Can viscous drag account for CME deceleration?

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Introduction

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- These forces have ben characterized so far in terms of a "drag parameter" $C_{\rm D} \sim 1$ that quantifies the role of the aerodynamic drag experienced by a typical CME due to its interaction with the ambient solar wind.

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- We envisage the CME as a bubble propagating through the solar wind and compute the drag on it using these viscosity prescriptions applied to a simple 1D hydrodynamical model.
- We find that the viscous drag is very inadequate to account for the observed slowing down of CME from the Sun to the Earth.
- Perhaps C_{D} is a proxy for other effects like slowing down due to shock driving, tension in B fields "holding back" the CME, etc.

CME-solar wind interaction

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- This suggestion of momentum coupling is the central idea behind a heuristic aerodynamic drag coefficient for CMEs as they propagate through the solar wind (e.g., Byrne et al 2010; Maloney & Gallagher 2010; Vrsnak et al 2004; 2008; 2010; Cargill 1996; 2004)

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- Most authors have focussed on the overall dynamics of the CME during its propagation through the solar wind, using the (dimensionless) drag coefficient C_D as a fitting parameter
- Fits to observations yield $C_{\rm D} \sim 1$ (e.g., Cargill 2004)

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- The drag force $F_{\rm D}$ on a high Reynolds number bubble is (Moore 1963; Merle et al 2005)

$$F_{\rm D} = 6\,\pi\,\eta\,R_{\rm CME}\left(1 - \frac{2.211}{Re_{\rm B}^{1/2}}\right)(V_{\rm B} - V_{\rm sw})$$

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- To proceed further, one needs to know the operative viscosity in the fluid.

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- We survey some of the salient collisionless viscosity models in the literature and apply it to calculating the viscous drag on the CME bubble.

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- Density turbulence in the solar wind $\sim$ Kolmogorov. Inner (dissipation) scale is due to proton cyclotron resonance (Coles & Harmon 1989)
- We take $\lambda_{\rm coh}$ to be equal to the inner scale l_i of solar wind density turbulence: $\lambda_{\rm coh} = l_i = 684\, N_i^{-1/2} \quad {\rm km}$

Solar wind viscosity ν as a function of heliocentric distance

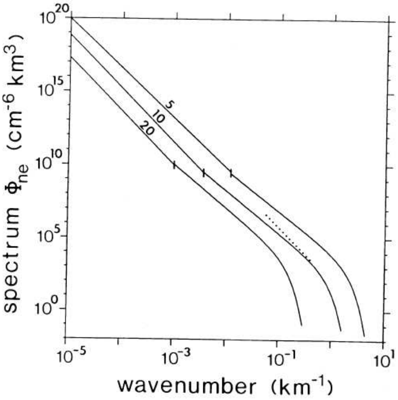

Figure: Typical spectra for Kolmogorov density turbulence, showing the inner scale l_i (Coles & Harmon 1989)

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- We use $l_d = l_i$ (Coles & Harmon 1989) and the solar wind energy dissipation rate (Vasquez et al 2007, Marino et al 2008): $\epsilon(R) = \frac{3}{2}\left(\frac{4}{3} - \beta\right) \frac{V_{\rm sw}(R)\, k_{\rm B}\, T_i(R)}{R\, m_p}$

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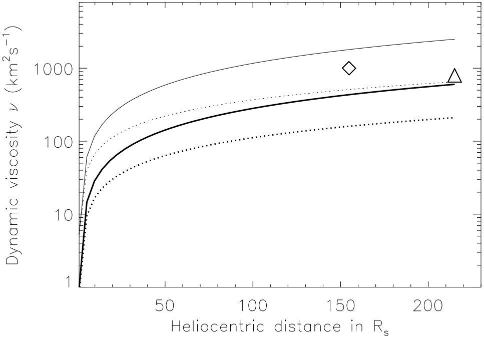

Figure: Thin solid line: $\nu_{\rm hyb}$ w/ $T_p = 10^6$ K, thin dotted line: $\nu_{\rm hyb}$ w/ $T_p \propto R^{-\beta}$, $\beta = 1/2$. Thick dashed line: $\nu_{\rm verma}$ w/ $T_p = 10^6$ K, thick solid line: $\nu_{\rm verma}$ w/ $T_p \propto R^{-\beta}$, $\beta = 1/2$. Diamond: Perez-de-Tejada (1999) (from thickness of Venus ionosheath), triangle: Eviatar & Wolf (1968), Parker (1958) (from thickness of Earth's magnetopause boundary layer)

CME velocity profile

- We solve a simplified 1D equation of motion for a spherical CME bubble through a steady, uniform, irrotational flow at high Reynolds numbers:

$$C_{\rm M}\, m_{\rm CME}\, V_{\rm B}\, \frac{dV_{\rm B}}{dR} = -48\,\pi^2\, R_{\rm CME}\, \eta \left(1 - \frac{2.211}{Re_{\rm B}^{1/2}}\right) (V_{\rm B} - V_{\rm sw})$$

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- We investigate solutions to this simplified equation because we wish to understand the effects of the viscous drag force on the dynamics of the CME in *isolation*, since this force has been commonly held to be the primary influence on the the dynamics of the CME in the interplanetary medium.

CMEs hardly slow down!

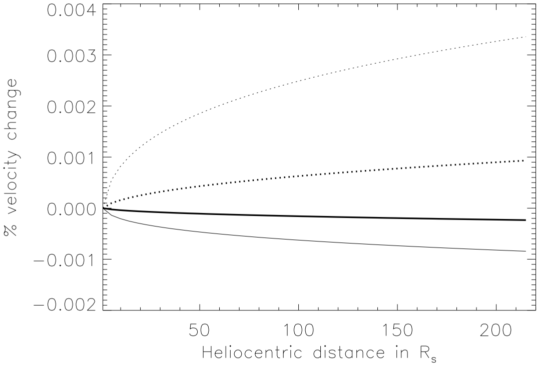


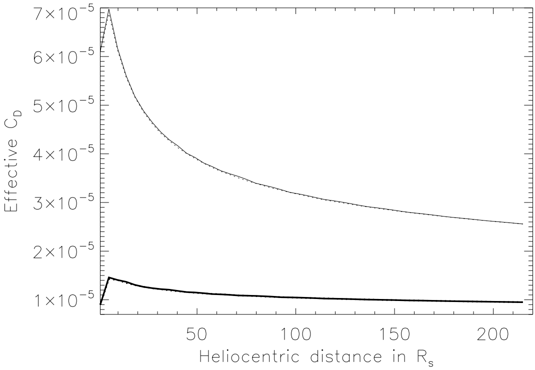
Figure: The quantity $100\,[(V_{\rm B}(R) - V_{\rm B}(2))/V_{\rm B}(2)]$ as a function of heliocentric distance R

Equivalent drag coefficient: very small

It is also useful to extract an equivalent $C_{\rm D}$ from these velocity solutions:

$$m_{\rm CME}\, V_{\rm B}\, \frac{dV_{\rm B}}{dR} = \frac{1}{2}\, \rho_{\rm sw}\, A_{\rm CME}\, (V_{\rm B} - V_{\rm sw})^2\, C_{\rm D}\,,$$

: (contrast with $C_{\rm D} \sim 1$!)



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- We have used fiducial numbers for quantities such as the mass, size scaling, etc., and found that the drag thus computed is grossly inadequate to account for the observed slowing down of CMEs from the Sun to the Earth
- We speculate that other factors, such as shock driving might be the primary cause of deceleration, and can appear as an effective drag on the CME