Magnetic moment and plasma environment of exoplanets as determined from Lyα observations

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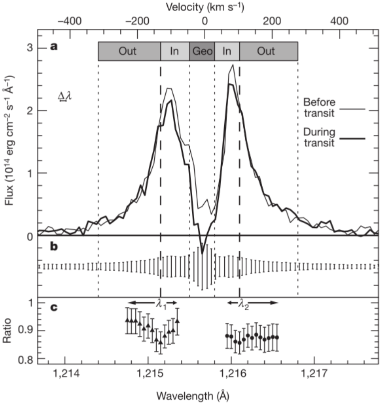
HD209458b in Lyα: Vidal-Madjar et al.



Nature, vol. 422, 2003. 15% absorption in L-alpha during the transit found

An extended upper atmosphere around the extrasolar planet HD209458b

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The planet in the system HD209458 is the first one for which repeated transits across the stellar disk have been observed[1,2]. Together with radial velocity measurements[3], this has led to a determination of the planet's radius and mass, confirming it to be a gas giant. But despite numerous searches for an atmospheric signature[4–6], only the dense lower atmosphere of HD209458b has been observed, through the detection of neutral sodium absorption[7]. Here we report the detection of atomic hydrogen absorption in the stellar Lyman α line during three transits of HD209458b. An absorption of 15 ± 4% (1σ) is observed. Comparison with models shows that this absorption should take place beyond the Roche limit and therefore can be understood in terms of escaping hydrogen atoms.

New data analysis: Ben-Jaffel et al.

EXOPLANET HD 209458b: INFLATED HYDROGEN ATMOSPHERE BUT NO SIGN OF EVAPORATION

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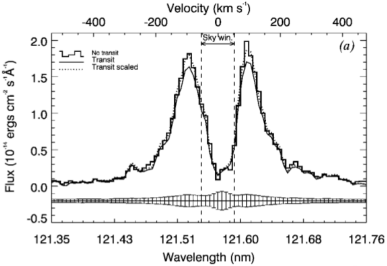
ABSTRACT

Many extrasolar planets orbit closely to their parent star. Their existence raises the fundamental problem of loss and gain in their mass. For exoplanet HD 209458b, reports on an unusually extended hydrogen corona and a hot layer in the lower atmosphere seem to support the scenario of atmospheric inflation by the strong stellar irradiation. However, difficulties in reconciling evaporation models with observations call for a reassessment of the problem. Here we use *HST* archive data to report a new absorption rate of ~8.9% ± 2.1% by atomic hydrogen during the HD 209458b transit and show that no sign of evaporation could be detected for the exoplanet. We also report evidence of time variability in the HD 209458 Lyα flux, a variability that was not accounted for in previous studies, which corrupted their diagnostics. Mass-loss rates thus far proposed in the literature in the range $5 \times (10^{10}\text{–}10^{11})$ g s^{-1} must induce a spectral signature in the Lyα line profile of HD 209458 that cannot be found in the present analysis. Either an unknown compensation effect is hiding the expected spectral feature or else the mass-loss rate of neutrals from HD 209458 is modest.



The Astrophysical Journal, 671: L000–L000, 2007 December 10

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LETTERS

Energetic neutral atoms as the explanation for the high-velocity hydrogen around HD 209458b

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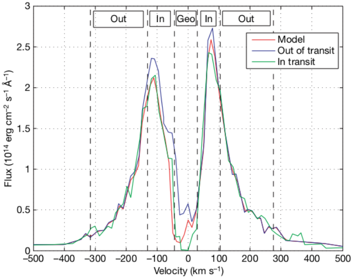

Absorption in the stellar Lyman-α (Lyα) line observed during the transit of the extrasolar planet HD 209458b in front of its host star reveals high-velocity atomic hydrogen at great distances from the planet[1,2]. This has been interpreted as hydrogen atoms escaping from the planet's exosphere[1,3], possibly undergoing hydrodynamic blow-off[4], and being accelerated by stellar radiation pressure. Energetic neutral atoms around Solar System planets have been observed to form from charge exchange between solar wind protons and neutral hydrogen from the planetary exospheres[5–7], however, and this process also should occur around extrasolar planets. Here we show that the measured transit-associated Lyα absorption can be explained by the interaction between the exosphere of HD 209458b and the stellar wind, and that radiation pressure alone cannot explain the observations. As the stellar wind protons are the source of the observed energetic neutral atoms, this provides a way of probing stellar wind conditions, and our model suggests a slow and hot stellar wind near HD 209458b at the time of the observations.

EXOPLANET MAGNETISM

Magnetic moment and plasma environment of HD 209458b as determined from Lyα observations

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Petra Odert,[3] Maxim L. Khodachenko[1,4]

Transit observations of HD 209458b in the stellar Lyman-α(Lyα) line revealed strong absorption in both blue and red wings of the line interpreted as hydrogen atoms escaping from the planet's exosphere at high velocities. The following sources for the absorption were suggested: acceleration by the stellar radiation pressure, natural spectral line broadening, or charge exchange with the stellar wind. We reproduced the observation by means of modeling that includes all aforementioned processes. Our results support a stellar wind with a velocity of ≈400 kilometers per second at the time of the observation and a planetary magnetic moment of ≈1.6 × 10^{26} amperes per square meter.

[Science, **346**, 981, 2014]

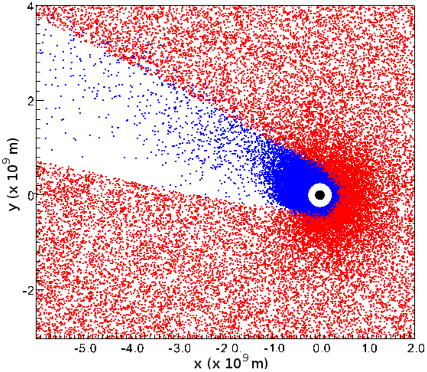
Aims & processes

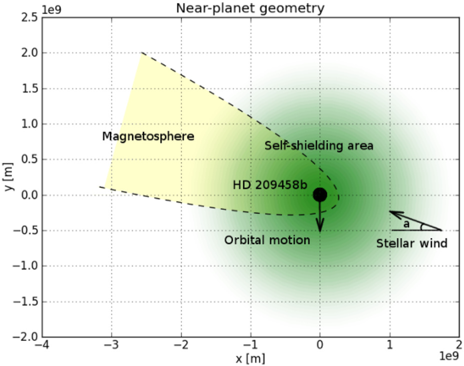
- Characterization of the stellar plasma environment around exoplanets
- Estimation of the pickup ion escape
- Estimation of the planetary magnetic moment

Included processes for an exospheric atom:

- Charge-exchange with stellar H^+
- Ionization (photoionization, electron impact ionization)
- Scattering of an UV photon (radiation pressure, velocity dependent)
- Elastic collision with another hydrogen atom
- Gravitational effects (besides gravity - tidal, coriolis, centrifugal forces)
- Self-shielding (optical thickness in Lyα).

Geometry and modelling, HD 209458b





The coordinate system used is centered at the planet and has its x-axis toward the star, the y-axis opposite the orbital velocity, and the z-axis completes the right-handed coordinate system. The assumed magnetospheric obstacle

$$X = R_s \left(1 - \frac{\rho^2}{R_t^2} \right)$$

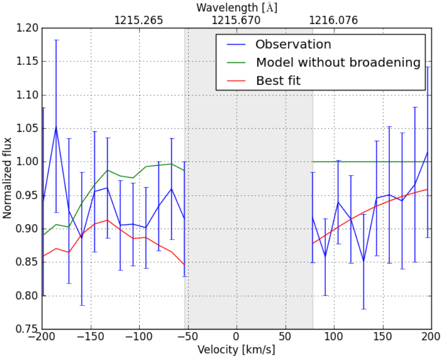
Inputs used for the modeling

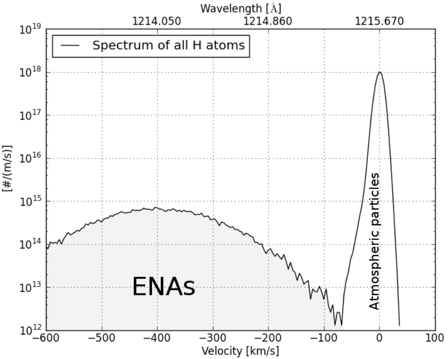
Name	Symbol	Value	
Star mass	M_{st}	2.28×10^{30} kg	$\approx 1.148\ M_{Sun}$
Star age		$\approx 4 \pm 2$ Gyr	
Planet radius	R_{pl}	9.54×10^{7} m	$\approx 0.71\ M_{Jup}$
Planet mass	M_{pl}	1.21×10^{27} kg	$\approx 1.38\ R_{Jup}$
Orbital distance		7.1×10^{9} m	≈ 0.047 AU
Inner boundary radius	R_{ib}	2.7×10^{8} m	$\approx 2.8\ R_{pl}$
Inner boundary temperature	T_{ib}	6×10^{3} K	
Inner boundary density	n_{ib}	2×10^{13} m^{-3}	
Obstacle standoff distance*	R_{s}	2.76×10^{8} m	$\approx 2.9\ R_{pl}$
Obstacle width*	R_{t}	2.86×10^{8} m	$\approx 3.0\ R_{pl}$
Photoionization rate	τ_{pi}	6.0×10^{-5} s^{-1}	
Electron impact ionization rate	τ_{ei}	1.25×10^{-4} s^{-1}	
Stellar wind density	n_{sw}	5×10^{9} m^{-3}	
Stellar wind velocity	u_{sw}	400×10^{3} m/s	
Stellar wind temperature	T_{sw}	1.1×10^{6} K	

*Assuming that the Alfvenic Mach number $M_A > 1$.

Some numerical parameters play a role as well: cell size, velocity and spacial grid, number of so-called «metaparticles»

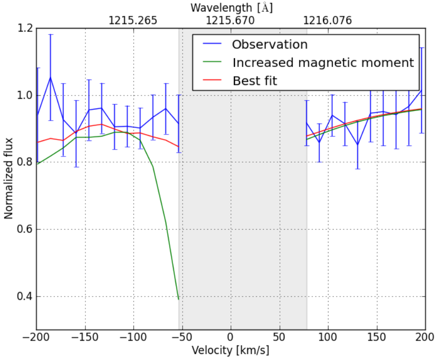
Modelling results, HD 209458b

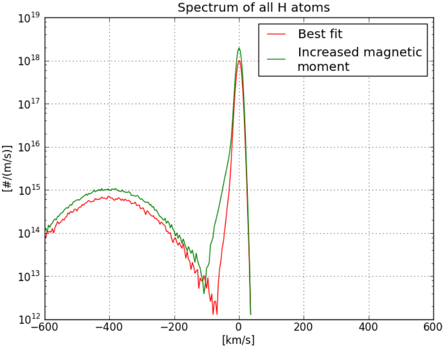




$$\mathcal{M}_{\rm pl} = \left(\frac{8\pi^2 R_{\rm s}^6 \rho_{\rm sw} v_{\rm rel}^2}{\mu_0 f_0^2} \right)^{1/2}$$

Estimated magnetic moment: $\mathcal{M}_{\rm pl} \approx 1.6 \times 10^{26}$ A$\times$m$^2 \approx 0.1\ \mathcal{M}_{\rm Jup}$





The influence of the obstacle shape: subtellar distance $R_s = 4$ and obstacle width $R_t = 6$.
Best fit: $R_s = 2.9$, $R_t = 3$ (in units of R_{pl}).

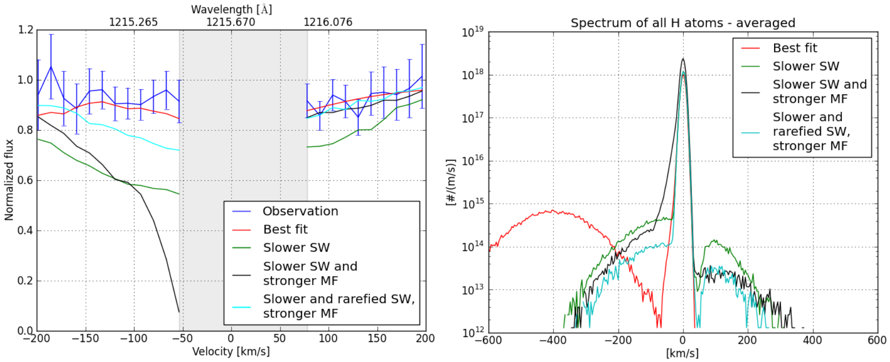
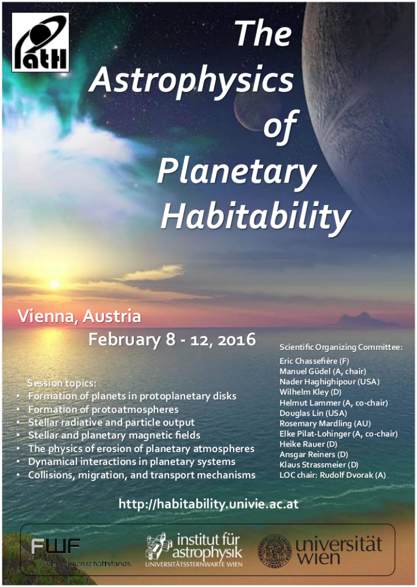


Illustration of the influence of the stellar wind speed; $v_{\rm sw} = 50$ km/s is assumed

Main conclusions

- High radiation pressure and intense charge-exchange reshape the hydrogen cloud around the planet leading to strong asymmetry
- DSMC modelling combined with Lyα transit observations can be used to determine the magnetic moment of an exoplanet
- Taking HD 209458b as an example, the method predicts the magnetic moment of $\approx$10% $\mathcal{M}_{Jup}$ ...
- ...and a stellar wind with $v_{sw} = 400$ km/s
- The method can be applied to other exoplanets for which Lyα observations are available



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