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P2 7 What do stars do best? Shine!

Joel E. Grout, Oliver J. T. Brough, Corban C. B. Gardiner, Tom E. Halliday

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

In the film 'Stardust', the magical realm of Stormhold encounters a fallen star in the form a human woman. In the final encounter against the evil witch, she does what stars do and shines as bright as she can to destroy said witch. By modeling the 'starlight' as surface power density (surface irradiance) equivalent to the Sun at 6.41 $\times 10^7$ Wm^{-2}, we determined a radiation pressure acting on the witch to be 1.48 $\times 10^{-3}$ Pa at a distance of 3 m. For a radiation pressure strong enough to destroy human skin, we calculated a surface irradiance of 1.17 $\times 10^{18}$ Wm^{-2}.

Introduction

The film Stardust introduces a realm where stars are in the form of human beings. A star named Yvaine is knocked out of the sky unwittingly and undertakes an adventure in order to get home, falling in love with a young man (Tristan) on the way. When an evil witch (Lamia) tries to take Yvaine and eat her heart, to grant herself everlasting life, Yvaine uses her love for Tristan and her natural ability as a star to shine so bright that Lamia is obliterated [1].

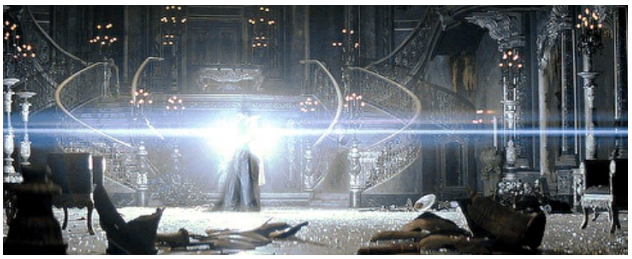

Figure 1: The final shine of Yvaine to Obliterate Lamia in the climax of the film Stardust [1]

Theory

We choose to model the cause of obliteration as radiation pressure strong enough to overcome the tensile properties of the skin. The mean ultimate tensile strength of skin has been recorded to be 27.2 ± 9.3 MPa [2] so for this paper we will use 27 MPa. We ignore any temperature effects on the surroundings. We take the radiation pressure in terms of photons and their energies defined as

$$p = \frac{h}{\lambda} = \frac{E_p}{c}, \tag{1}$$

where p is photon momentum, h is Planck's constant, λ is wavelength, c is the speed of light and E_p is the energy of a photon that can be quantised as [3]

$$E_p = \frac{hc}{\lambda}. \tag{2}$$

We express that surface irradiance, H, is just a wave of irradiance, I_f, incident on a surface with area, A, which is assumed to be a perfect absorber. Mathematically this is represented by the product of I_f and A. We assume the flux of photons is equal to I_f/E_p and multiplied the

momentum given in Equation 1 by this to achieve a radiation pressure as followed:

$$P_{rad} = p\,\frac{I_f}{E_p} = \frac{I_f}{c}. \tag{3}$$

From this, we developed our model to express the irradiance of Yvaine. We chose to model Yvaine's power around our best known star, the Sun. The irradiance can be defined a distance from the Sun as

$$I_f = \frac{R_{star}^2}{d^2}\,H_{Sun}, \tag{4}$$

where R_{star} is the radius of the source, d is the distance from the source and H_{Sun} is the surface irradiance of the Sun [4]. This can be calculated by the Stefan Boltzmann black-body equation using σT^4 where T is temperature and σ is the Stefan Boltzmann constant [5]. This comes out to be 6.41 $\times 10^7$ Wm^{-2} at a surface temperature T of 5800 K [6]. If we assume Yvaine to be a sphere when she shines of radius 0.25 m and Lamia to be standing approximately at a distance of 3 m away, then the irradiance is calculated to be $\approx$ 445000 Wm^{-2}. If we input this back into Equation 3, we find that Lamia would be subjected to 1.49 $\times 10^{-3}$ Pa of pressure.

Discussion

Our value of radiation pressure is far too low to be noticeable by any living being and hence Lamia would be unaffected, if not a bit blinded. We reverse engineer these equations to find what surface irradiance Yvaine would need to cause obliteration. If we assume that the breaking tensile strength of skin to be 27 Mpa, we find that her irradiance needs to be greater than 8.09 $\times 10^{15}$ Wm^{-2}. Keeping the size of the source and distance from the source consistent, we find that a value of H_{Sun} would have to be greater than 1.17 $\times 10^{18}$ Wm^{-2}. In reality, the temperature emitted by Yvaine would destroy much more of the surroundings than just Lamia.

Conclusion

The film Stardust's climactic ending sequence would not end well for our heroes if Yvaine is modelled off our Sun's surface irradiance, due to the fact she is a very small emitting source. We found that the surface irradiance of Yvaine would have to be 1.82 $\times 10^{10}$ times greater than the surface irradiance of the Sun to cause skin to tear apart due to radiation pressure and for the realm of Stormhold to be safe.

References

[1] Stardust (2007), [DVD], Directed by Matthew Vaughn, Marv Films and Ingenious Film Partners, and Paramount Pictures

[2] A.J. Gallagher, A. Ní Anniadh1, K. Bruyere, M. Otténio, H. Xie, M.D. Gilchrist1, *Dynamic Tensile Properties of Human Skin*, IRCOBI Conference 2012, IRC-12-59

[3] `https://en.wikipedia.org/wiki/Radiation_pressure` [Accessed 7th November 2023]

[4] `https://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-in-space` [Accessed 7th November 2023]

[5] `https://byjus.com/jee/stefan-boltzmann-law/#:~:text=What%20Is%20Stefan%20Boltzmann%20Law,fourth%20power%20of%20the%20temperature.&text=Where%20e%20%3D%20emissivity%20(which%20is,lies%20between%200%20to%201.` [Accessed 6th November 2023]

[6] `https://earthobservatory.nasa.gov/features/EnergyBalance/page2.php#:~:text=(Illustration%20adapted%20from%20Robert%20Rohde.)&text=The%20surface%20of%20the%20sun,visible%20and%20near%2Dinfrared%20light.` [Accessed on 7th November 2023]