Space Vehicle Glow Measurements on STS 41-D

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A flight experiment using a hand-held image-intensified spectrographic camera was performed on mission 41-D. The instrument enabled the photographic documentation of the position of the spectral slit on the image. Because of this feature, the spectrum of the glow on the shuttle tail pod could be clearly separated from the spectrum of the scattered light reflected from the orbiter. From the measurements, it is clear that the spectrum of the glow is a continuum in the passband of the instrument between 4200 Å and 8000 Å. The scattered light reflected from the orbiter surfaces distinctly show the components of the Earth's airglow at 5577 Å and 7620 Å. Results from samples representative of the material overcoatings used on the Space Telescope show that polyethylene produces a very weak glow while most black overcoating materials produce significant glow. MgF_2 was also found to produce a relatively intense glow. Materials which are unstable in the low earth orbit environment, such as polyethelene and kapton, were found to be weak glow producers; stable materials, such as MgF_2, produced more intense glow. From this, we can deduce that glow production is not associated with the stability of the bulk material and is most likely a surface catalytic phenomenon.

Introduction

A GLOW which is associated with a ram effect has been reported on Atmospheric Explorer (AE-E),[1,2] Dynamic Explorer-B (DE-B),[3] and Space Shuttle spacecraft.[4-9] The Space Shuttle observations have also reported glows associated with thruster firings.

The physical process leading to the glow phenomenon is not well understood at present. Programs such as Space Telescope, Infrared Telescope and other optical facilities can be planned and optimized around ram glow phenomena given an understanding of the physical process. These planning considerations can include operational restraints with respect to telescope ram during observations, orbit altitude, instrument baffle materials and coatings, and surface conditioning of the orbiter (for shuttle payloads).

The AE-E satellite was equipped with a visual airglow experiment (VAE) which observed atomic and molecular features in the earth's airglow layer. Backgrounds in the photometer filter channels were found to have a variability with ram angle. This data was reported by Yee and Abreu and displayed a detectable level of luminosity in the near-UV channels of the instrument (3371 Å), with increasing luminosity towards the red wavelengths (7320 Å).[2,10] When plotted, the background in all filter channels described a bright ram source, increasing in brightness toward the red wavelengths. The analysis presented suggested the glow extended well away from the spacecraft, implying that the emitter is metastable. OH Meinel bands were reported as being a likely candidate species for emission since the general red character and emission lifetime seemed to fit the evidence. The Yee and Abreu[2] analysis had found a strong correlation between the ram emission intensity and altitude. The emission intensity closely followed the atomic oxygen scale height above 160 km altitude. Atomic oxygen then is the probable aeronomical constituent to be a chemical reagent for whatever process is occurring. Slanger[11] was among the first to report the OH hypothesis.

The DE-B spacecraft was equipped with a high resolution Fabry-Perot interferometer (FPI).[12] In this instrument, a 7320 Å filter was utilized in series with the Fabry-Perot etalon. Abreu reported on the background with ram effect associated with this channel.[3] A ram glow was reported and the deduced etalon spectrum showed similarity with the OH spectrum observed in nightglow from the atmospheric limb. The available evidence from these two spacecraft seems to favor the OH hypothesis for the observed glows.

Glow observations have been reported by a number of investigators from shuttle missions STS 3, 5, 8 and 9. Banks et al.[4] reported glow from orbiter television and still camera pictures around aft spacecraft surfaces, while documenting glows associated with an electron accelerator experiment on STS 3. Mende et al. have documented ram glows associated with STS 5, 8, and 9 using an intensified camera.[5-8] On the later missions, STS-8 and -9, objective grating imagery of spacecraft glow from the vertical stabilizer depicted a red spectrally structureless glow.[8] The spectral resolution was on the order of 150 Å. On the STS-8 mission it was observed that glows from surface samples including aluminum, kapton, and Z306 (a polyurethane black paint typically used in low light level detection instrument baffles) were not equally bright. The surface characteristic and/or the material constitution clearly was shown to affect the glow brightness.

High resolution spectral measurements of the Imaging Spectrometer Observatory (ISO) spectrometer on Spacelab 1 show the presence of N_2 1PG bands.[13] There are also a number of other observed emission features which may be part of the natural aurora airglow background environment and, therefore, the precise determination of the source of the emission could be difficult.

Green recently reviewed the ram glow data and theory for the Shuttle environment.[14] The review described the two

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classes of mechanisms: one being molecular emission from surface collisions and another due to the plasma critical velocity effect. In his discussions, vibrationally excited CO, OH or electronically excited N_2 were postulated as the most likely candidates and were chemically plausible with the evidence at hand.

There is a proposed plasma process for glow production[15] which involves a two-stream instability between incoming ram and reflected ions. The ion instability sets up an electrostatic wave which heats the ambient electrons. The energetic electrons can in turn excite in situ and ramming constituents. Pumping the electrons to 20+ eV will allow electron impact excitation of many molecular and ionic transitions. The energy is sufficient to excite N_2 to 2nd positive, and possible ionize to 1st negative. A lot of UV emissions could arise with this process whereas the chemical processes postulated are energetically limited to be red and infrared emitters. N_2^+ 1st negative (1,0) at 3914 Å and N_2 2nd positive band at 3371 Å are spectral features expected for this physical process.

In view of the current state of knowledge, it was essential to obtain spectral data with improved spectral resolution and with simultaneous documentation of the spatial extent of the glow source region. In addition, it was thought desirable to obtain more engineering data on the glow associated with materials which are potentially useful in the construction of the Space Telescope. Such a glow experiment was scheduled for mission 41-D.

Description of the Instrument

For mission 41-D a special glow spectrometer was constructed. The instrument has three operating modes. The three modes are schematically illustrated on Fig. 1. The top illustration shows the instrument with the grating and slit out of the optical path. In this mode, the intensifier camera works in a straight through imaging mode with an image being formed near the targeting slit by the objective lens. It is then collimated by the collimating lens and refocused on the image intensifier photo-cathode by the camera objective lens. The image intensifier has a light amplification gain of 50,000. The output phosphor of the image intensifier tube is re-imaged on the film or in the viewfinder of the 35 mm single lens reflex camera attached to the system. The observer looking through the viewfinder will see the targeting slit superimposed on the image. In this mode, the astronaut is able to aim the instrument appropriately for the analysis of different features of the image.

The second mode shows the spectrometer with the grating in the optical path. In this mode, the grating produces an objective spectrum. In addition to the image which was produced in the previous mode, another image, the first order image, also appears. The distance between the two images is proportional to the wavelength of the light forming the image. This type of slitless objective grating was used for previous glow investigations by Mende et al.[5-8]

The third mode represents the higher solution spectrographic mode. In this mode, the slit covers are also placed into the optical train. They cover up the image except the narrow slit formed by two parallel bars of the targeting slit. In this mode, the system is equivalent to a transmission grating spectrometer with grating rulings NL of 300 lines per mm. Three identical lenses were used. All three were F/1.4, f = 50 mm. The slit width W was .0508 mm.

The theoretical resolution d of the spectrometer with a 300 line/mm grating can be estimated as $d\lambda = 1/N_L * \sin(w/f) = 34$ Å.

The complete system is illustrated on Fig. 2 which is a photograph of the system assembled with a 35 mm photographic camera.

Flight Operation

The experiment was originally scheduled on flight STS-41-D. On this mission, the orbiter was to fly a dual altitude mission with the last altitude a relatively low 120 nm. From previous observations, it is known that at this altitude very intense glow could be observed. Because of the problems associated with the orbiter Discovery, the 41-D flight in June was cancelled and a combined mission was scheduled in early September 1984. On the new mission, the low altitude portion for the flight was deleted. The experiment hardware, however, was stowed on the orbiter and the crew was trained in the operation of the flight instrument. On the day just prior to landing, the experiment was performed by a mission specialist as a "shopping list" addition to the flight activities. Due to the high altitude of the orbiter, the signal-to-noise ratio of the glow was much lower than expected. For the experiment, the orbiter was flown in an attitude with the velocity vector directed into the payload bay, thus producing maximum glow on the engine pods and the material samples on the remote manipulator arm.

The crew procedures required the taking of a series of exposures of each subject with the slit covers and grating out of

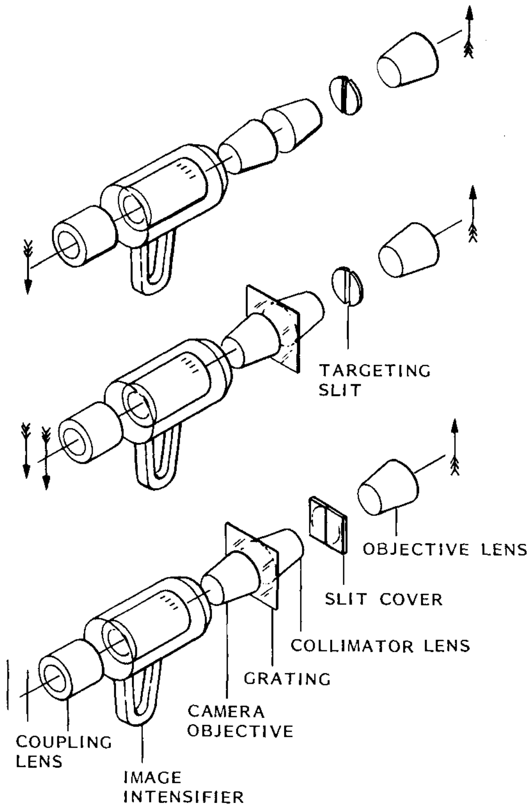

Fig. 1 Image intensified slit spectrograph for shuttle glow observations. Top: straight-through imaging configuration; middle: objective grating configuration; bottom: spectrometer configuration.

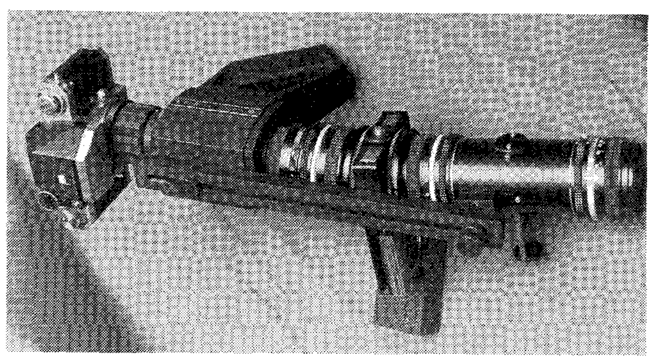

Fig. 2 Image intensifier slit spectrograph instrument.

the optical train. Following that, spectral photographs were taken with grating only, which was followed by photographs with slit covers and grating both in the optical train. To complete each series, another set of photos were taken with slit cover and grating out of the field of view to establish that no movement of the instrument occurred during the spectral photography.

The above sequence was followed by repositioning the camera to a new object. Three sequences were photographed according to the above procedure. The first and second subjects were the glow at two different distances above the samples on the arm. In taking these sequences, the crew man lined up the spectrographic slit parallel to the arm at a certain distance from the arm. The final sequence of photos depicted the bright glow of the shuttle tail and engine pod and its spectrum.

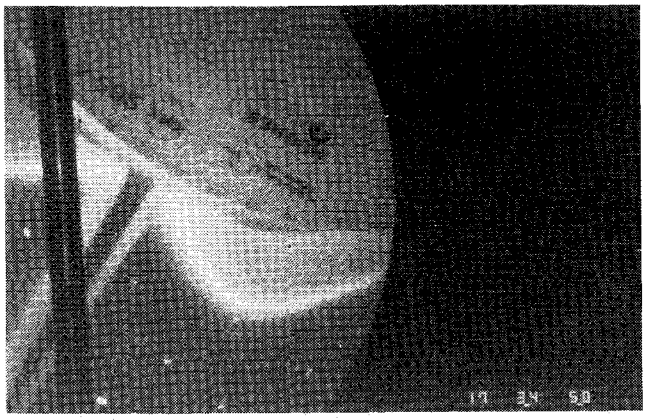

Fig. 3a Straight through imaging looking at the shuttle tail, port engine pod and bulkhead.

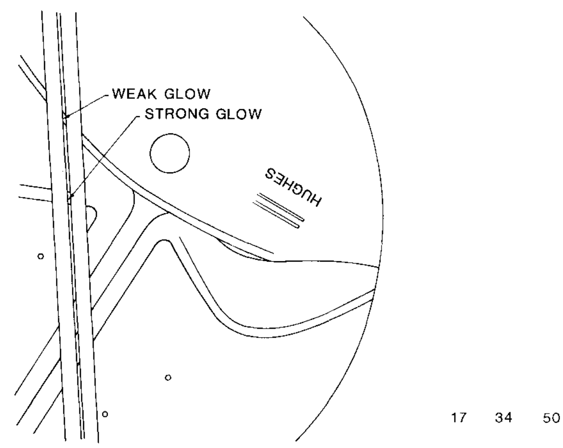

Fig. 3b Schematic drawing of photograph in Fig. 3a.

Spectrum of the Glow on the Shuttle Engine Pod Surfaces

The reference photographic image of the shuttle tail and engine pods is shown on Fig. 3a taken on September 4, 1984 at 17:34:50. Figure 3b is a schematic illustration of the photograph of Fig. 3a. In this image, the spectral slit was superimposed on the tail section, the engine pod and a bulkhead in the payload bay. The slit crosses some other areas on the orbiter skin which are also somewhat luminous.

The corresponding spectrum taken with the grating and slit in the optical train is shown on Fig. 4 (17:36:01). From the comparison of Figs. 3 and 4, the spectrum of the glow and the orbiter surfaces may be identified. Starting from the top of the photograph, the top region is the spectrum of the bulkhead. This shows two distinct lines. From the preflight calibration of the wavelength dispersion, these lines are clearly identified as atomic O at 5577 Å and the O_2 (O,O) band at 7620 Å. It may be seen that while 5577 is a narrow spectral line showing up as a thin line, the O_2 (O,O) band is quite wide, representing the larger wavelength extent of the O_2(O,O) band. This demonstrates that the observed luminosity on the orbiter is mainly due to scattering of the Earth's airglow.

The slit crosses two glow regions, one at the top of the bulkhead (near the top of the photograph), and a second brighter region above the engine pod. Corresponding to the image there is a large diffuse glow spectrum. From a cursory inspection of this spectrum in Fig. 4, it is evident that the glow is an uninterrupted continuum within the resolving power of the spectrograph.

The relatively noisy appearance of the trace is caused by the high quantum noise of the image intensifier camera system. A solid line was drawn to represent the best estimate smooth spectrum. Microdensitometer tracings of this glow were obtained (Fig. 5). This smooth spectrum was then corrected for device responsivity (dashed line Fig. 5) The responsitivity was determined from preflight calibration data obtained from a light source of known emissivity as a function of wavelength.

Discussion of Spectra

The measured spectrum of the spacecrft glow on STS-41 D shown in Fig. 5 portrays the same features as those reported on STS-8[8]. A peak is obtained around 7100 Å with a gradual fall off towards both the short and longer wavelengths. The approach of using the spectral slit eliminates the contamination of earlier results from scattered airglow and leaves no doubt about the absence of any distinct spectral features in the spectrum of the spacecraft glow.

In a recent report of Torr and Torr,[16] a high-resolution spectrum of the glow taken by the Spacelab 1 ISO instrument was published. The ISO spectrum was taken when the sunlight conditions on the orbiter and surrounding atmosphere were not ideal for these low light level observations. The instrument was looking directly into the ram. Many features of this spectrum were attributable to natural airglow and vehicle glow in front of and within the instrument. Since the resolution of the ISO instrument is 6 Å, it would be necessary to convolute the ISO spectrum with a 35-Å slit width prior to comparison with our data. It is evident that even if such convolutions were performed, the two spectra would be significantly different. Aside from the difficulties caused by the possible dayglow contamination in the ISO spectrum, the difference can be explained by the fact that the ISO measurement would give a total column-integrated intensities in a direction perpendicular to the spacecraft skin. The intensity of any glow feature in the ISO spectrum would be independent of the scale length associated with the emitting feature. Our measurements, however, favor the short scale length components which appear brightly near the ram surface of the vehicle. It is also possible that the short scale length ram glow component is very faint when viewed perpendicularly to the ram surface and its intensity is comparable to the natural background.

Glow Intensity and Material Samples

Another purpose of the 41-D experiment was the comparison of the glow intensity above different material samples mounted on the arm. As we have explained previously, the high altitude of the flight greatly diminished the signal-to-noise ratio obtained and therefore handicapped this part of the experiment.

The photograph of the arm with the samples is shown in Fig. 6a. Figure 6b is a schematic sketch of the photograph of Fig. 6a. The camera was aimed so that the slit was perfectly parallel with the arm. Due to the weakness of the image, the glow within the slit could not be analyzed. To obtain the best

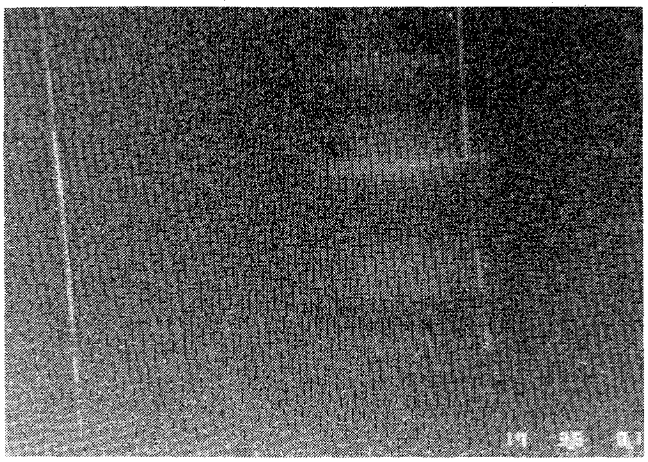

Fig. 4 Same image as Fig. 3 except that grating and slit has been included.

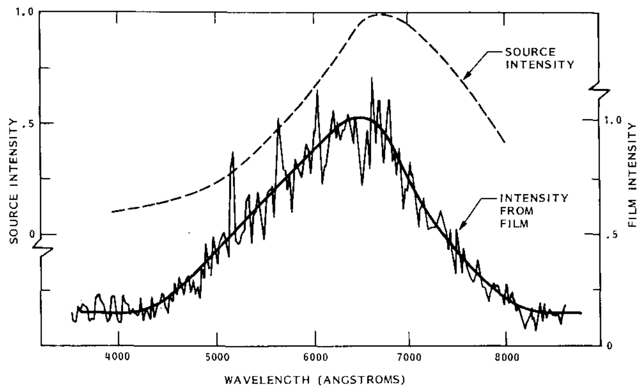

Fig. 5 Uncorrected microdensitometer tracing of dispersed spacecraft glow on engine pod (bottom curve). Solid line represents smoothed spectrum with image intensifier noise removed. The smoothed spectrum for corrected spectral responsivity of the instrument (top curve.).

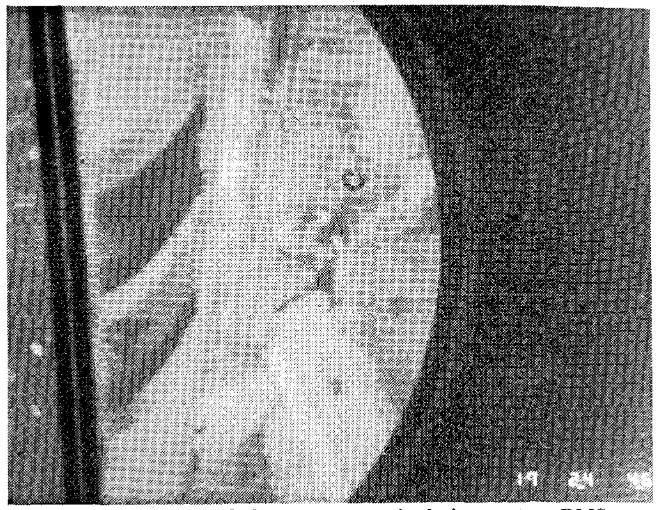

Fig. 6a The image of the remote manipulating system RMS arm through the image intensified slit spectrograph in the imaging mode.

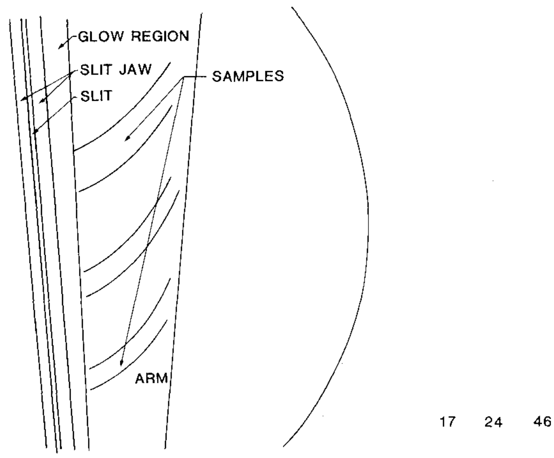

Fig. 6b Schematic illustration of photograph in Fig. 6a.

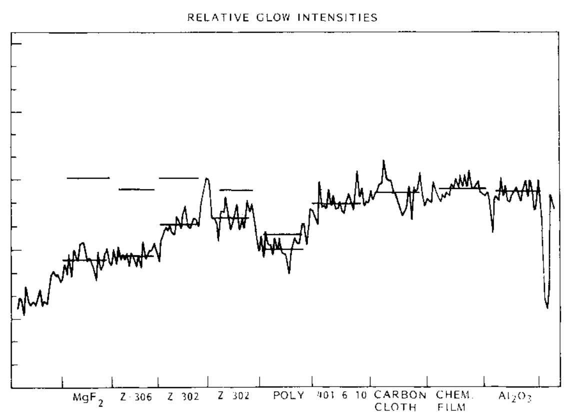

Fig. 7 The densitometer tracing of the glow region just above the arm.

data we used the "flow region" between the slit and the arm. Since the glow was very faint, the comparison proved to be very difficult.

Perhaps, the clearest visible evidence that there is a difference between the glow intensities is seen by looking at the glow above the lightest surface brightness sample (sample no. 5). The glow above this sample is perceptible fainter than the glow above any of the other samples.

Microdensitometer tracings parallel with the arm were obtained. The first tracing, shown in Fig. 7, included the region of the glow which is between the black bar of the targeting slit and the arm. Another densitometer tracing was taken of the night sky just above the slits. This night sky tracing was used as a basis for correction because of a nonuniform response in the system.

Figure 7 shows the uncorrected microdensitometer tracings, the position identification of each material sample, and a horizontal bar representing averaged glow intensity above the sample. The intensity above the sample was corrected for the apparent nonuniformity derived from the night sky trace. The correction resulted in an increase of the glow intensities above the material samples on the left side of the image. The corrected values were represented by the upper horizontal bars. It is interesting to note our corrections are consistent with visual observation of the flight crew. During the performance of the experiment the crew reported that the samples furthest away on the left of Fig. 7 were glowing the most intensely. Examination of the uncorrected photographic data, e.g. Fig. 6a, appears to show the opposite of this.

The analysis presented above was also performed using another similar image which was taken four minutes later and, therefore, contained a different star field background. Based on the data obtained from the image of Fig. 6 and another image, the materials samples were ranked from 1 to 9 in order of their glow-producing properties, from minimum to maximum respectively (Table 1).

A value of 1 was assigned to polyethylene and 9 to their apparently brightest glowing Z302 overcoated with Si. However, the marginality of the signal-to-noise ratio makes it difficult to draw strong conclusions.

Table 1 The material samples and the glow intensity

Material	Ranking
MgF_2	8
Z306	6
Z302	9
Overcoated with Si	
Z302	7
Polyethylene	1
401-C10	2
Carbon cloth	4
Chemical conversion film	5
Anodized Al	3

Conclusion

It has been well established that the spacecraft glow is generated by emission from metastable molecules which has been excited on the surface of the spacecraft. There are several possibilities with regard to the source of the metastable molecules. These molecules could be resistent on the surface as contaminants. In this case, however, one would expect the glow intensity to be greatly variable, depending on the length of the on orbit exposure or the temperature of the surface. No such evidence has been reported so far. One would also expect adjacent surface samples to be contaminated equally; therefore, no surface material specific glow intensity would be expected. Another source of the molecules could be the bulk surface material. This contradicts the evidence discussed by Mende et al.[8] where it was reported that on STS-8 the intensity of the glow in front of the kapton sample was much less than in front of the chemglaze sample and the depletion rate of kapton was much higher than that of the chemglaze. We can draw similar conclusions from the present experiment. For example, the chemically stable MgF_2 sample exhibits intense glow characteristics. Polyethylene seems to produce the least glow. All these results point to the fact that in the glow production the surface accommodation property of the sample, and not the chemical stability of the bulk material, is important. Thus we may propose that the surface acts as a catalyst, and that the source of the metastable molecules producing the glow must be the environment itself.

Acknowledgments

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