Planetary and Space Science 109-110 (2015) 129–134

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Gamma rays and cosmic rays at Venus: The Pioneer Venus gamma ray detector and considerations for future measurements

Ralph D. Lorenz*, David J. Lawrence

Space Department, The Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA

ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form
12 February 2015
Accepted 13 February 2015
Available online 24 February 2015

Keywords:
Lighting
Venus
Atmosphere
Gamma ray spectroscopy

ABSTRACT

We draw attention to, and present a summary archive of the data from, the Pioneer Venus Orbiter Gamma-ray Burst Detector (OGBD), an instrument not originally conceived with Venus science in mind. We consider the possibility of gamma-ray flashes generated by lightning and model the propagation of gamma rays in the Venusian atmosphere, finding that if gamma rays originate at the upper range of reported cloud top altitudes (75 km altitude), they may be attenuated by factors of only a few, whereas from 60 km altitude they are attenuated by over two orders of magnitude. The present archive is too heavily averaged to reliably detect such a source (and we appeal to investigators who may have retained a higher-resolution archive), but the data do provide a useful and unique record of the cosmic ray flux at Venus 1978–1993. We consider other applications of future orbital gamma ray data, such as atmospheric occultations and the detection of volcanic materials injected high in the atmosphere.

1. Pioneer Venus gamma ray observations

The 1978 Pioneer Venus mission was a 'small flagship', comprising four probes and their carrier, plus a separately launched orbiter spacecraft. The Pioneer Venus Orbiter conducted important ionospheric investigations, thermal and ultraviolet mapping of the clouds, and the first spaceborne radar investigations of the surface. The spacecraft also carried a gamma-ray spectrometer—although this is often forgotten since it was not carried to investigate Venus. The instrument (Klebesadel et al., 1980), formally the Orbiter Gamma-ray Burst Detector (OGBD), was carried to determine the location of transient astrophysical gamma ray sources by the relative timing of detections at various Earth-orbiting and other spacecraft as the wavefront propagates from the source at the speed of light. The large baseline between Earth and Venus made the OGBD instrument particularly effective (e.g. Hurley et al., 2000).

The OGBD consisted of a pair of identical sensors (Klebesadel et al., 1980) mounted at the periphery of the Orbiter spacecraft equipment platform, diametrically opposite each other to provide nearly uniform omnidirectional response. The sensors each contained a 3.8-cm diameter × 3.2-cm long CsI scintillation crystal optically bonded to a 0.5-cm shell of Pilot B plastic scintillator. The composite scintillator (phoswich) is passively shielded from low energy radiation by a jacket of 0.25-mm lead foil and by the sensor housing and was optically coupled to a photomultiplier tube. The OGBD detected its first gamma ray burst within 3 h of activation, when the spacecraft was still near Earth (Evans et al., 1979).

The Venusian atmosphere is too thick to permit gamma ray emissions from the surface to be detected from orbit (as has been performed at Mars and the Moon) so no gamma rays of Venusian origin were expected: we believe therefore that the OGBD data has not been searched for Venusian gamma rays.

2. Venusian gamma ray flashes?

Lightning is one of the most energetic phenomena to occur in a planetary atmosphere (e.g. Desch et al., 2003; Rakov and Uman, 2003, Yair, 2012). In addition to the importance of characterizing possible Venusian lightning as a process in its own right (e.g. Ksanfomaility et al. (1983), Russell et al. (2007)), the influence of lightning on Venusian atmospheric chemistry is important to understand (Lorenz, 2008). It was recognized quite early on (e.g., Bar-Nun, 1980) that lightning could play a major role in the generation of NO, indicated by spectroscopic observations (Krasnopolsky, 2006) to be 5.5 ppb below 60 km, apparently consistent with lightning production.

Gamma ray emissions associated with lightning on Earth were first discovered (Fishman et al., 1994) by the Compton Gamma Ray Observatory. This discovery was made after Pioneer Venus burned up in the Venus atmosphere in 1992. These Terrestrial Gamma-ray Flashes (TGFs) were seen in photons of energy 20 keV and higher (i.e. in the OGBD energy range) and had a duration of a few

---

* Corresponding author. Tel.: +1 443 778 2903; fax: +1 443 778 8939.
E-mail address: ralph.lorenz@jhuapl.edu (R.D. Lorenz).

http://dx.doi.org/10.1016/j.pss.2015.02.009

milliseconds. The short duration of these flashes implies a relatively small source, and the angular response of the detectors suggested that the gamma rays came from below the horizon, i.e. from the Earth.

It was immediately noticed that the distribution of the location of these events correlated with the distribution of lightning. Subsequent work has shown most TGFs occur within milliseconds of lightning discharges observed with radio emissions, and geographically close to them (see e.g. Cummer et al., 2005; Inan and Lehtinen, 2005). An excellent recent review of TGF physics is that by Dwyer et al. (2012).

More recent observations with the Reuven–Ramaty Solar Spectral Imager (RHESSI) satellite have discovered many more TGFs, finding gamma rays with energies of up to 20 MeV (Smith et al., 2005). An interesting finding has been that TGFs do not appear to occur in conjunction with sprites. Whereas both phenomena result from the avalanche acceleration of electrons in the strong electric field above a thunderstorm, it seems (Williams et al., 2006) that sprites occur over positive ground flashes with exceptionally high charge moments (>500 C-km) whereas the mean charge moment associated with the RHESSI TGFs is only ~ 50 C-km. It has been therefore suggested (Williams et al., 2006) that intracloud flashes are the most likely scenario for TGF generation. Since Venusian lightning is likely intracloud lightning it seems at least possible that a similar process could occur there.

An important observation by Williams et al. (2006) is that TGFs are much more strongly concentrated over low latitudes than is lightning itself. The interpretation here is that the cause is the tropopause height (correlating with the typical cloud-top height), which is higher over the equator than midlatitudes. Thus assuming TGFs are generated in all storms, those at midlatitudes have to penetrate a larger column mass of air to reach space where they can be observed by orbiting gamma ray instruments. Absorption by air is therefore more severe at midlatitudes, and thus the observed flux is smaller. If Venusian lightning similarly generates gamma rays, their detectability may depend substantially on the altitude at which the discharge occurs. There is debate in the literature as to the details of the TGF mechanism and production altitude (perhaps around 10–15 km altitude), and the extent to which the gamma ray beam is collimated (e.g. Østgaard et al., 2008); recent work by Smith et al. (2010) suggests cloud top altitude is the major, but not only, factor in controlling the visibility of gamma ray flashes—the vast majority of flashes observed correspond to cloud top pressures of 100 mbar or less.

In exploring the possibility runaway discharge from lightning on other worlds, Roussel-Dupré et al. (2008) note that the threshold electric field for runaway breakdown is ~ 1.5 times larger on Venus than Earth, while the bremsstrahlung spectrum on Venus will be harder for the same electric field and atmospheric density. Since the circumstances of TGF generation are not completely understood on Earth, it is difficult to transpose the phenomenon directly to Venus. However, there seems little reason to think the process should be fundamentally different.

3. Data recovery and analysis

Two datasets were required for this analysis. First is the principal gamma ray dataset itself, “OGBD-15 min Averages of Detector Count Rates” (NSSDC ID: SOGA-00007, formerly 78-051A-05D—the highest time-resolution dataset available). This dataset was held as VAX 11/780 magnetic tape (originally recorded at 1600 bit per inch, and submitted to NSSDC in 1991) at the National Space Science Data Center and was transmitted to us as an ASCII file on request.

The dataset spans 1978-06-11 to 1989-03-13 and consists of 15 min-averaged data from the Pioneer Venus Orbiter Gamma-Ray Burst Detector. The first two entries in each record consist of the date and UT in seconds at the beginning of the data sample. The third entry is the averaged count rate for the entire energy interval, 100–2000 keV. The 4th entry is simply the sum of the 5th through 8th entries, which are the count rates in the energy intervals (in keV) 100–200, 200–500, 500–1000, and 1000–2000, respectively. The 4th entry is not necessarily the same as the 3rd, because photons occasionally were counted twice, if their energy was near the borderline between two energy intervals. The 3rd through 8th entries all refer to “guarded” count rates; i.e., those which have been adjusted by deleting counts which were also detected by the charged particle scintillation shell. The 9th entry contains the unguarded count rate for counts with energy above 100 keV. The 10th entry contains the count rate for the “trigger reference,” used as a baseline for the gamma-ray burst logics. Note that the record is not complete, there being some dozens of orbits during which no data from the orbiter was obtained due to conjunctions.

For searching for astrophysical sources, ‘Venus’ is an adequate descriptor of the spacecraft’s location. However, for our search for correlations between gamma ray emissions and Venus locations, we need the trajectory relative to the planet (we are likely the first investigators ever to have used this data together with the OGBD data). Thus the second dataset required is the spacecraft ephemeris. The Pioneer Venus predates the widespread use of SPICE kernels as a format for spacecraft trajectory data. Trajectory information for PV is held (at the Plasma Interactions Node of the Planetary Data System—at UCLA) as a series (PVO-V-POS-5–VSOCOORDS-12SEC-V1.0) of about 4000 files, each containing about 1 day of ASCII trajectory data at 12s intervals. The files contain time (Seconds since 1966-01-01T00:00:00) – allowing cross-reference with the OGBD data – as well as altitude and planetocentric latitude and longitude. The elliptical orbit, 150 × 66,000 km, yielded a very wide range of altitudes.

The ephemeris files were sampled to provide coordinates corresponding to the OGBD times, and the resultant listing, together with the raw OGBD data obtained from NSSDC, is included as supplemental information to this paper, and is also available at http://www.lpl.arizona.edu/~rlorenz/pvgamma/.

Terrestrial gamma ray flashes (TGFs) emerge as a cone of radiation (collimated by the direction of the relativistic electrons accelerated after the lightning stroke, and by the absorption of the atmosphere—see later). Very crudely, Kepler’s third law specifies that the angle swept by an orbiting body is inversely proportional to its distance. Thus if radiation is emerging continuously in a cone above a point on Venus, the spacecraft spends an amount of time exposed to that radiation that is inversely proportional to distance. However, if that radiation corresponds to a constant number of photons, the photons are spread over an area that is proportional to the square of distance. Combining these two effects yields the result a fixed-area detector would see a rate that is inversely proportional to distance, which would serve as a ‘signal’ that a component of the detector signal is sourced at Venus.

It has been speculated that lightning on Venus could be associated with specific geographical locations on Venus. Such a correlation might emerge because convection leading to lightning can be triggered by surface topography (i.e. orographic effects. Another possible effect is the association of lightning with volcanic plumes, which would similarly be fixed in planetocentric location

A simple evaluation of the correlation between altitude and flux appears, however, to be confounded by the highly non-uniform character of the background. While some transient spikes in gamma ray flux were expected due to the bursts for which the instrument was designed, it is clear (Fig. 1) that there is a large-scale variation over the 12-year observation period, as well as short-term dips (likely Forbush decreases—e.g. Cane, 2000).