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The Communicating Pipe Model for Icy Plumes on Enceladus

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Abstract

We analysis the "communicating pipe" model on Enceladus, and predict that Saturn's strong tidal force in Enceladus is playing a significant role in the plumes. In this model, the scale of the volcanoes can be evaluated based on the history of the craters and plumes. The correspondence of the data and observation make the model valid for the eruption. So it is imaginable that tidal force is pushing the liquid out through the "communicating pipe" while reshaping the surface on Enceladus.

1. Introduction

Cassini has passed by Enceladus several times in 2005, bringing back much surprising information. In March and October, 2008, Cassini's fly-by which sends many clear pictures has proved the magnificent ice-volcano and the young parallel rifts in the south polar terrain again. As shown in the picture offered by National Aeronautics and Space Administration (NASA), there exits magnificent icy plume on Enceladus' south polar terrain, while no plume has been observed in anyplace else. The observation also shows that many ancient rifts, which are probably created by tidal force, exit on Enceladus' global surface. Except for the ancient rifts globally, there are many young fissures in the south pole, which are roughly parallel. The closer observation has shown that 4 "tiger stripes" (the linear depressions) are each typically about 500m deep, 130 Km in length, and are about 35 Km apart [1]. It is difficult to believe a mass of substance are spurting out supersonically on such a tiny icy moon. The main substance is H_2O due to the observation. Stellar occultation and mass spectrometer data suggest that the vapor plume mass flux is 120-180 Kg/s [2], and the velocity of the plume can reach the escape speed, so as to supply the substance source of E ring. The average temperature on the surface of Enceladus is only 75 K, but in the south polar region the mean temperature is as high as 145 K, with liquid water beneath the icy shell.

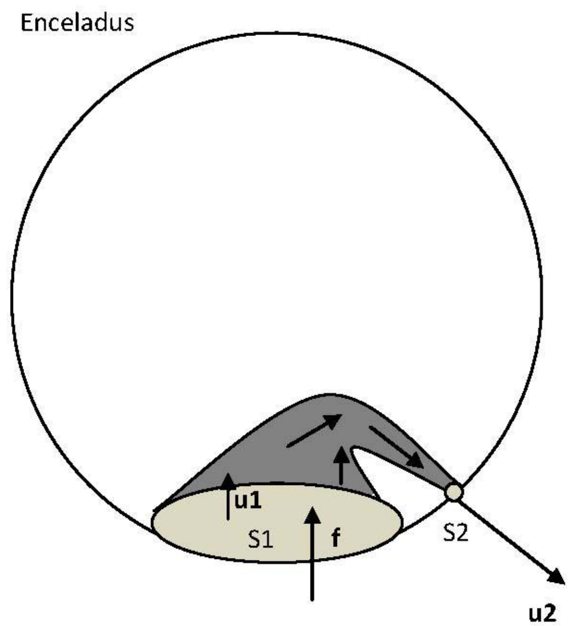

Figure 1: "Communicating pipe" model for the plume.

2. Communicating pipe model

We would like to propose that the "communicating pipe" model will be one possible mechanism for plume: the higher pressure at south polar point makes the fluid erupt at the place where the pressure is relatively lower. The "communicating pipe" model is shown as Fig. 1. In the figure, f stands for the outer pressure which makes the area S_1 sink with the velocity of u_1; after going through the pipe noted as the grey part, the fluid will erupt at the crater area of S_2, with the average velocity of u_2.

If we were to solve the motion of the internal fluid, many unclear details such as the general circulation of sea, or the pressure increase after liquid is heated, should be considered. However, the time average in the history of the rifts will tell us the plume scale effectively, and the data fits the observation well.

The mechanism is not obscure: As the south polar region is tidally pressed, the terrain in someplace goes down, while the material is spurting out somewhere else; Because of the conservation relationship in this process, the lost mass when the terrain goes down will spurt out entirely; The plume speed is so high that a small part of the mass can escape, and the other parts are sprinkled on the much broader surface of Enceladus, engendering “snow” on Enceladus’ surface, which makes the albedo on Enceladus extremely high (~90%).

Treating the process above as a quasi-static one, based on the mass conservation relation we have:

$$\rho_1 u_1 S_1 = \rho_2 u_2 S_2 \ , \tag{1}$$

where ρ_1 stands for the sinking crust’s density, ρ_2 stands for the spurted out material’s density. It is observed that as the atmospheric pressure on the surface of Enceladus is extremely low, the volume per mole of substance after spurting out is 24,000 times that of liquid water [1]. So if the shell density adopts the average density $1.6083*10^3$ Kg/m^3, we can calculate that:

$$\frac{\rho_1}{\rho_2} = 38600 \tag{2}$$

Note the width between the rifts d=35 Km, the rifts’ length s=130 Km, depth L=500 m, it is observed that the history of the rifts is as young as 500,000 years or younger [1], namely $t=1.58*10^{13}$ s, for a uniform velocity model we have:

$$S_1 = sd \tag{3}$$

$$u_1 = \frac{L}{t} \tag{4}$$

In Cassini’s images, the brightness profile up to one Enceladus radius above the surface fits a model in which the vertical velocity v has a Gaussian distribution[1], i.e. proportional to $\exp(-v^2/u_2^2)$, while the other velocity components are zero. As a reasonable estimation, when there is about 0.3% of the mass escape based on Gauss distribution, the average velocity u_2 is about 80 m/s. Moreover, we can calculate the corresponding plume height h.

Based on the energy conservation law we have:

$$\frac{1}{2}{u_2}^2 - \frac{Gm}{R} = -\frac{Gm}{R+h} \tag{5}$$

So the plume height h=31.8 Km, a reasonable height compared with the photos.

Go on with the discussion of formula (1). After substituting (2), (3), and (4) into (1), we will find that the crater area caused by one rift is:

$$S_2 = 70m^2 \tag{6}$$

On a moon with a diameter of only about 500 Km, such a crater is quite large, easily observed and shown in photos. There are 4 larger rifts in the south polar region, and more fissures are shown in higher resolution pictures, so the plume scale is probably larger, i.e. the practical area is broader than 70 m^2, or the average speed surpasses 80 m/s.

3. Conclusions

So far, we can figure out the images of the south polar plume on Enceladus sketchily: Because of the short distance with Saturn, Enceladus is bearing enormous tidal force; While tidal force is reshaping the terrain on Enceladus, the fluid is erupting through the “communicating pipe”; This process has been sustained for 500,000 years, making the new young “tiger stripes” on Enceladus’ south polar terrain.

Acknowledgements

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References

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