UV-induced volatile emissions form carbonaceous chondrites with a focus on the Martian surface

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Introduction

Methane (CH₄) is a strong greenhouse gas that is abundant on Earth. ~90% of terrestrial CH₄ is produced by microorganisms. The discovery of CH₄ in the atmosphere of Mars (e.g., Mumma et al., 2003) has led to widespread speculation and several theories on its origin, including life (Krasnapolsky et al., 2004). One of the other methods at which CH₄ can be produced is the irradiation of carbonaceous chondrites (a class of meteorites). An expected 3 to 60 million kg of meteorites and interplanetary dust particles (IDPs) reach the Martian surface each year (Flynn & McKay, 1990). These meteorites contain compounds such as amino acids, aromatic hydrocarbons, and macromolecular carbon. Irradiation of this carbon rich material has been proven to yield CH₄ in small amounts (Keppler et al., 2012). Here, we conduct a study to find what organics, including CH₄, can be produced by photolysis of meteoritic organic carbon. In the near future, we will perform isotopic analysis of the produced organics to determine the process' isotopic fingerprint.

Methods

To test qualitatively and quantitatively what organics are emitted from carbonaceous chondrites, we built a setup consisting of a Xe-arc UV enhanced lamp (Osram), a reaction vessel through which a carrier gas is pumped, a Cavity Ring-Down Spectroscopy instrument (CRDS, Picarro), and a Proton Transfer Reaction Time Of Flight Mass Spectrometer (PTR-TOFMS, IONICON Analytik). A small piece (~100mg) of the Murchison meteorite (named after its fall in Murchison, Australia in 1969) is ground to a fine powder and irradiated in the sealed reaction vessel. A stream of N₂ gas flushes the headspace of the reaction vessel, carrying the emitted organics to the different analytical instruments. Every 30 minutes, the inlet to the instruments switches between the headspace gas and the pure carrier gas (as a background). Concentration data of the aforementioned volatiles are collected every 1 to 5 seconds and from these concentrations, emission rates can be calculated. Our experiments run up to 2 weeks, providing us with unique high resolution, long term experimental data.

Volatile cycling on Mars

UV radiation

Meteorites and IDPs

Acetone

Formaldehyde

Acetaldehyde

CO₂

CH₄

Reactive Oxygen species

UV radiation

OH

Formaldehyde

CH₄

CO₂

H₂O

UV irradiation and radicals break down CH₄ into intermediate volatiles and eventually CO₂ and water

Possible surface CH₄ sources

Possible subsurface CH₄ sources

Water

Serpentization

Olivine

Methanogenic microbes

Methane clathrates

UV irradiation of organic carbon in carbonaceous chondrites yields CO₂, CH₄, and several other volatile organics

Results

Methane emissions follow a three-term exponential function. The three terms contribute to ~5%, ~25%, and ~70% of the total emitted methane in every experiment. It is not yet understood why the emission follows these curves or whether there are 3 different processes involved in CH₄ emission. At most, a total of ~0.1% of organic carbon can be converted to methane, probably due to the limited penetration depth of UV in solid materials, which is usually less than 1 μm. Several volatiles are emitted besides CH₄ and CO₂. PTR-TOFMS measurements show several tens of compounds emitted when meteorite material is irradiated. Although not every mass detected can be immediately linked to a molecular structure, experiments suggest meteorite material emits methanol, formaldehyde, acetaldehyde, acetone, and many other compounds when irradiated. The image on the left shows the concentration of an unknown volatile organic compound in the sampled head space (H) and in the pure carrier gas (K). Clearly visible is the increase in concentration of this compound in the headspace gas when the lamp is turned on.

Implications for the Martian atmosphere

Understanding the emission of volatile organic compounds from meteorite material is important when trying to model the composition of the Martian atmosphere. It can predict what volatile organics could potentially be found in the Martian atmosphere and what compounds they can derive from. Future modelling of the CH₄ cycle on Mars should take into account that photodegradation products of CH₄ can also be a degradation products derived from the photodegradation of meteoritic carbon. In the future, higher sensitivity organic measurements and CH₄ isotope data (e.g., by ESA’s Trace Gas Orbiter) can provide new data on the presence of methane and other volatiles, and the origins and pathways through which they form. Apart from the impacts meteoritic carbon can have on a planetary atmosphere, this research sheds light on the behavior of organic compounds - the building blocks of life – and could eventually improve our understanding of the origin of life.

References


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