

## GALACTIC KITES

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### ABSTRACT

I show that interstellar films of material thinner than a micron, drift away from the Galactic plane as a result of stellar radiation pressure. Such films, whether produced naturally by dust coagulation in proto-planetary disks or artificially by technological civilizations, would accumulate over the age of the Milky-Way and hover above the Galactic disk at a scale-height set gravitationally by the dark matter halo. Limits on scattered starlight imply that this population carries a fraction below  $2 \times 10^{-3}$  of the interstellar medium mass.

## 1. INTRODUCTION

The luminosity per unit mass of the Sun is  $\sim 3 \times 10^{-5}$  of the Eddington limit, at which the outward radiative push equals the inward gravitational pull on ionized hydrogen (Shapiro & Teukolsky 1983). Therefore, an increase by a factor bigger than  $1/(3 \times 10^{-5})$  in the cross-sectional area per unit mass over the fiducial value of  $(\sigma_T/m_p) = 0.4 \text{ cm}^2 \text{ g}^{-1}$ , would make the radiative force larger than the gravitational force. Here,  $\sigma_T = 0.67 \times 10^{-24} \text{ cm}^2$  is the Thomson cross-section for electron scattering and  $m_p = 1.67 \times 10^{-24} \text{ g}$  is the proton mass. Under optically-thin conditions, both the radiative and gravitational forces scale inversely with the square of the distance from a star. Therefore, their ratio is independent of position.

For a thin flat film of solid material with a mass density  $\rho_s$  and thickness  $w$ , the face-on area-per-unit-mass equals  $(1/w\rho_s)$ . The required enhancement to a value  $\gtrsim 1.2 \times 10^4 \text{ cm}^2 \text{ g}^{-1}$  so that radiation dominates gravity, is possible at a thickness  $w$  satisfying,

$$w < w_c = 0.8 \mu\text{m} \left( \frac{\rho_s}{1 \text{ g cm}^{-3}} \right)^{-1}. \quad (1)$$

Instabilities could lead to tangled, non-planar configurations or to arbitrary orientations of the film (Manchester & Loeb 2017), which do not provide the full frontal area of the film facing the radiation source. Below we refer to the “effective width”,  $\bar{w}$ , corresponding to the value that  $w$  should have had for face-on orientation after averaging over all geometries of the population of films.

For the thin disk of Milky-Way stars, the repulsive radiative force away from the midplane would exceed the attractive gravitational force for  $\bar{w} < w_c$ . The surface mass density of interstellar gas is smaller than that of stars (McKee et al. 2015) and is ignored in our order-of-magnitude considerations here.

The local surface density of stars,  $\Sigma_\star \approx 30 \text{ M}_\odot \text{ pc}^{-2}$  (McKee et al. 2015), yields the gravitational acceleration towards the midplane of the stellar disk,

$$g_\star = G\Sigma_\star = 5 \times 10^{-10} \text{ cm s}^{-2}. \quad (2)$$

The mass-to-light ratio of the local disk is of order unity in solar units (Flynn et al. 2006), hence maintaining the numerical coefficients mentioned above for the Sun.

For a face-on film of material, the radiative acceleration away from the disk midplane exceeds  $g_\star$  by a factor  $(w_c/\bar{w})$ . As a result of friction with the interstellar medium, the film would develop a drift speed perpendicular to the disk plane,  $v$ , at which the radiative acceleration,  $a_{\text{rad}} = g_\star(w_c/\bar{w})$ , is balanced by the ram-pressure deceleration induced by the ambient gas. For  $\bar{w} \ll w_c$ , the two accelerations scale in proportion to the area-per-unit-mass, yielding

$$a_{\text{rad}} = \left( \frac{\rho_{\text{ISM}}}{\rho_s} \right) \left( \frac{v^2}{\bar{w}} \right), \quad (3)$$

where  $\rho_{\text{ISM}} \approx m_p n_{\text{ISM}}$  is the mass density of the interstellar medium; for a fiducial proton number density of  $n_{\text{ISM}} \sim 1 \text{ cm}^{-3}$  we get  $\rho_{\text{ISM}} \sim 10^{-24} \rho_s$  (Draine 2011).

## 2. RESULTS

Equations (1)-(3) imply a drift speed of  $v \sim 2 \text{ km s}^{-1} (n_{\text{ISM}}/1 \text{ cm}^{-3})^{-1/2}$ , away from the Galactic midplane. At this subsonic drift speed, ambient gas particles deposit an energy equivalent of  $\sim 2 \times 10^{-2} \text{ eV} = 260 \text{ K}$  per proton, making such impacts insignificant relative to thermal effects (Hoang et al. 2018).

At a sufficiently high elevation relative to the midplane, the gravitational force from the dark matter halo binds the film population. Since the local mass density of dark matter is comparable to that of stars (Buch et al. 2019), the scale-height of the film population  $h_f$  would exceed that of stars  $h_*$  (of order a few hundred pc) by a factor of  $(a_{\text{rad}}/g) \sim (w_c/\bar{w})$ .

The time it takes films to populate this scale-height is of order  $(h_f/v) \sim 3 \times 10^8 \text{ yr}$ , much shorter than the age of the Galaxy.

## 3. IMPLICATIONS

Thin films of the required surface-area per unit mass could be produced naturally by coagulation of dust particles in the midplane of protoplanetary disks (Moro-Martín 2019; Luu et al. 2020) or artificially by technological civilizations like ours (Bialy & Loeb 2018; Loeb 2021).

The potential population of films above the Galactic disk would scatter starlight. Limiting their cumulative optical-depth for scattering to be below observed limits (Lauer et al. 2022), we find that the fraction,  $f_g$ , of the interstellar gas mass incorporated into thin films of effective width,  $\bar{w}$ , is limited to the small value, well below the abundance of heavy elements,

$$f_g < 2 \times 10^{-3} \left( \frac{\bar{w}}{w_c} \right), \quad (4)$$

Interstellar films with  $\bar{w} \gg w_c$  (Bialy & Loeb 2018), would enter the solar system and could be identified by the upcoming *Legacy Survey of Space and Time* (LSST) on the Vera C. Rubin Observatory (Bianco et al. 2022), as they would reflect sunlight during their passage close to Earth, similarly to the first reported interstellar object 1I/2017 U1/'Oumuamua (Meech et al. 2017).

## ACKNOWLEDGEMENTS

This work was supported in part by a grant from the Breakthrough Prize Foundation and by Harvard's *Black Hole Initiative* which is funded by grants from GBMF and JTF. I thank Morgan MacLeod and Sunny Vagnozzi for insightful comments on the manuscript.

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