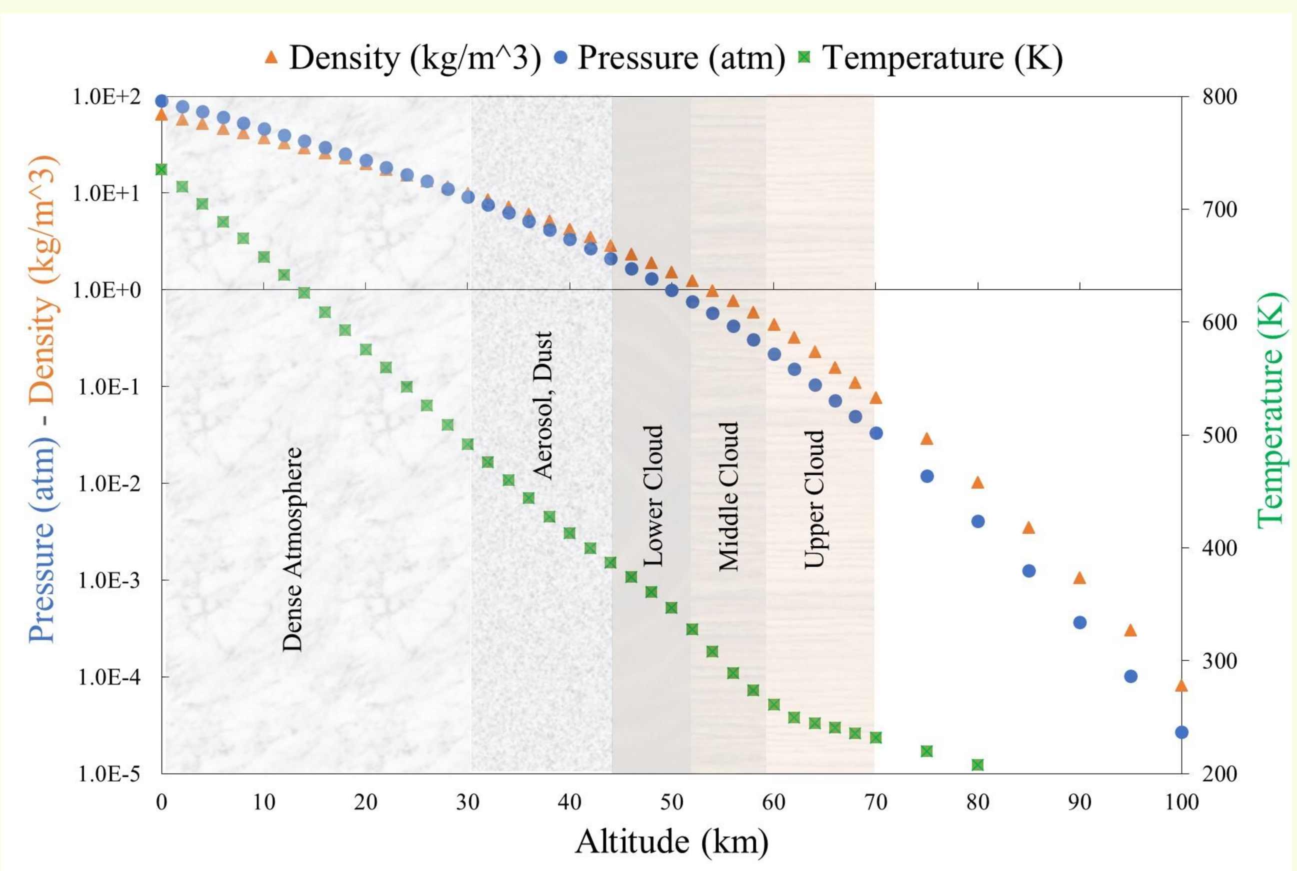

Fig. 1 – Pressure, temperature and density profile of Venus atmosphere from surface up to 100 km [*Moroz*, 1981].

Carbon dioxide (96.5%) and nitrogen (3.5%) are the main constituents of Venus atmosphere. Middle clouds of Venus have almost the same temperature, pressure and atomic density as at Earth's surface. We have used this region's properties to simulate the production and propagation of runaway electron and gamma rays.

Planet	Atomic number	Atomic number^2	Atomic density (cm^-3)	Excitation energy (eV)
Earth	7.26	53.45	5.38E+25	85.7
Venus	7.32	54.46	5.38E+25	88.45

Monte Carlo Simulation

We have used REAM Monte Carlo simulations to study the development and propagation of runaway electron avalanches at Venus' atmosphere. This simulation includes all of important interactions involving runaway electrons, positrons, X-rays and gamma rays [*Dwyer*, 2007]. The Bethe equation is used to consider energy losses of electrons due to ionization and atomic excitation. The simulation fully models elastic scattering using a shielded-Coulomb potential and considers bremsstrahlung production of x-rays and gamma-rays and the subsequent propagation of the photons, including photoelectric absorption, Rayleigh scattering, Compton scattering and pair-production. Positions propagation and annihilation, and generation of energetic seed electrons via Bhabha scattering of positrons and Compton scattering and photoelectric absorption of energetic photons are also included.

To study RREA and gamma-ray flashes properties at Venus, we injected energetic seeds of electrons into avalanche region at different electric field magnitudes and collected the resulting particles at the end of field region. Those particles were used to calculate avalanche length and energy spectra. Then, the gamma rays produced at the end of avalanche region were initiated from different source altitudes and collected at low-Venus orbit to calculate the fluence.

Lightning at Venus

Over the last decades, there have been several searches for lightning activity on the Venus, including radio frequency, spectroscopic and optical measurements. Recent observations by Venus Express (VEX) and Pioneer Venus (PV) have recorded signals attributed to lightning discharges in the Venus clouds [*Russell et al.*, 2006]. In addition, dissociation of carbon dioxide by lightning discharges that could lead to the production of nitric oxide is suggested to be the main loss mechanism of atmospheric molecular nitrogen [*Krasnopolsky*, 2006]. Also, ground-based optical observations of lightning on the night side of Venus captured several potential lightning flashes at the wavelength of 777.4 nm associated with the emission line due to excitation of neutral oxygen [*Hansell, et al.*, 1995].

So far, the Elster-Geitel mechanism which involves drop rebound due to friction between sulfuric acid droplets in the clouds is suggested to be the main electrification mechanism at Venus clouds, however other mechanisms such as gravity, convection and Violent rupture of water drops could help this process [*Williams, et al.*, 1983].

Terrestrial Gamma-ray Flashes are short intense bursts of radiation produced by bremsstrahlung emission of runaway electrons. The Orbiter Gamma Burst Detector (OGBD) instrument on board Pioneer Venus had been searching for gamma ray burst around Venus between 1978 to 1992, but it did not detect any possible TGFs due to low time resolution of collected data [*Lorenz and Lawrence*, 2015].

RREA properties at Venus

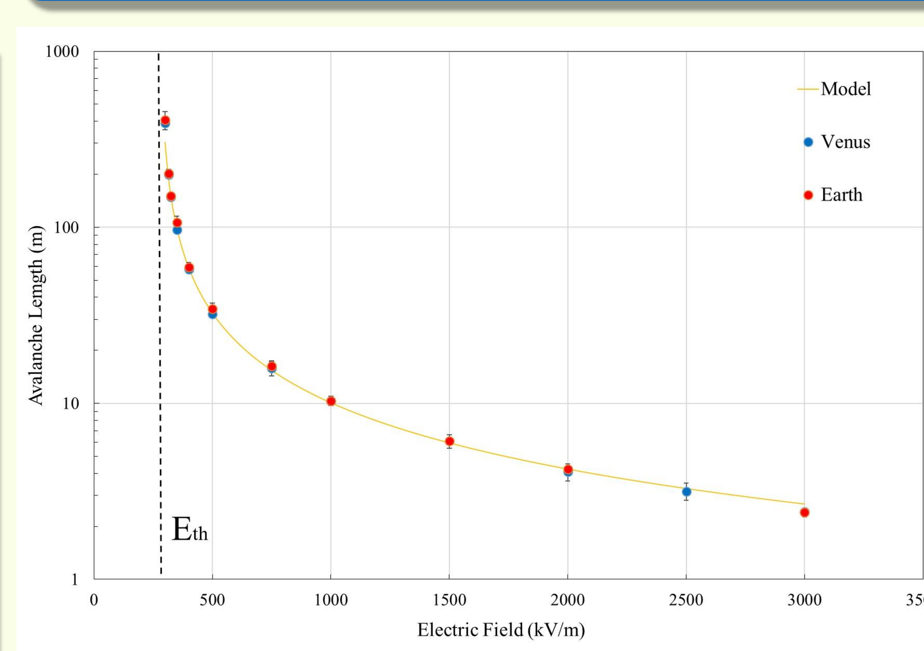

Fig. 2 – Characteristic avalanche length of runaway electrons of Earth and Venus. The model predicts the avalanche length versus electric field as:

$$\lambda = \Gamma / [(E - E_{th}) \times n] \quad (1)$$

Γ and E_{th} for the Earth and Venus are respectively equal to 7.12 MeV and 276 kV/m, and 7.15 MeV and 276.2 kV/m.

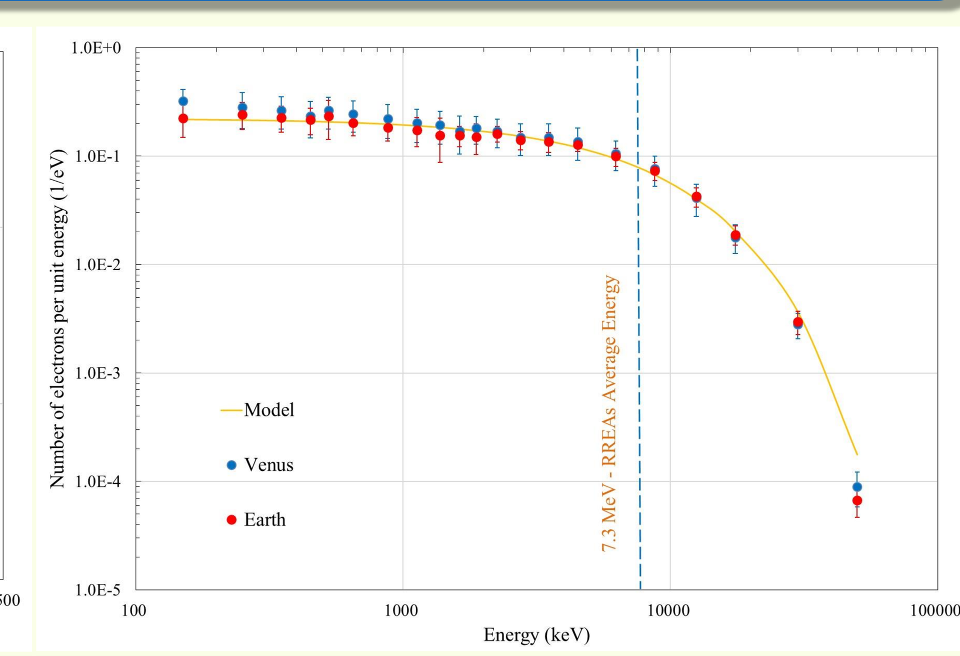

Fig. 3 – Electrons energy spectra produced by RREAs on the Earth and Venus. The model predicts the energy spectra versus energy as:

$$f_{re} = \frac{F_{RREA}}{7.3\ \mathrm{MeV}} \exp\left(\frac{-\varepsilon}{7.3\ \mathrm{MeV}}\right) \quad (2)$$

Due to similarities between Venus and Earth atmosphere mentioned in the left table, similar energy spectra were not unexpected.

Gamma-Ray detection at low-Venus orbit

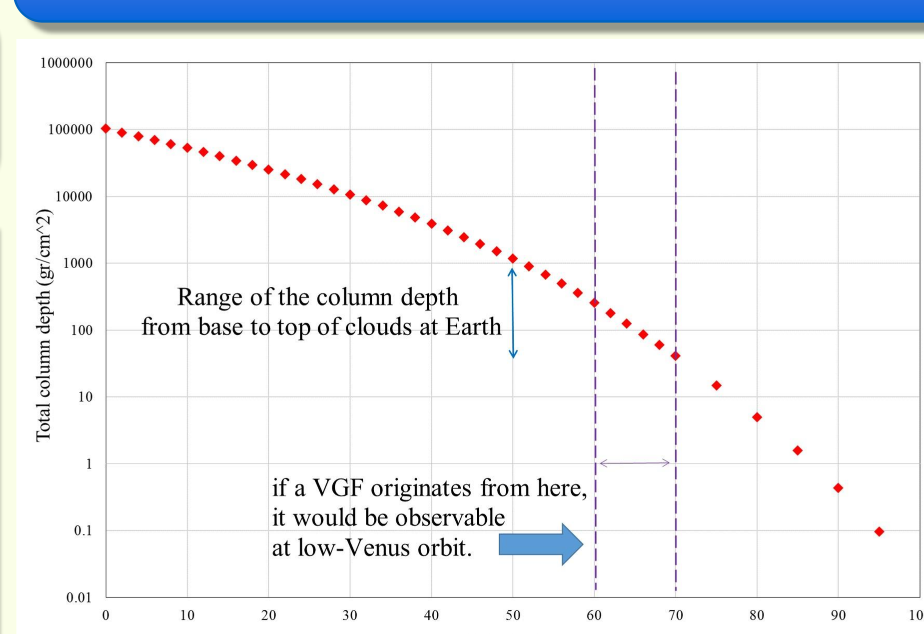

Fig. 4 – Total column depth of atmosphere above each point versus its altitude. Larger column depth means that gamma rays have a lower chance to escape out of atmosphere. The average column depth for the clouds at Earth are ranging from 50-1000 gr/cm^2. Gamma ray flashes that originate from middle and upper clouds of Venus would be detectable at low-Venus orbit.

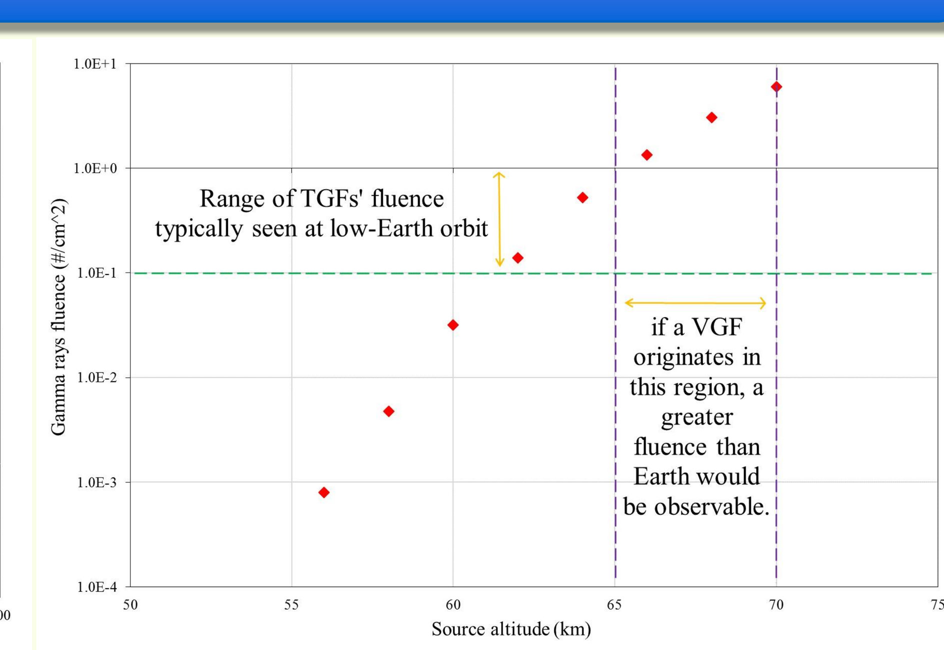

Fig. 5 – Gamma rays fluence at 550 km above Venus surface versus source altitude, assuming similar number of gamma rays produced at source as TGFs on Earth. The typical fluence of TGFs seen on low-Earth orbit is ranging from 0.1-1 $photons/cm^2$, so gamma ray flashes originating in upper clouds of Venus produce a greater fluence at low-Venus orbit.

Conclusion

I. Avalanche length and energy spectra of runaway electrons at Venus middle clouds had similar values to those at the Earth's sea level, which leaded to the same threshold electric field (286 kV/m) × n. The average energy of runaway electrons was about 7 MeV which was in agreement recent works. This presentation is published at JGR space physics [*Bagehri and Dwyer*, 2016].

II. The fluence of gamma rays at low-Venus orbit produced by bremsstrahlung emission is reported to be 10^{-3} $photon/cm^2$ to 4 $photon/cm^2$ for the source altitude between 58 to 70 km.

III. It seems if electrification occurs in the clouds of Venus, and the gamma-ray flashes initiate in the middle and upper clouds are similar to that on the Earth, they should be detectable by spacecrafts at low-Venus orbit. We propose calling these events Venusian Gamma-ray Flashes (VGFs).

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