Detecting lightning signatures on extrasolar planets and brown dwarfs

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The study of lightning activity on extrasolar bodies is a new field in extrasolar sciences. In 2010 the LEAP Group (www.leap-2010.eu) was founded with one of its goals being to study the physics of lightning and the impact on its environment mainly on exoplanets and brown dwarfs (BDs). One of the topics our group is working on is collecting and analysing the potential observable signatures of lightning discharges coming from cool, extrasolar bodies. The main purpose of this PhD project is to investigate potentially observable lightning signatures depending on the specifics of the extrasolar object of interest. The signatures investigated so far are in the radio band although, because of the nature of lightning a great variety of other wavelength signatures can be studied in the future.

1. Introduction

Electrostatic discharges of planetary atmospheres have been observed in the Solar System, most notably on Earth. With the latest announcement of the Kepler Team, the number of confirmed exoplanets has almost reached the 2000 [1][2]. This enormous number of planets leads to the possibility of investigating their atmospheres and comparing the results with Solar System bodies'.

However, lightning can appear not only on planets but on brown dwarfs (BDs) as well. BDs are a few ten times more massive objects than Jupiter. They are suggested to link the planetary and stellar regime. The most common theory about their formation says that BDs form like stars but they didn't have the optimal conditions to fuse Hydrogen in their core. The characterization of BD atmospheres, based on observations and theoretical work, has made considerable progress [3][4].

We may argue that both exoplanets and BDs host optimal conditions for lightning to initiate and indications for lightning may have already been detected in such atmospheres [3]. Both X-ray and radio emission was detected from BDs, which could be seen as first indication for lightning activity in the atmosphere of these objects. Exoplanets and BDs are suitable for investigating which ionization processes occur in cool atmospheres [5][6][7], what role dust particles play for the electrification of such atmospheres [8][9], and last but not least, what are the observable signatures that are the result of lightning discharges originated in them [3].

We summarize different signatures that can be the result of lightning activity on Earth and Solar System bodies and argue if they could be observed on extrasolar bodies. Space instruments will be introduced which can potentially observe extrasolar lightning signatures.

2. Examples of lightning signatures

Lightning related signatures can be found in the whole spectral range from radio to gamma-rays. Lightning activity is known mainly from Earth, but it was also detected on other Solar System planets like Jupiter [10], Saturn [11] or Uranus [12].

2.1. Radio frequencies

Lightning induced radio signatures have three main types. Sferics emit in the low-frequency (LF) range with a power density peak at 10 kHz on Earth [13]. Whistlers are electromagnetic waves propagating along magnetic field lines and emitting in the very low-frequency (VLF) range [14]. While Schumann-resonances are VLF lightning discharge-induced electromagnetic oscillations of the earth-ionosphere cavity [15].

Due to the low cutoff frequency of Earth's ionosphere and other limiting factors, radio signatures with frequency below 10 MHz might only be observable from space and waves below 30 kHz would not reach the inner Solar System [16].

2.2. Effects on the local chemistry

Depending on the original composition of the atmosphere, the temporary increase, decrease or appearance of certain key molecules could be observed in the spectrum of the planet if lightning occurs. Such examples on Earth are nitrogen-oxyds, like NO or NO_2 which are usually denoted as NO_x.

Nitric acid, a result of NO_2 precipitation, is an important source of nitrogen for living creatures. Especially on early Earth lightning played a main role in producing such acids [17]. Laboratory experiments showed that HCN and C_2H_2 may occur on Jupiter [14] and on Titan [18] as a result of lightning discharges. While lightning was observed on the first body, it is yet to be found in the latter one's atmosphere.

2.3. Emission from lightning related phenomena

Terrestrial Luminous Events (TLEs) are widely varying emissions (sprites, elves, halos, blue jets etc.), which occur in the upper terrestrial atmosphere above thunderstorms [19]. They have typical emissions in the blue and red range of the spectrum. The emission of these events also depends on the chemical composition of the atmosphere. This is the reason why mainly nitrogen-based signatures, such as the first and the second positive band systems of N_2, are found in the spectra of Earth's sprites. [20]

3. Volcano lightning

Besides atmospheric electrical discharge processes, lightning occurs in volcano plums as well. These spectacular phenomena usually appear during (or following) an explosive eruption [21]. The conditions inside the volcano plume are remarkably similar to the dusty atmospheres of the investigated extrasolar bodies (exoplanets and BDs). The knowledge from such eruptions helps us as useful analogon for our extrasolar studies.

4. Conclusions

Lightning produces a wide range of signatures through the whole spectral range. Apart from the obvious detection on Earth, lightning was detected on the giant planets and was also discussed as a possible phenomenon on Mars, Venus and Titan.

In Bailey et al. (2014), we summarize instruments that are in operation for astrophysical observations and would potentially be able to detect lightning signatures based on their wavelength ranges [3]. Some of these instruments, especially in the radio band, would probably be able to detect extrasolar lightning signatures, while others might not reach the optimal signal-to-noise ratio. This question requires further investigations.

Future space missions (e.g. JWST) would possibly be able to detect lightning signatures on exoplanets and BDs. Missions like TARANIS [22] will give an exceptional tool to characterize TLEs from outside Earth's atmosphere, which would lead to a comparable data that exoplanetary scientists could use to detect such events from outside the Solar System.

6. Acknowledgement

We highlight the financial support of the European Community under the FP7 by an ERC starting grant.

5. References

[1] Rowe, J. F., Bryson, T. S., Marcy, G. W. et al. 2014, ApJ, 784, 45R

[2] Lissauer, J. J., Marcy, G. W., Bryson, S. T. et al. 2014, ApJ, 784, 44L

[3] Bailey, R., Helling, Ch., Hodosán, G. et al. 2014, ApJ, 784, 43B

[4] Crossfield, I. J. M., Biller, B., Schlieder, J. E. et al. 2014, Nature, 505, 654

[5] Helling, Ch., Jardine, M. & Mokler, F. 2011, ApJ, 737, 38H

[6] Rimmer, P. B. & Helling, Ch. 2013, ApJ, 774, 108R

[7] Stark, C. R., Helling, Ch., Diver, D. A. & Rimmer, P. B. 2013, ApJ, 776, 11S

[8] Helling, Ch., Jardine, M., Diver, D. & Witte, S. 2013, P&SS, 77, 152

[9] Helling, Ch., Jardine, M., Stark, C. & Diver, D. 2013, ApJ, 767, 136H

[10] Baines, K. H., Simon-Miller, A. A., Orton, G. S. et al. 2007, Science, 318, 226

[11] Fischer, G., Kurth, W. S., Gurnett, D. A. et al. 2011, Nature, 475, 75

[12] Zarka, P. & Pederson, B. M. 1986, Nature, 323, 605

[13] Aplin, K. L., '*Electrifying atmospheres*', Springer, 2013

[14] Desch, S. J., Borucki, W. J., Russell, C. T. & Bar-Nun, A. 2002, Rep. Prog. Phys. 65, 955

[15] Simões, F., Pfaff, R. F., Hamelin, M. et al. 2012, LPICo 1683, 1052

[16] Zarka, P., Bougeret, J.-L., Briand, C. et al. 2012, PSS 74, 156

[17] Lorenz, R. D. 2008, SSRv, 137, 295

[18] Kovács, T. & Turányi, T. 2010, Icarus, 207, 938

[19] Yair, Y., Fischer, G., Simões, F. et al. 2008, SSRv, 137, 29

[20] Pasko, V. P. 2007, PSST, 16, S13

[21] James, M. R., Wilson, L., Lane, J. S. et al. 2008, SSRv, 137, 399

[22] Lefeuvre, F., Blanc, E., Pinçon, J.-L. et al. 2008, SSRv, 137, 301