Lightning on exoplanets and brown dwarfs: modelling and detection of signatures

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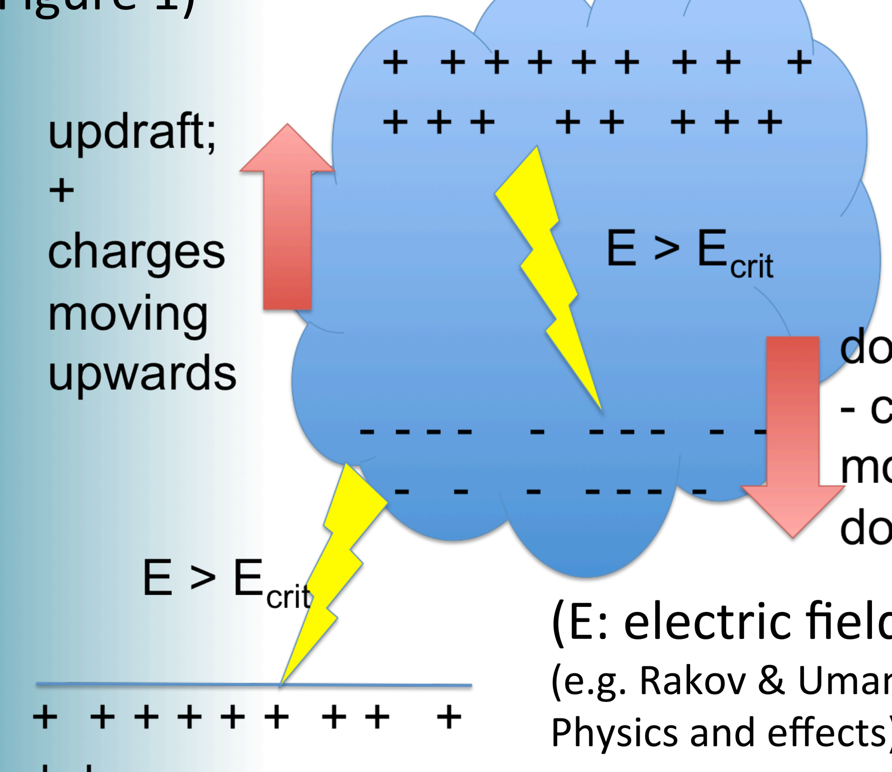
Context: Large-scale electrostatic discharges (i.e. lightning) have been observed in the Solar System. With the detection of hundreds of new substellar objects such as exoplanets and brown dwarfs (BDs) the number of potentially cloud-hosting atmospheres has increased dramatically.

Aim and Method: The aim of this study is to apply our knowledge of lightning properties and signatures, derived from Solar System lightning, to the potential discharge characteristics on extrasolar objects. We study the spatial and temporal distribution of lightning on Earth and Jupiter. We also model the radio signatures emitted by lightning discharges.

1. Introduction: Lightning formation

(Figure 1)

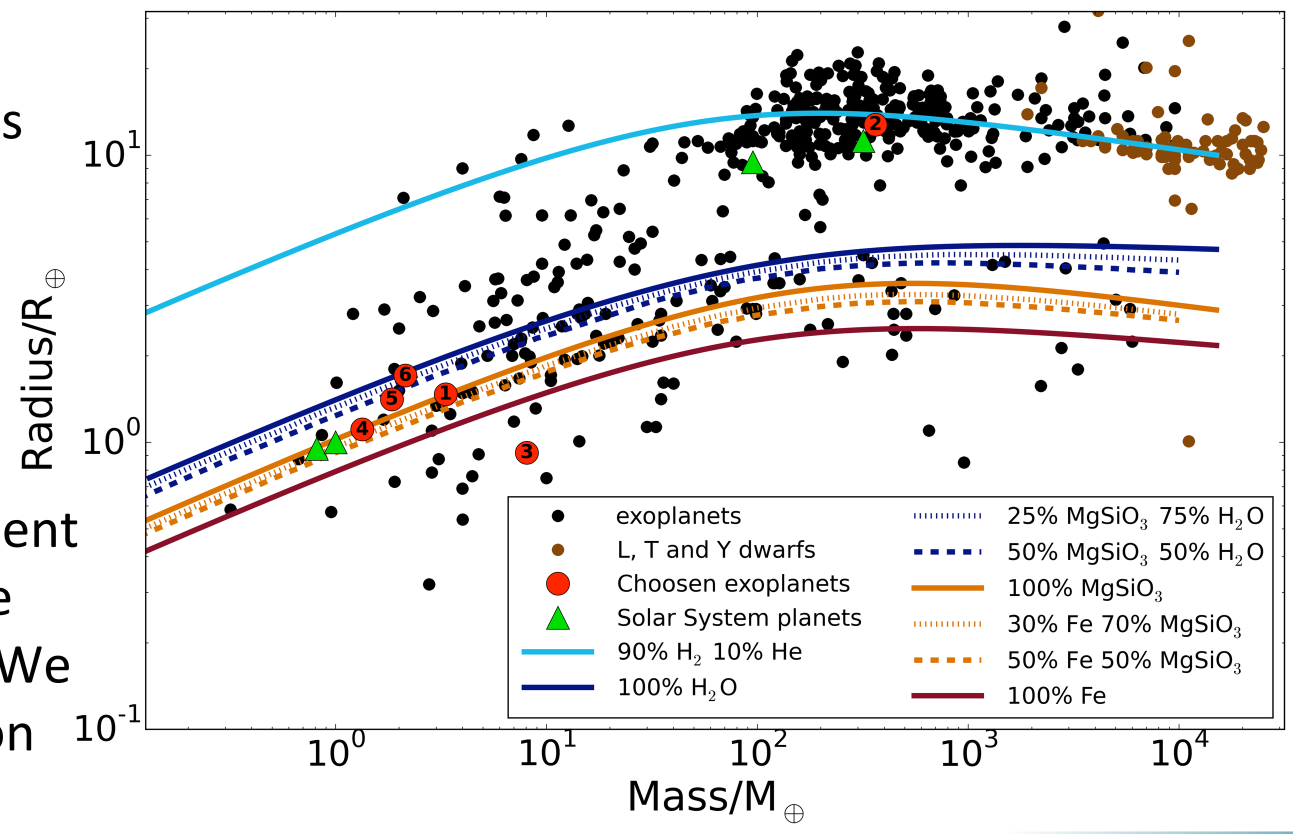


(E: electric field; E_{crit}: critical E)
(e.g. Rakov & Uman 2003, "Lightning: Physics and effects")

2. Targets of interest

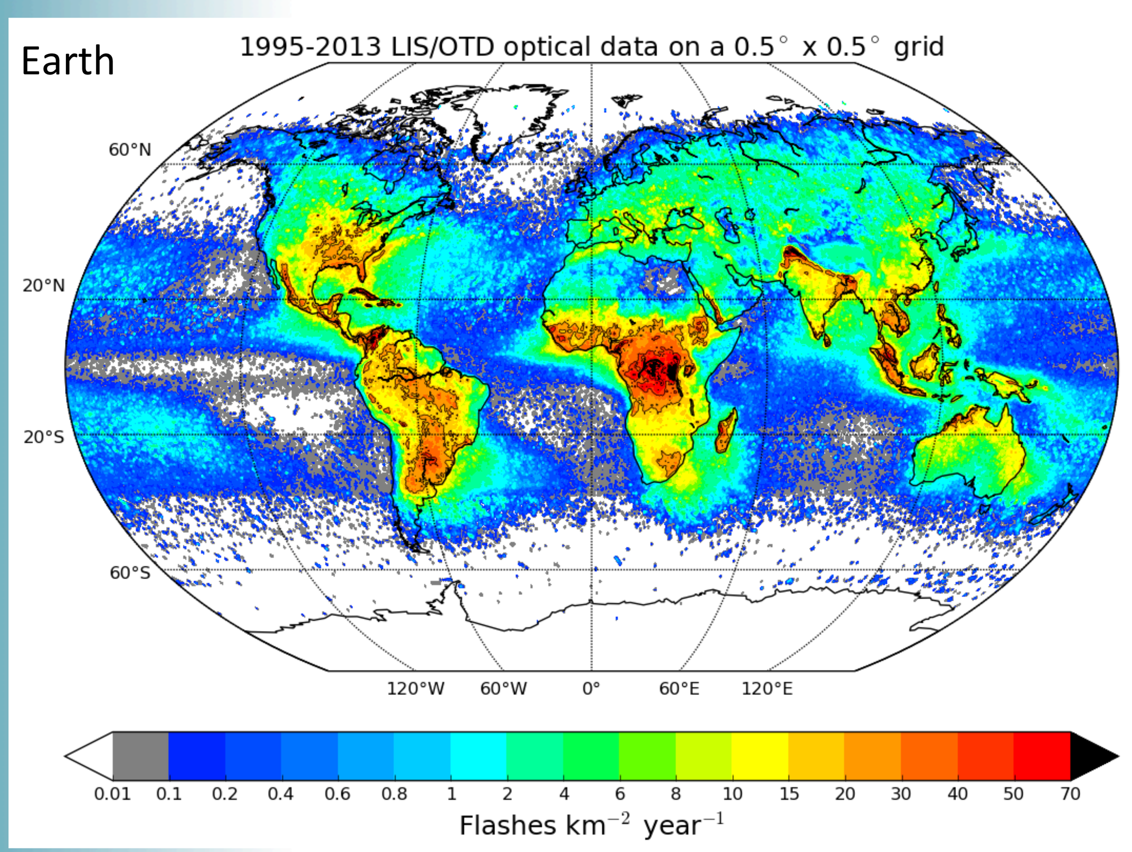
Figure 2: Mass-Radius plot of exoplanets (black donts) and brown dwarfs (brown dwarfs). The lines show mass-radius relationships for various bulk compositions.

Our targets for lightning-hunting represent various types of objects from Venus-like planets to Earth- and Jupiter-like ones. We apply knowledge of lightning distribution and properties known from the Solar System to these extrasolar objects.

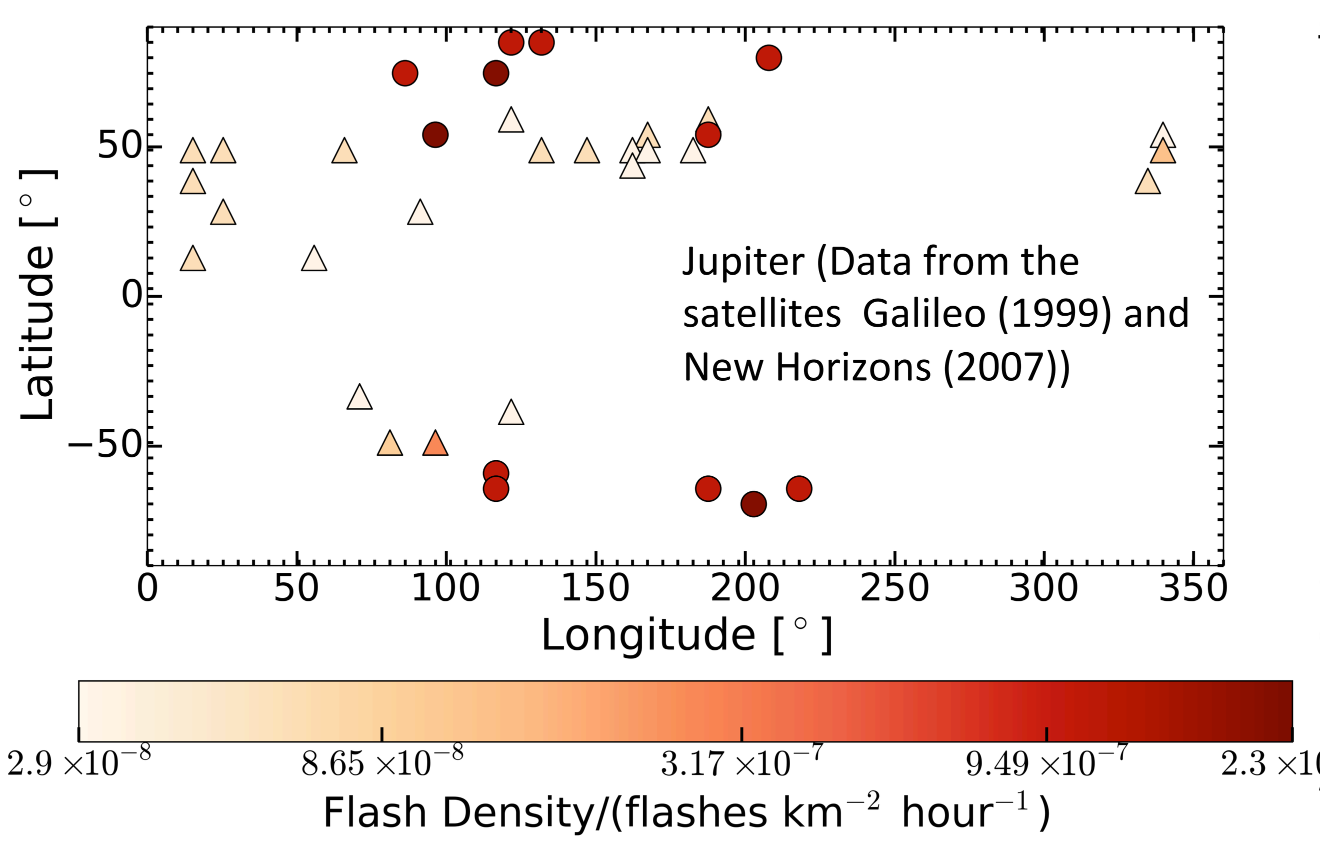


(Hodosán et al. 2016, MNRAS, 461, 3927)

3. Lightning climatology on Earth and Jupiter



(Hodosán et al. 2016, MNRAS, 461, 3927)



(Hodosán et al. 2016, MNRAS, 461, 3927)

Figure 3: Lightning distribution maps for Earth (left) and Jupiter (right)

Solar System flash densities (flashes km^{-2} h^{-1}) are applied to selected exoplanets.

How much lightning can we expect on a certain surface area during a certain time interval?
Q: How many flashes could occur on the planet HD189733b during its <2 h transit?
A: ~6 x 10^4 flashes, using Jovian flash densities
(Hodosán et al. 2016, MNRAS, 461, 3927)

4. Modelling lightning radio signatures

Model:

① Current channel

$$i(t) = i_0(e^{-\alpha t} - e^{-\beta t})$$
$$\mathbf{v}(t) = \mathbf{v}_0 e^{-\gamma t}$$

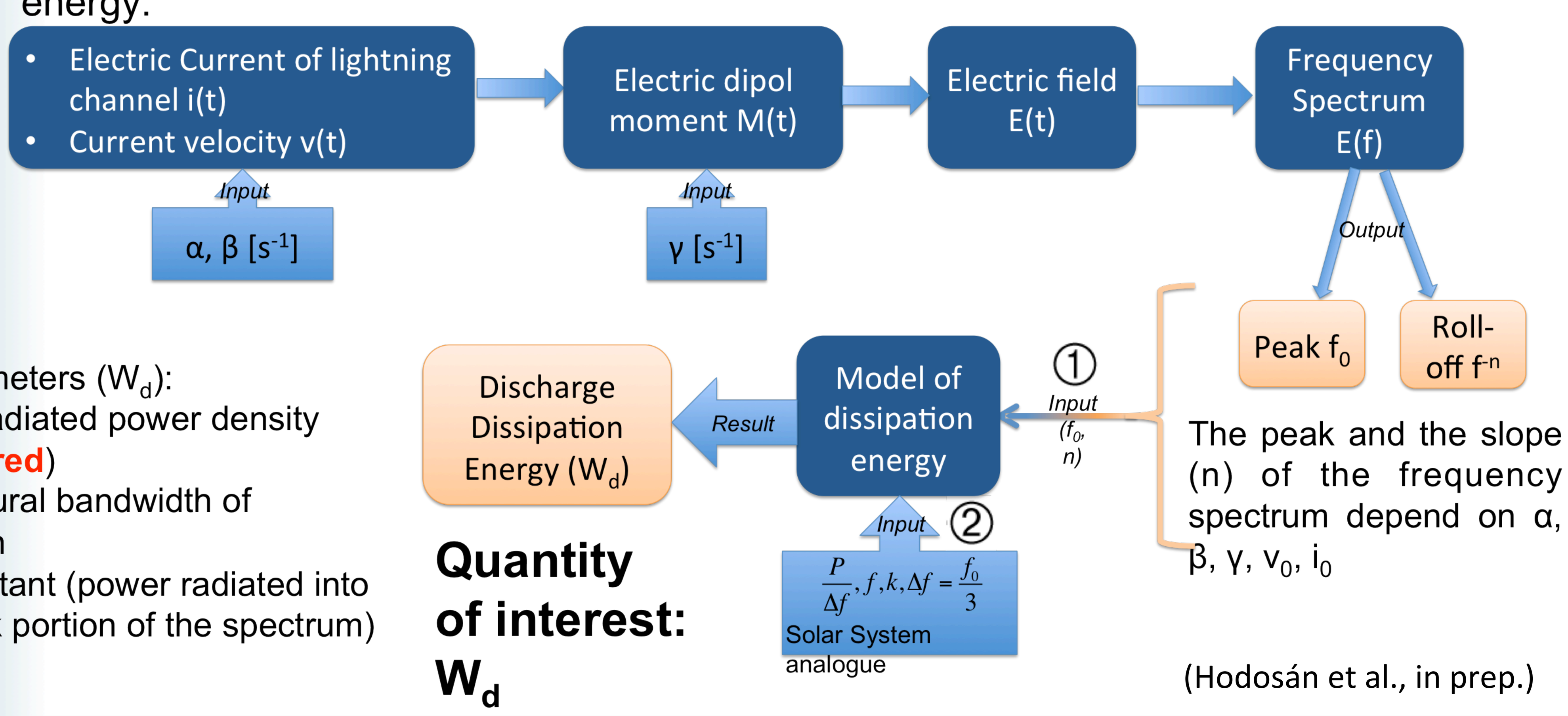
(dipole radiation)

Input parameters (Frequency spectrum model):
- α, β, γ – frequency-type constants (**related to exoplanetary properties**)
- i_0 – current peak

② Discharge dissipation energy:

$$W_d = \frac{P}{\Delta f}\left(\frac{f}{f_0}\right)^n \Delta f \frac{1}{k 2\pi f_0}$$

Method:



The peak and the slope (n) of the frequency spectrum depend on α, β, γ, v_0, i_0

Input parameters (W_d):
- P/Δf – radiated power density (**measured**)
- Δf – natural bandwidth of emission
- k – constant (power radiated into the peak portion of the spectrum)

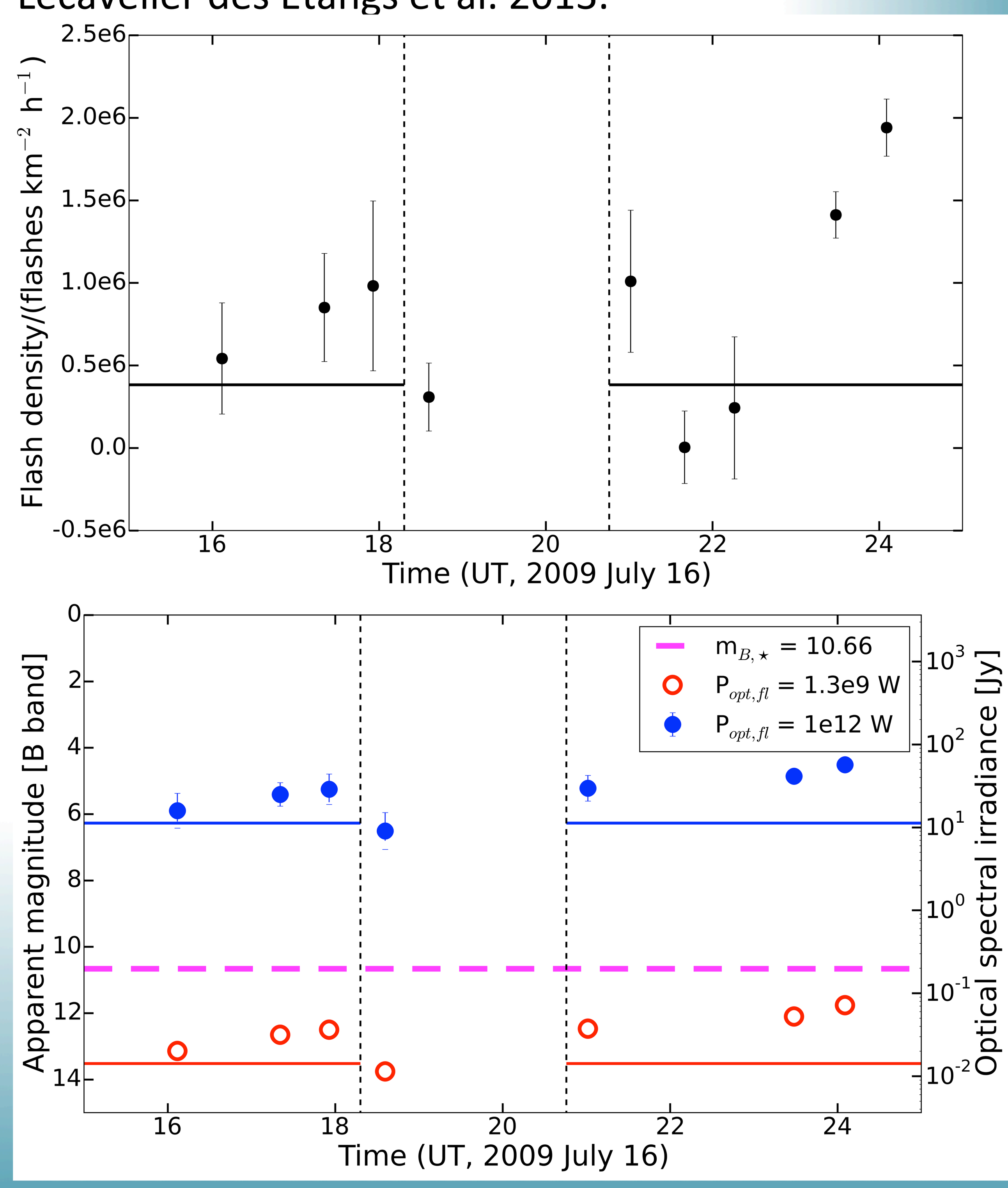
Quantity of interest: W_d

(Hodosán et al., in prep.)

5. HAT-P-11b: radio emission from lightning?

Radio observations by Lecavelier des Etangs et al. (2013, A&A, 552, A65) revealed a small, transient, signal at 150 MHz, attributed to the planet HAT-P-11b. Could it be caused by lightning?

Figure 4: **Top:** Flash densities needed to explain the observed radio flux in fig. 2 of Lecavelier des Etangs et al. 2013. **Bottom:** Optical flux density and brightness of flashes producing radio fluxes shown in fig. 2 of Lecavelier des Etangs et al. 2013.



(Hodosán, Rimmer & Helling 2016, , MNRAS, 461, 1222)

Conclusion and Future Work

The knowledge we have from lightning on Earth and other Solar System bodies can be extrapolated to extrasolar planets and brown dwarfs. However, we need a more detailed exploration of the parameter-space that describes lightning initiation and the production of lightning signatures. This allows us to determine potential lightning activity of different environments. In the future we will study the effect of lightning on the local chemistry and whether the produced molecules would have an impact on the observable spectra of extrasolar objects.

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