Probing Bow Shocks Around Exoplanets During Transits

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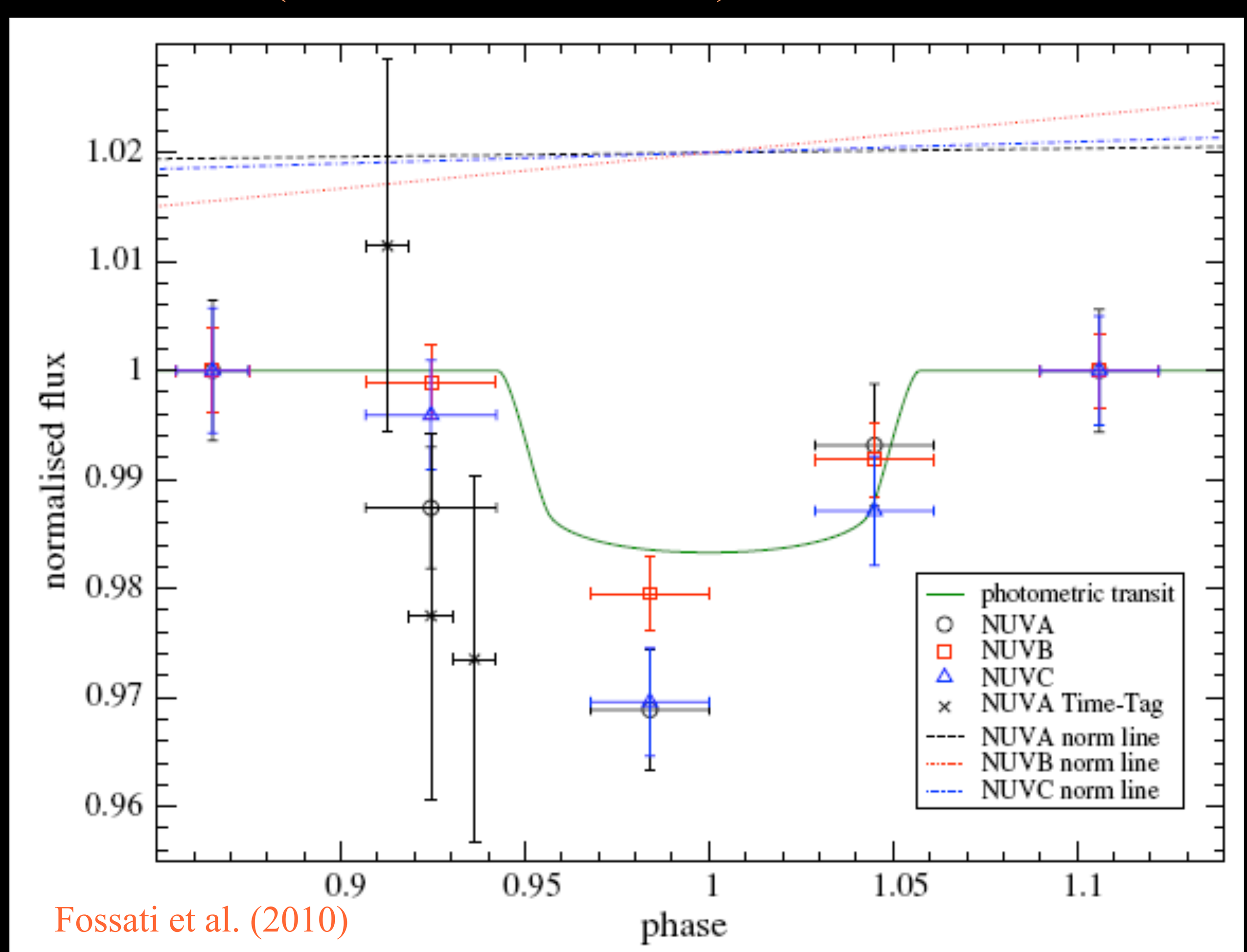
The Earth hosts a bow shock that is formed around its magnetosphere as a result of its interaction with the solar wind. Analogously, from the interaction of an exoplanet with the coronal material of its host star, similar shock structures are expected to develop. Recently, near-UV transit observations of the gas giant planet WASP-12b detected the presence of an extended material ahead of the planetary orbit. We propose that this material is indeed the bow shock surrounding WASP-12b. We investigate the conditions that might lead to the formation of such a bow shock and conclude that observable shocks should be a common feature in other transiting systems as well. We also show that shock detection through transit observations can constrain the planetary magnetic field B_p. In the case of WASP-12b, the material revealed by near-UV observations extends out to 4.2 planetary radii, implying an upper limit of B_p<24G.

Observations

Near-UV transit starts prior to optical transit: such early ingress suggests the presence of material around WASP-12b (Fossati et al. 2010a)

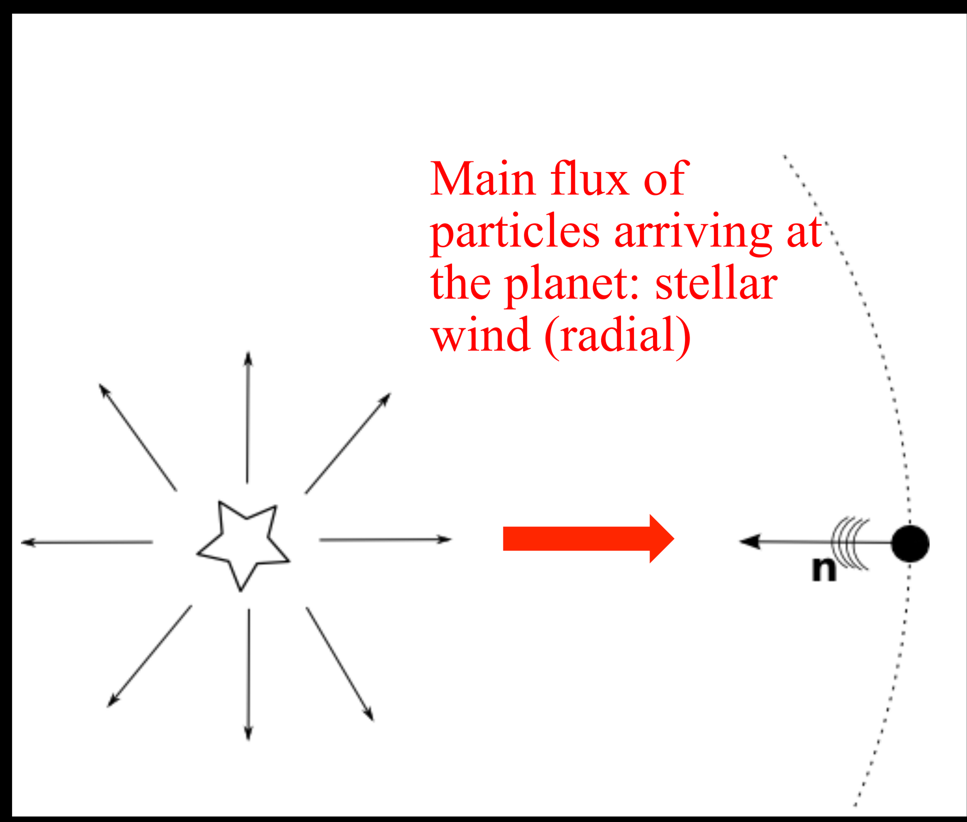


Vidotto, Jardine & Helling (2010) → presence of a bow shock could explain this light curve asymmetry.

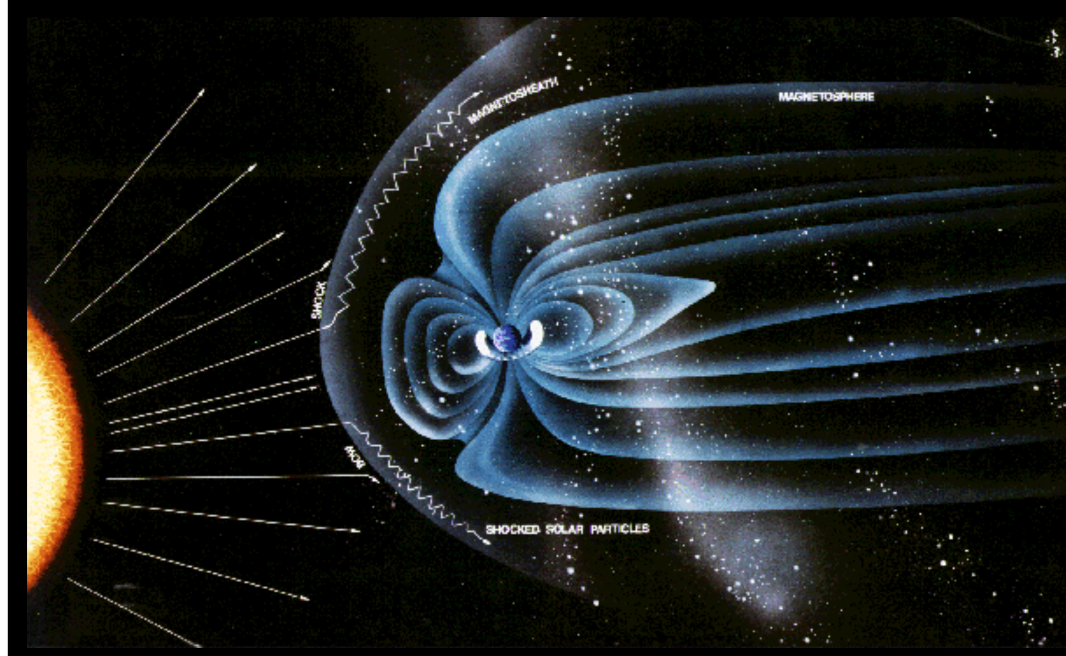
Shock Formation around planets: Limiting cases

(a) Dayside-shock: Planet is far from the host star

… similar to what is observed around the Earth

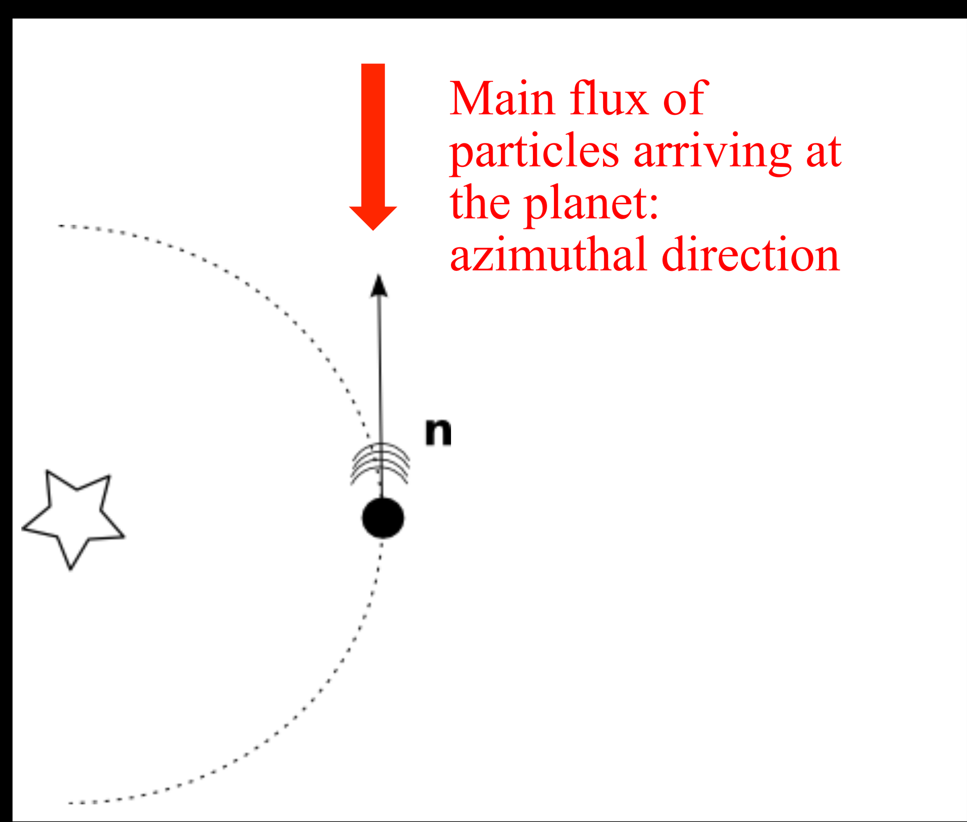


Sketch of the interaction of the host star's wind (radial arrows) with the planet magnetosphere, giving rise to a shock around the planet. The dashed semi-circle represents the planet orbital path as seen face on.

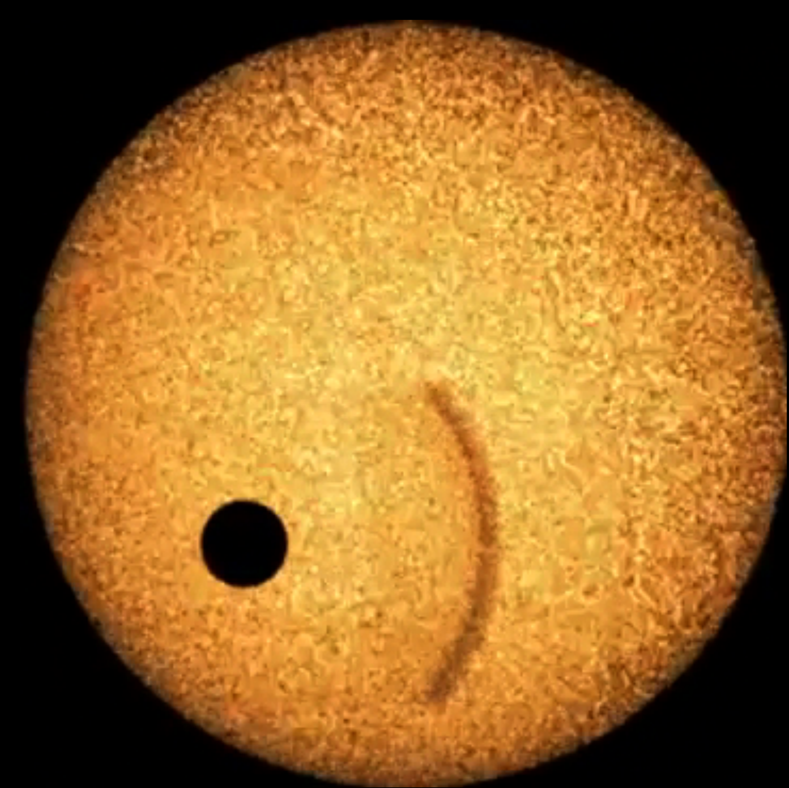


(b) Ahead-shock: Planet is much closer to the host star

… the case for close-in hot Jupiters!



Sketch of the interaction of the host star's trapped coronal material with the planet magnetosphere. The Keplerian velocity of the planet is high enough to allow shock formation ahead of the planetary orbit (dashed semi-circle). Face-on view.



Monte Carlo simulation of the transiting system (planet + bow-shock, Llama et al 2011). Edge-on view.

System Parameters

WASP-12b (Hebb et al. 2009)

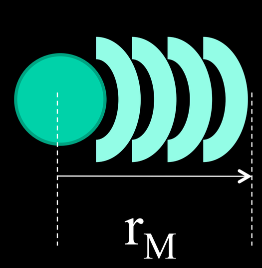
- Mass: 1.41 M_J
- Radius 1.79 R_J (Optical)
- Orbital distance: 0.023 AU (3.15 R_*) → P_{orb}=1 day

WASP-12 – Host star:

- Late F/Early G → corona (Temperature: a few MK)
- Density @ the planet: 1.5×10^6 cm^{-3} (Lai et al. 2010)
- Slow rotator: v sin(i) < 4.6km/s (Fossati et al. 2010b)

Results: Measuring Planetary Magnetic Fields

- Near-UV light curve suggests the material extends out to 4.2 planetary radii, taken to be the size of the magnetosphere r_M.



- Pressure balance between the stellar coronal medium and planet

$$p_w + \frac{B_c(R_{\rm orb})^2}{8\pi} + p = \frac{B_p(r_M)^2}{8\pi} + p_p$$

dominant terms

- I.e., the coronal magnetic field B_c is balanced by the planetary magnetic field B_p at r_M.

$$B_c(R_{\rm orb}) \simeq B_p(r_M)$$

- Assuming dipolar magnetic field configurations for the star and the planet and from observational upper limit in the stellar magnetic field (<10G, Fossati et al 2010b)

$$B_p < 24 \text{ G}$$

Summary:

- Shock occurs for a large range of coronal parameters: compression of the planetary atmosphere should be a **common** effect in close-in planetary systems.
- Ahead-shock model: new technique to probe for the presence of a planetary magnetic field.
- In the case of WASP-12b: B_p<24 G.
- Other equally interesting planets, where the model can be successfully applied once UV data is provided: WASP-19b, WASP-4b, WASP-18b, CoRoT-7b, HAT-P-7b, CoRoT-1b, TrES-3 and WASP-5b (Vidotto, Jardine & Helling, 2011).

More details:

➢ Vidotto, Jardine & Helling (2010) ApJ Letters **722**, 168
➢ Vidotto, Jardine & Helling (2011) MNRAS Letters, **411** 46
➢ Llama et al. (2011) MNRAS Letters, in press