THE DYNAMIC NATURE OF THE ADAMS RING ARCS
- FRATERNITE, EGALE (2,1), LIBERTE, COURAGE

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ABSTRACT

By considering the finite mass of Fraternite, the dynamic nature of the Adams ring arcs is regarded as caused by the reaction of a test body (a minor arc) through the Lindblad resonance (LR). Assuming the eccentricity of the test body is larger than that of Galatea, this generates several locations along the ring in the neighborhood of Fraternite where the time averaged force on a test body vanishes. These locations appear to correspond to the time dependent configuration of Egalite (2,1), Liberte, and Courage, and seem to be able to account for the dynamics of the arcs. Such a configuration is a dynamic one because the minor arcs are not bounded by the corotation eccentricity resonance (CER) externally imposed by Galatea, but are self-generated by LR reacting to the external fields.

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Since the first observation of the Neptune arcs [Hubbard et al 1986], the Voyager 2 mission provided a closed-up measurements of the arcs [Smith et al 1989]. Follow-up ground observations have revealed changes in arc brightness [Sicardy et al 1999, Dumas et al 1999]. More recently, these dynamic natures of the arcs are confirmed in another ground observation [de Pater et al 2005]. These arcs are named Fraternite, Egalite (2,1), Liberte, and Courage. Measuring from the center of the main arc Fraternite, they extend a total of about 40° ahead of Fraternite. According to the currently accepted theory, these arcs are confined by the corotation resonance potential of the inner moon Galatea because of its eccentricity (CER). Orbital parameters are as such that it is at the 42/43 resonance giving a resonant site of 8.37° on the Adams ring [Goldreich et al 1986, Porco 1991, Horanyi and Porco 1993, Foryta and Sicardy 1996]. With Fraternite centered at the potential maximum of CER spanning approximately 5° on each side, it appears to fit well the CER site. Nevertheless, we remark that the 10° span of Fraternite contains within it two unstable potential points which ought to reduce the angular spread. Furthermore, the minor arcs leading ahead of Fraternite and their angular span are mislocated with the CER potential maxima. In order to account for these minor arcs, the 84/86 corotation resonance due to the inclination of Galatea (CIR) is remembered giving a potential site of 4.18° which offers more options in housing the minor arcs. On the other hand, this CIR model contradicts directly with the main arc Fraternite. While the arc configuration has yet to be resolved in detail, recent comparisons among the Voyager and different ground observations have shown that the arc intensities are changing in time. Occassionally, some arcs flare up and others fade away. Furthermore, the arc configuration appears to be changing in time as well. The leading arc Courage appears to have leaped over to another CER site recently [de Pater et al 2005]. These dynamic properties show that the arcs are not in a stable equilibrium configuration contrary to the corotation resonance scenario.

Here, we complement the CER model by considering the role of Fraternite with its finite mass and eccentricity. The finite mass of Fraternite has been suggested by Namouni and Porco [2002] to pull on the pericenter precession of Galatea to account for the mismatch between the CER pattern speed and the mean motion of the arcs. By following on this suggestion, the
Lindblad resonance (LR) of a test body (a minor arc) under the presence of Fraternite has been evaluated. Through the equations of motion of the test body, it is shown that the LR of the test body generates locations on the Adams ring where the time averaged force acting on it vanishes. These locations appear to be compatible to Egalite (2,1) [Tsui 2007]. In this model, where the direct action of Fraternite surpasses the CER potential of Galatea, the arc locations are determined by the LR reaction of the arc. For this reason, the arc configuration does not have to be static. We extend this same model to include also Liberte and Courage for the entire arc system.

According to this LR reaction model, only Fraternite is confined by the externally imposed CER of Galatea, while the minor arcs are hosted at these locations by Fraternite. The locations of the minor arcs are given by the roots of Eq.(9) of Tsui [2007] which is

\[
4 \tan\left(\frac{1}{2} \Delta \theta_{sf}\right) \sin\left(\frac{1}{2} \Delta \theta_{sf}\right) \cos[(n + 1)\Delta \theta_{sf} - \Delta \phi] = -0.5490 \times 10^8 \frac{m_f}{M},
\]

where \(\Delta \theta_{sf} = (\theta_s - \theta_f)\) is the difference of the longitudes, \(\Delta \phi = (\phi_s - \phi_f)\) is the difference of the arguments of perihelion, and \(n = 42\). The subscripts \(s\) and \(f\) denote the test body and Fraternite, and \(M\) is the mass of the central body Neptune. The third factor, \((n+1)\Delta \theta_{sf}\), on the left side is a fast oscillating term that gives \((n+1)\) CER sites along the Adams ring. The first two factors, \(\Delta \theta_{sf}/2\), on the left side are slow oscillating terms that modulate the third factor. The left side of Eq.(1), with \(\Delta \phi = 0\), is plotted in Fig.1 in thick line. It shows the fast oscillations of the third factor. These oscillations grow in amplitude because of the slow modulations of the first two factors. With mass ratio \(m_f/M = 6.4 \times 10^{-10}\), which corresponds to \(m_f = 6.4 \times 10^{16}\) Kg for Fraternite, the right side of Eq.(1) is also indicated in Fig.1 through a straight horizontal line. The intercepts of these two plots give the roots of Eq.(1) at \((11.8^0\) (Egalite 2), \(13.8^0\) (Egalite 1)), \((19.3^0, 22.7^0\) (Liberte)), \((27.4^0, 31.2^0\) (Courage 1999)), \((35.7^0, 39.7^0\) (Courage 2003)), \((44.0^0, 48.1^0)\), where the corresponding arcs are indicated at the estimated locations. The intercepts are grouped in pairs within brackets. Each pair comes from a downward cycle of
the fast oscillating third factor. We have also superimposed a set of constant amplitude CER sites in Fig.1, with Fraternite centered at a potential maximum, in thin line for comparison and discussion purposes. Since the right side of Eq.(1) is much less than unity, the intercepts are close to the $y = 0$ axis. For small $\Delta \theta_{sf}$, the first two factors are most important in determining the nearest intercepts corresponding to Egalite (2,1). Nevertheless, the position of these two intercepts for Egalite (2,1) are sensitive to the mass variation of Fraternite due to the mass factor $(m_f/M)$ on the right side. They could even disappear should Fraternite be fifty percent more massive. They are also sensitive to $\Delta \phi$ although not so much as the mass ratio.

As $\Delta \theta_{sf}$ increases, the intercepts are approximately given by the third factor

$$
\cos[(n + 1)\Delta \theta_{sf} - \Delta \phi] \simeq 0,
$$

(2)

which are near the mid-points of CER sites, not near the maxima. The mid-points are separated by 4.19° which reminds us the separation of CIRs. But, with Fraternite centered at a CIR maximum, the minor arcs would be positioned near the minima of CIRs, instead of maxima. Although the intercepts are there along the entire Adams ring, the action of Fraternite’s field gets progressively attenuated as such that the arcs can only be confined in its neighborhood. This happens to agree with the arc signals that attenuate away from Fraternite. The minor arcs indeed get less and less intense as they get farther and farther away from Fraternite. Let us now consider the slow change of $\Delta \phi$. This would make the cosine function of Eq.(2) drift by half a cycle, and cause the pairs of intercepts to drift out by approximately 2° which could account for the slight variations of the arc positions among measurements of different years.

Since the roots of Eq.(1) are locations where the force on a test body vanishes only on a time averaged base due to its reaction to the external fields through LR, this scenario is not one of a static equilibrium imposed externally. Test bodies could migrate on a long time scale from one site to another leading to flaring up of some arcs and fading away of others. This could also displace (resonant jump) Courage from 31.2° to 39.7° [de Pater et al 2005]. Although there are
only arcs in the leading positions ahead, it seems to the author that the measurements of de Pater et al [2005] tend to indicate also weak signals, under large background noise, of arcs in the trailing positions behind. It would be consistent to this dynamic model should weak new arcs are confirmed in the conjugate positions of Egalite on the trailing side.
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Fig. 1.— The left and the right sides of Eq.(1), denoted by the $y$ label, are plotted as a function of $\Delta \theta_{sf}$ in degree. The intercepts give the roots of Eq.(1) that define the locations where the time averaged force on a test body vanishes. Constant amplitude CER sites with Fraternite centered at a potential maximum are also shown in thin line for comparisons.