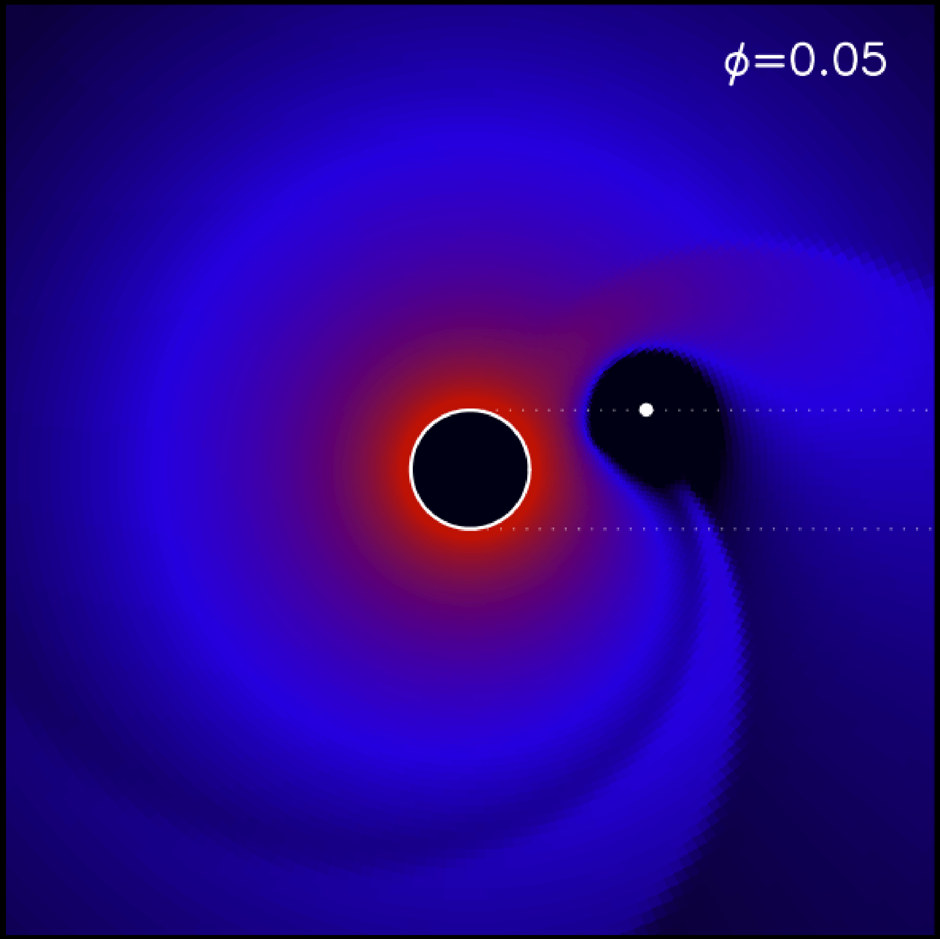
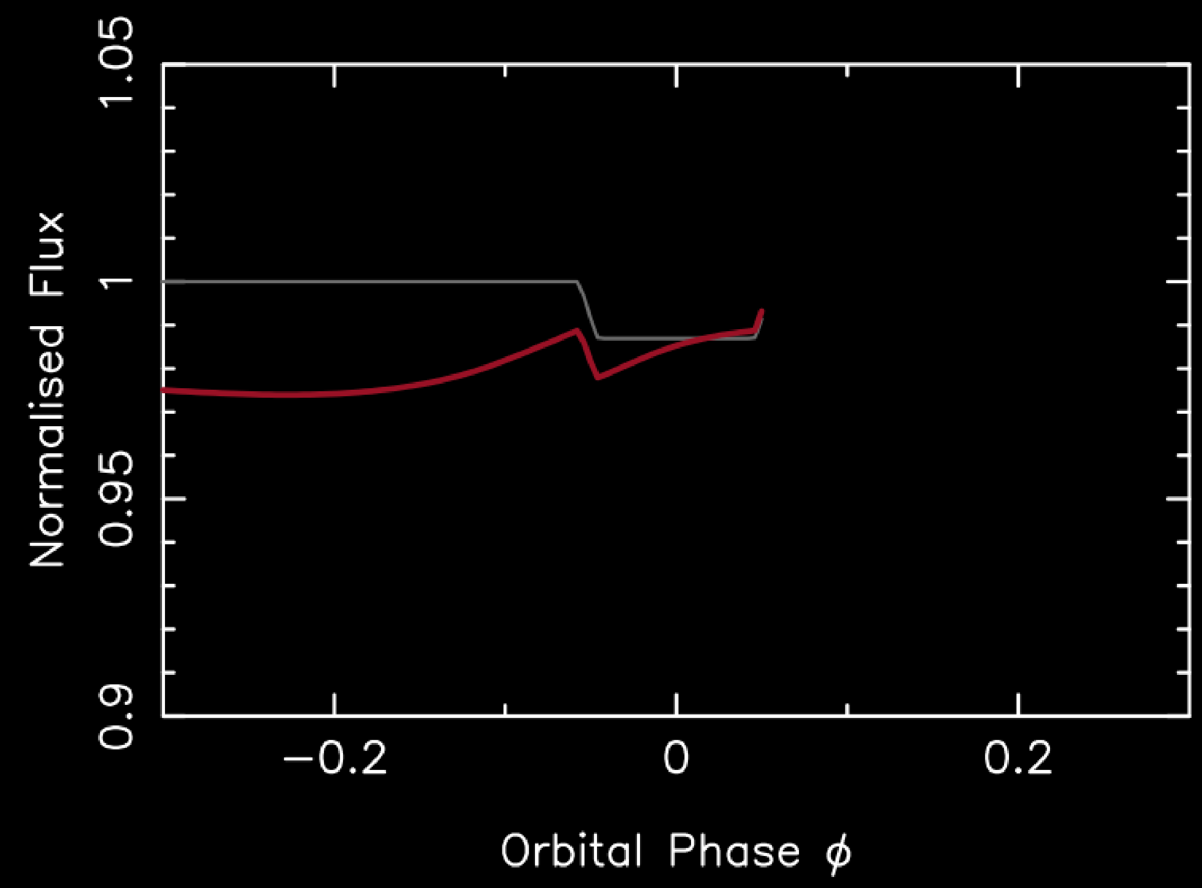
Hot-Jupiter magnetospheres: hydrodynamics & UV transit light-curves





Richard Alexander

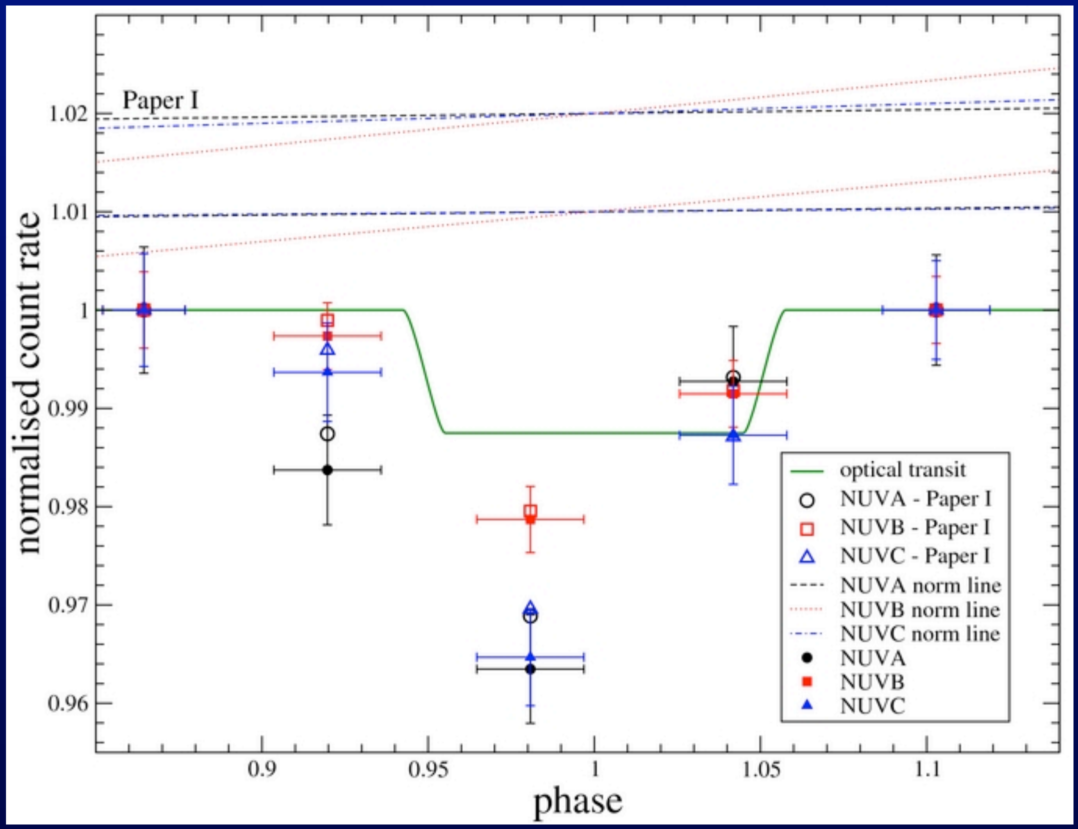
Graham Wynn, Hastyar Mohammed, Jonathan Nichols (Leicester), Barbara Ercolano (LMU)

Planet Formation & Evolution
Kiel, 8th-10th September 2014

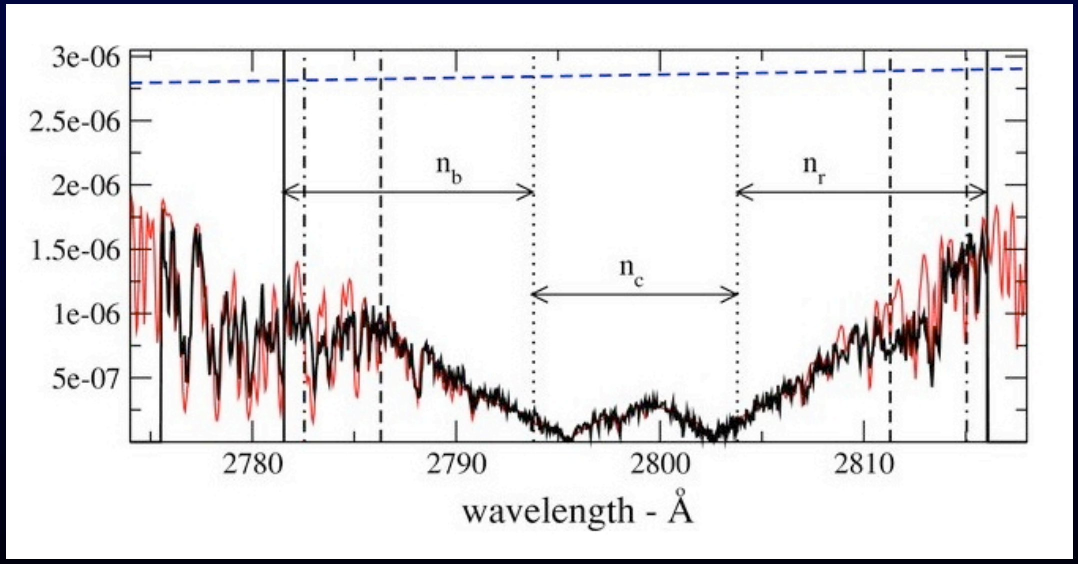
University of Leicester

WASP-12b

- WASP-12b is an extreme example of a hot Jupiter:
  - $P = 1.1\mathrm{d}$
  - $a = 3.1 R_*$
  - $M_\mathrm{p} = 1.4 \mathrm{M}_\mathrm{Jup}$
- WASP-12b shows "excess" absorption in its NUV transit:
  - deeper transit than at optical wavelengths.
  - very strong absorption in some lines (such as MgII 2798/2803Å).
  - possible "early ingress" in the UV transit light-curve.

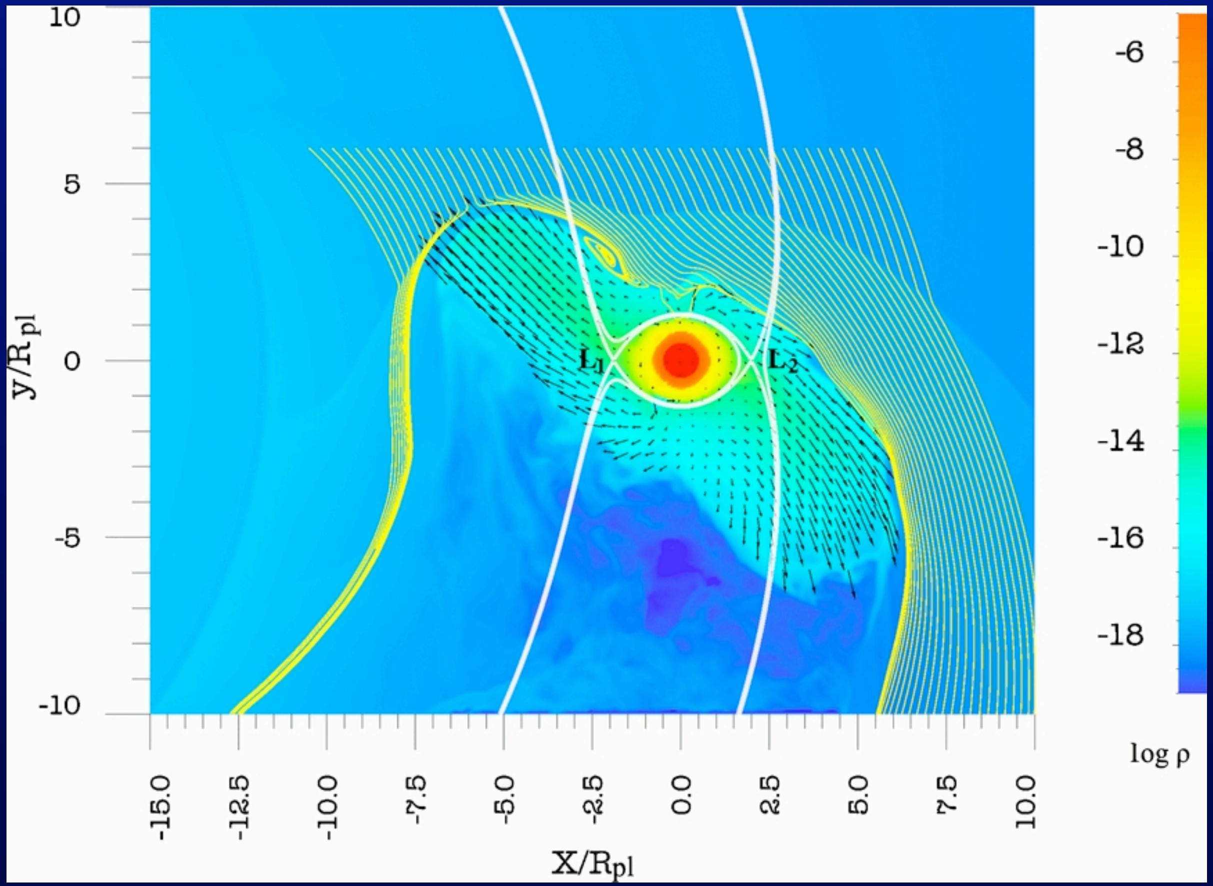


Haswell+ (2012)

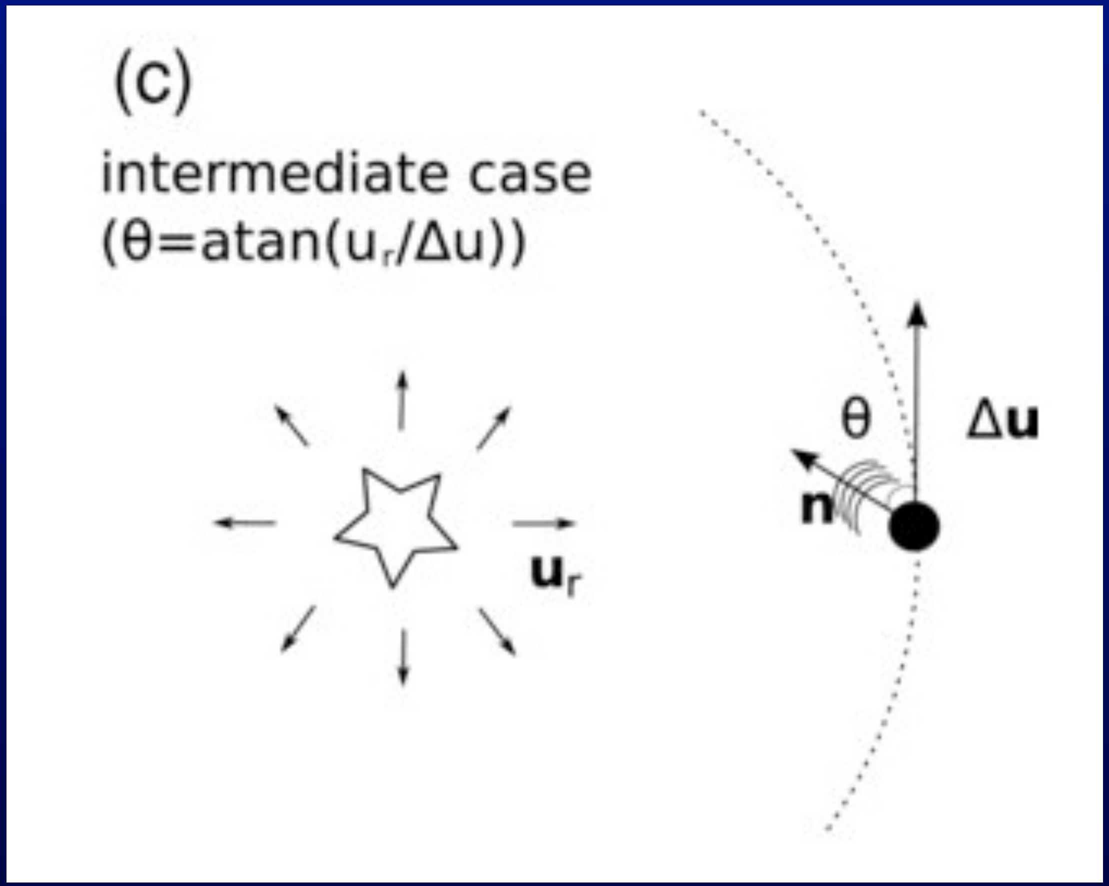


Fossati+ (2010)

Excess absorption: two theories



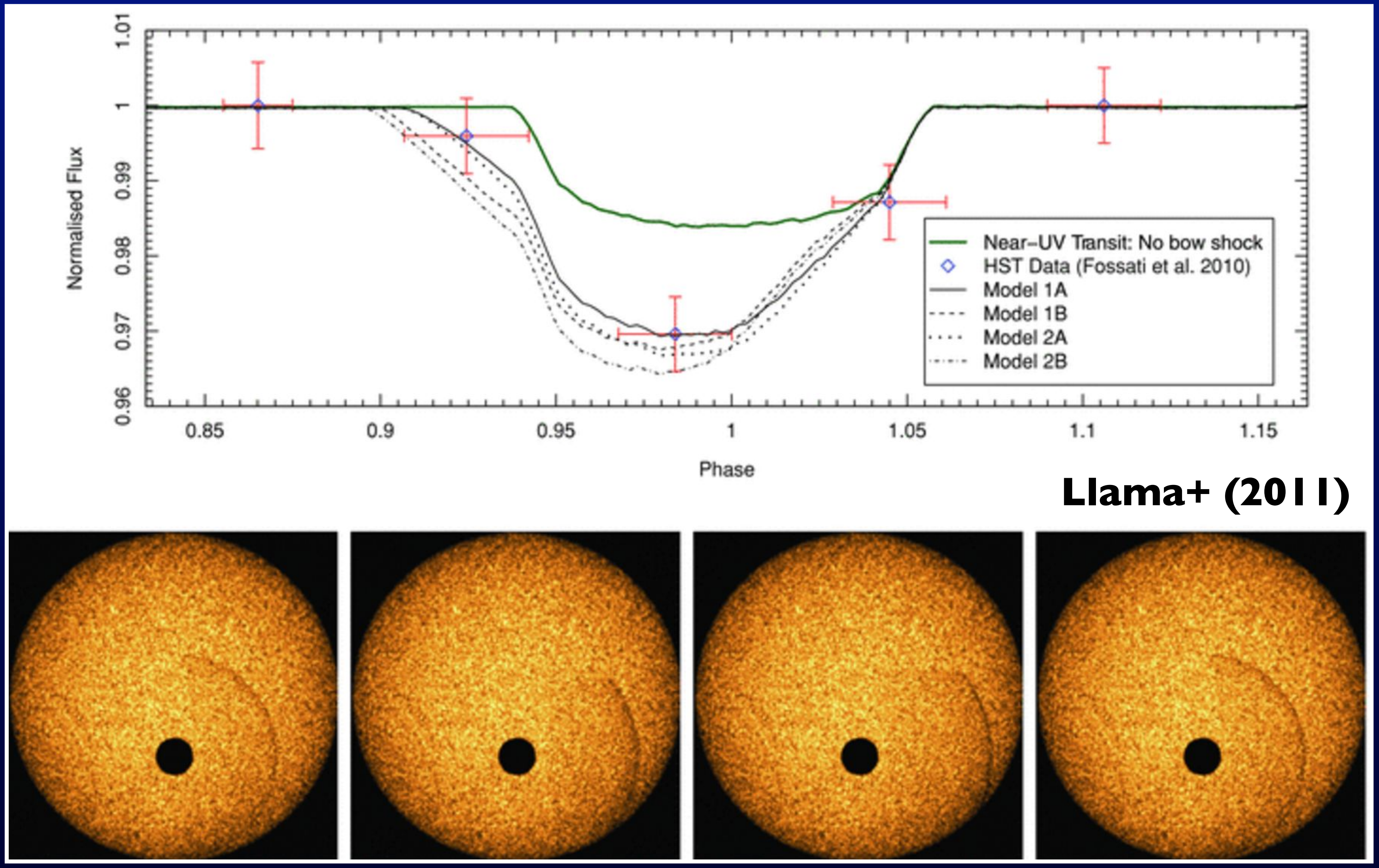
Bikisalo+ (2013)



Vidotto+ (2010)

- Two proposed explanations (Lai+ 2010):
  - Roche lobe overflow (mass loss)
  - magnetospheric bow shock (interaction with stellar wind).
- Both plausible, but no self-consistent models to date...

Magnetospheric bow shock

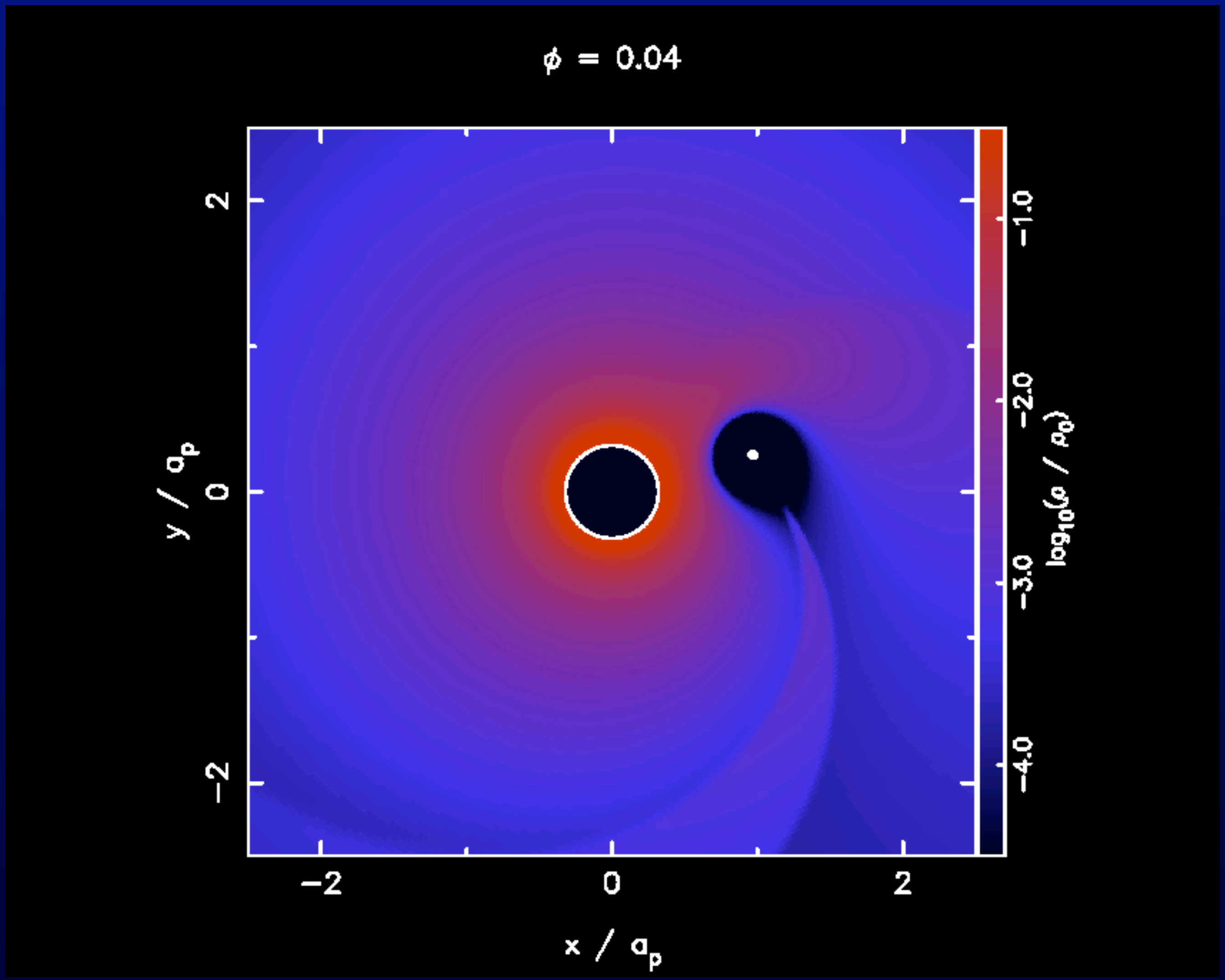


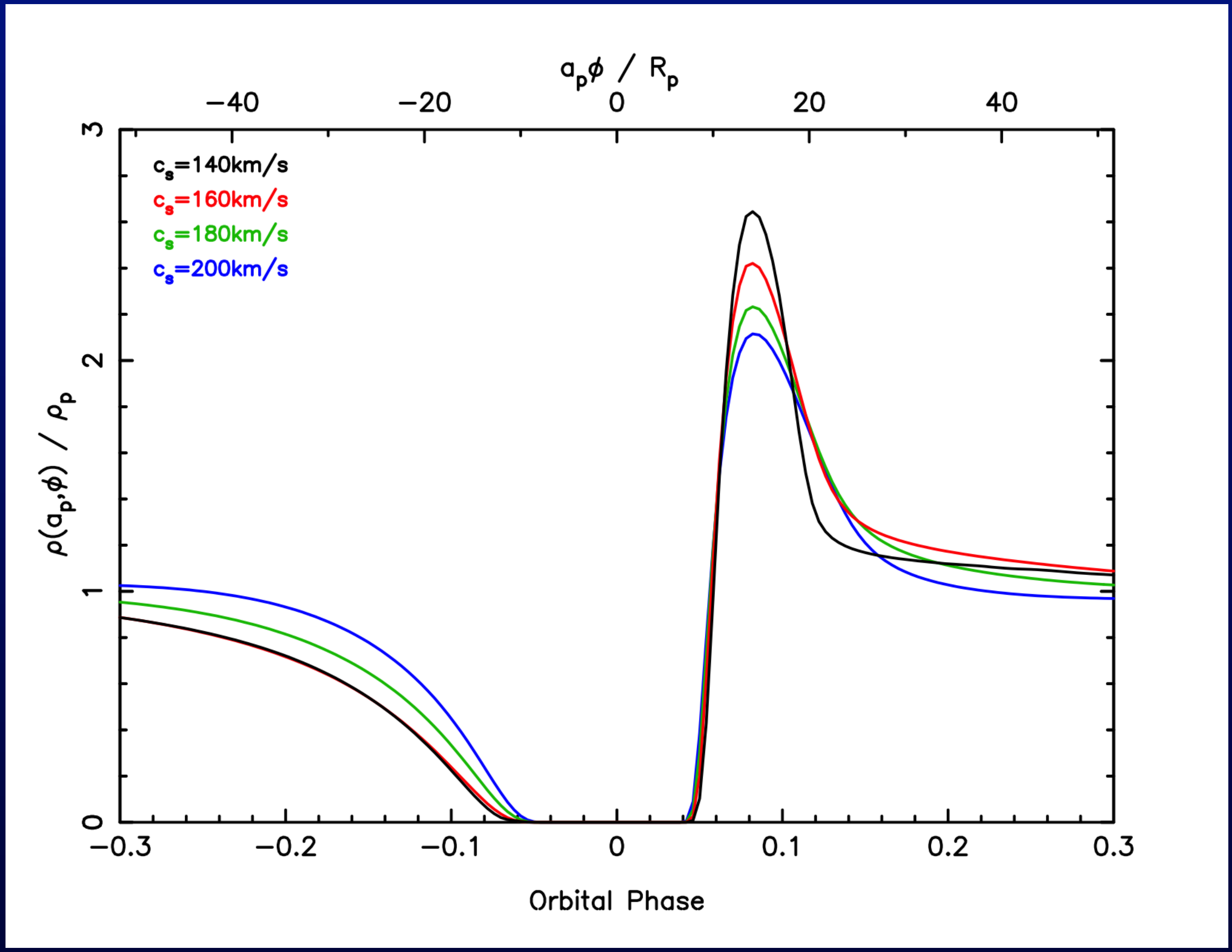
- Vidotto+ (2010,2011) and Llama+ (2011) assumed a toy shock model, and reproduced several key observables.
- Our question: do these results hold up if you compute the magnetospheric shock structure self-consistently?

Model

- 2-D Hydrodynamic models with ZEUS:
  - spherically-symmetric, isothermal (Parker) wind.
  - planetary B-field treated as $\propto 1/r^7$ acceleration (i.e., dipole field).
  - two free parameters: B-field strength and sound speed.
  - modelled three well-known cases (WASP-12b, -18b & HD209458b).
- By restricting problem to 2-D we capture the key physics while keeping the parameter space manageable.
- Run until steady state is reached (typically ~10 orbits).
- Use resulting structures as input to light-curve calculations.

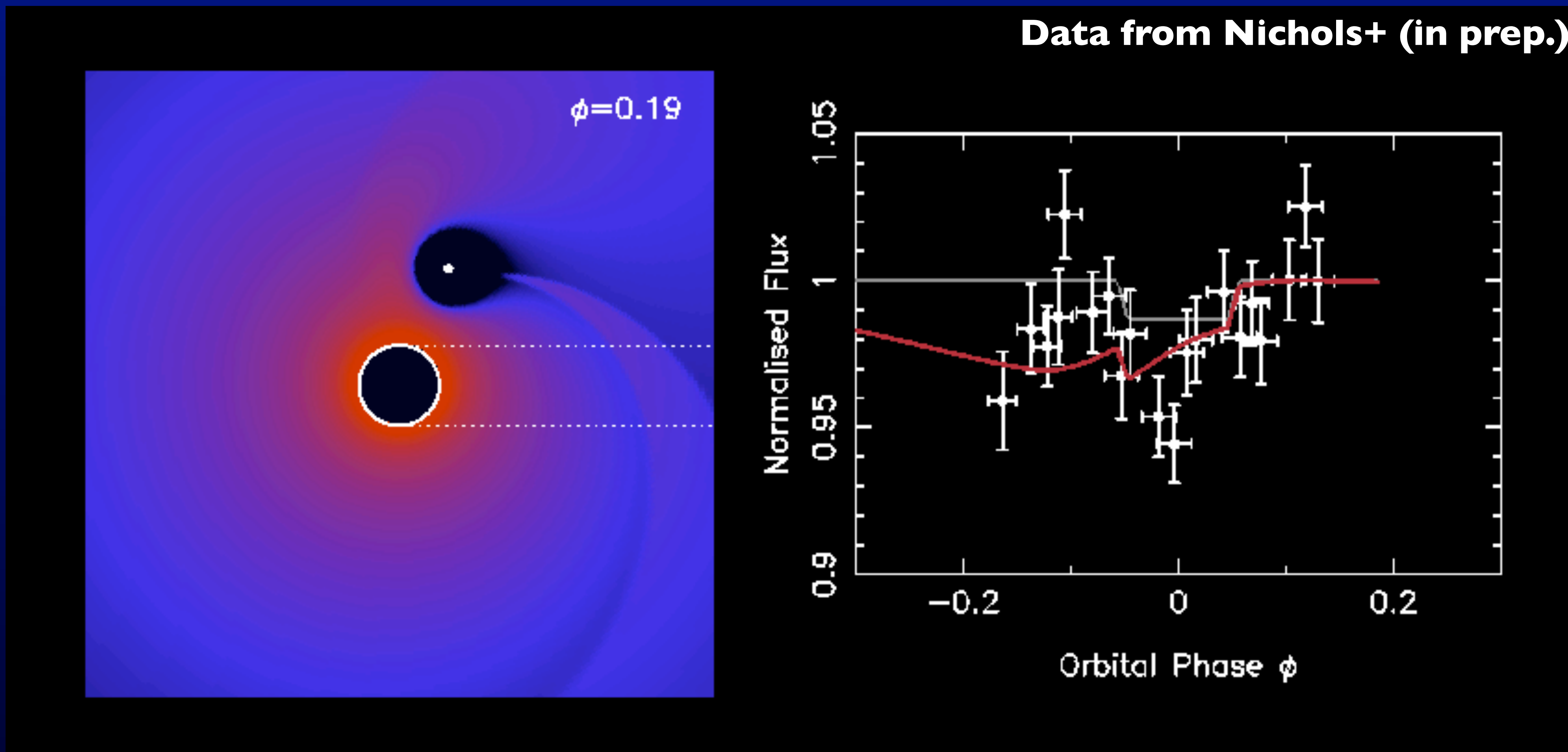
Hydrodynamics





- Low-density B-sphere preceded by weak, broad shock.
- Shock is much more extended, with a lower density contrast, than assumed in previous models.

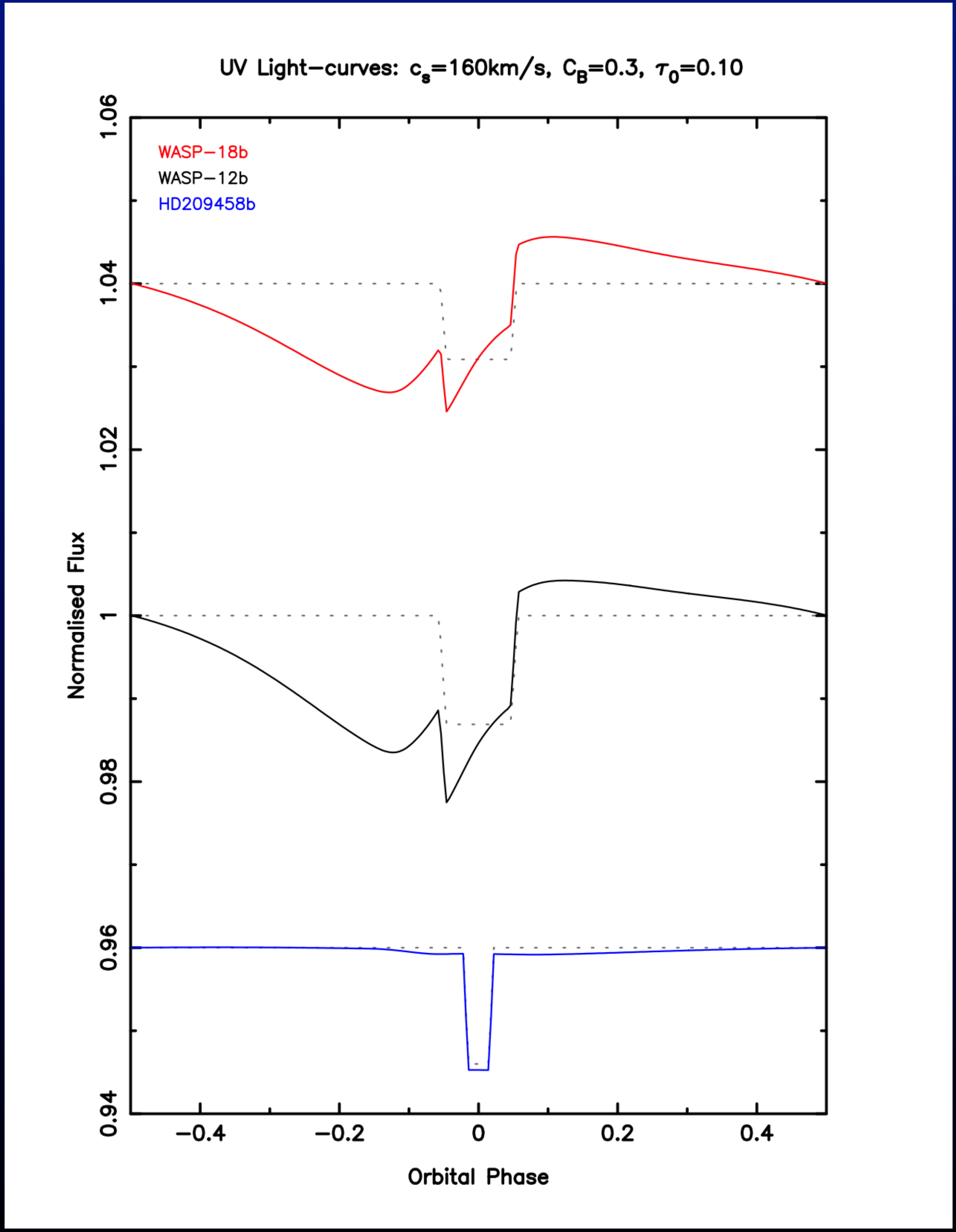
Light-curves



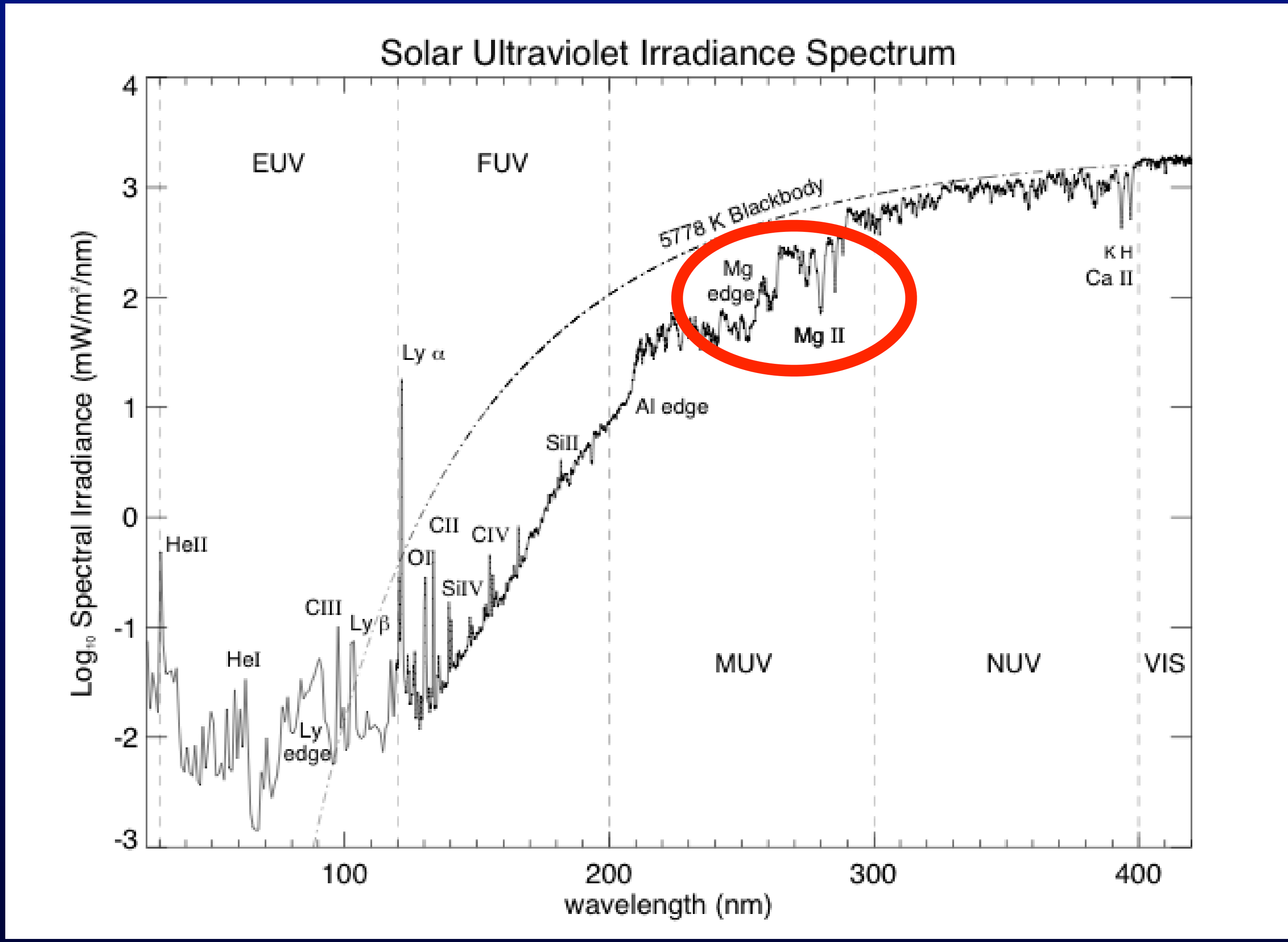
- Initially assume constant opacity to compute light-curves.
- Resulting light-curves are consistent with data if $\tau \sim 0.1$.
- 100% phase coverage is needed to break degeneracies between different models (and model parameters).

A critical test

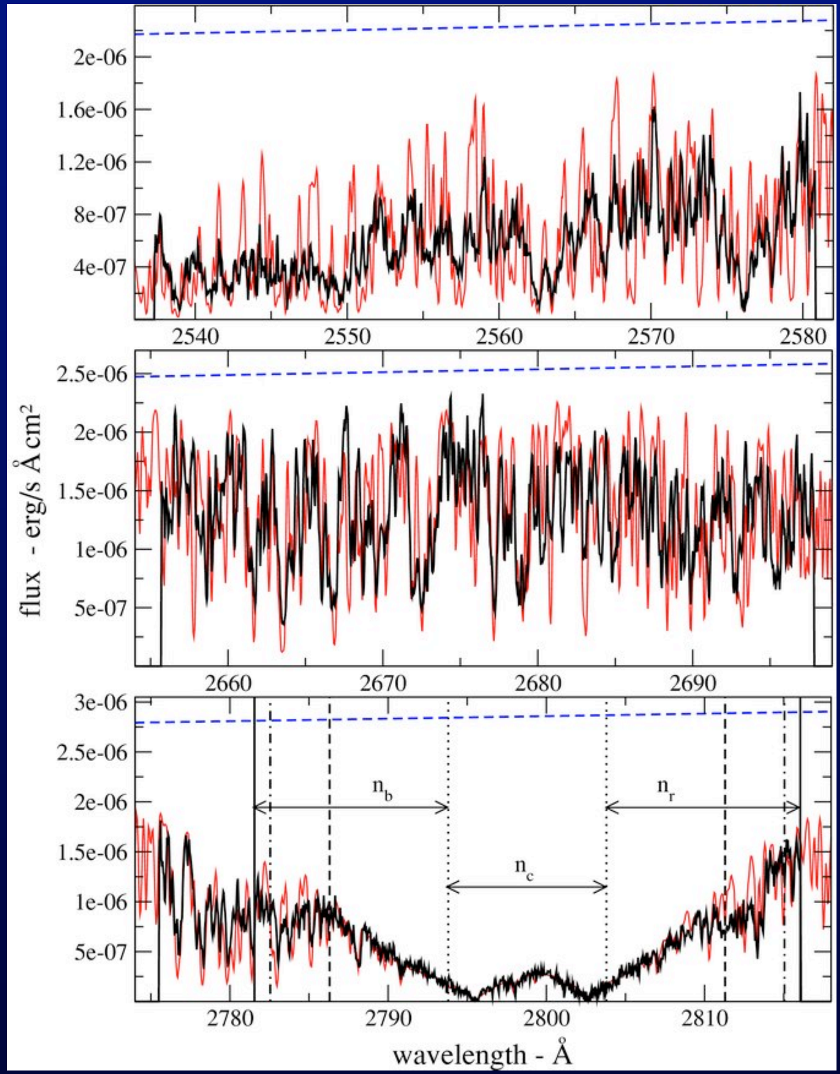
- Current data cannot distinguish between absorption in a magnetosheath and Roche lobe overflow.
- WASP-18b is in a similar orbit to WASP-12b, but is ~8 times more massive ($M_{\rm p} = 10.1 M_{\rm Jup}$).
- Near-UV observations of WASP-18b should distinguish clearly between these two scenarios.



Origin of the opacity?



Thullier+ (2005)



Fossati+ (2010)

- Near-UV opacity dominated by blended, blanketed lines.
- "Continuum" opacity very difficult to calculate.
- We require either: i) cooling in the shock.

  ii) absorption in the wind.

Summary

- Magnetospheric absorption is a plausible explanation for excess near-UV absorption seen in WASP-12b.
- Hydro models show that shock is weaker and broader than assumed in previous studies.
- If the magnetosphere is to provide sufficient opacity, we require absorption in the wind and/or cooling in the shock.
- Observations of other hot Jupiters (such as WASP-18b) should distinguish between competing models.