A Galaxy’s Arms Are Not Collections of Stars but Patterns the Stars Pass Through

— Placing a pattern rotating at **25** km/s/kpc in a disc with a flat rotation speed of **220** km/s gives a corotation radius of **8.800000** kpc — the separator is whether the pattern is stuck to the material or rotates at a speed of its own — [Paper 782]

Yuuki YAMAGISHI (山岸 勇輝)
Yamagishi Complexity Torus Lab, Japan
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— From thinking to syncing. —

Abstract

Looking at the arms of a spiral galaxy, stars seem to be lined up in that shape. But the inner disc rotates faster, so arms stuck to the stars would soon wind up.Arms rotating with the stars and arms as a pattern rotating at a speed of its own are set side by side, and how stars pass through the arms is counted.No new theorem or law is claimed. First, there is just one radius where pattern and stars rotate together——a corotation radius of 8.800000 kpc (Section 2). **Second, inside it, stars overtake the pattern——a star at 8 kpc overtakes at 2.500000 km/s/kpc and, with two arms, passes through an arm every 1228.729944 million years** (Section 2). **Third, outside it, the direction reverses——at 12 kpc the difference is −6.666667 km/s/kpc and the pattern overtakes the stars** (Section 2). **Fourth, and this is the core. If the arms were stuck to the stars, the shape would not survive——orbits at 4 and 8 kpc would differ by 44.761667 turns in 10 billion years, winding the pitch down to 0.203720 degrees** (Section 3). **Fifth, the same type appears on roads——at a density of 100 vehicles/km cars move at 33.333333 km/h and the pattern at −33.333333 km/h, so cars pass through the pattern** (Section 4). **Sixth, the separator is whether the pattern is stuck to the material or rotates at a speed of its own——“stars are lined up along the arms” has no truth value until one says at what speed the pattern rotates** (Section 5). **Keywords**: spiral arms, density waves, corotation radius, differential rotation, winding problem, kinematic waves.

Scope of this paper (scope note): **No new theorem or law is claimed——arms stuck to material winding up under differential rotation (the winding problem), the view of arms as density waves rotating at a speed different from the stars (Lin and Shu), corotation and Lindblad resonances, and density waves on roads moving at a speed different from the cars (Lighthill and Whitham) are all known (Lin and Shu 1964, Binney and Tremaine 2008, Lighthill and Whitham 1955).Values are representative——a flat rotation speed of 220 km/s and a pattern speed of 25 km/s/kpc are for comparison; the measured values of the Milky Way are not claimed.The mechanism that makes arms is not entered——the theory of density waves sustained by self-gravity is only named, and the pattern speed is taken as given.The pitch is a comparison value——12 degrees is a scale for measuring winding time; the pitch of real arms is not claimed.The road is a comparison of the same type——only the linear Greenshields relation is used, and neither the onset of jams nor the motion of shock waves is entered.Relation to earlier papers**: **Paper 394 showed that the same flow is realized by two different states, so measuring the flow does not tell which one you are in——its scope note stated that the onset of jams and shock waves were not treated and only steady states were considered. There the flow did not represent the state. Here the pattern speed is derived from the same relation, and the pattern is counted as not representing the cars (the cars pass through it), set beside galactic arms.**What is added is **counting how the direction of overtaking between stars and pattern swaps inside and outside corotation**, **deriving the passage interval of 1228.729944 million years and the resonance radii, confirming the resonances numerically**, **deriving the winding of arms stuck to stars two ways, by numerical differentiation and by formula**, and **setting the road's pattern speed beside it and placing the separator on the speed at which the pattern rotates**.

1. Notation and the Question

Setting: **in a disc with flat rotation speed v_0, a star at radius R has angular velocity $\Omega(R) = v_0/R$. When the arm pattern rotates at a constant angular velocity Ω_p, the following quantities are fixed (m is the number of arms and κ the epicyclic frequency of the stars).**

$$R_{\mathrm{CR}} = \frac{v_0}{\Omega_p}, \qquad T_{\mathrm{pass}} = \frac{2\pi}{m\,|\Omega(R) - \Omega_p|}, \qquad \kappa = \sqrt{2}\,\Omega, \qquad \Omega \mp \frac{\kappa}{2} = \Omega_p$$

If the arms were stuck to the stars, the arm pitch i after time t would be as follows.

$$\tan i = \frac{1}{R\,|\partial\phi/\partial R|} = \frac{1}{\Omega\, t}$$

Question: **do the stars that seem lined up along the arms rotate together with the arms?**

2. Stars Passing Through the Pattern

Computation 2.1: **with $v_0 = 220$ km/s and $\Omega_p = 25$ km/s/kpc, the corotation radius, the difference between star and pattern angular velocities at each radius, the passage interval through the arms, and the Lindblad resonance radii**

for two arms were derived.

radius	star angular velocity − pattern angular velocity
4 kpc	+30.000000 km/s/kpc
8 kpc	+2.500000 km/s/kpc
8.8 kpc (corotation)	0.000000 km/s/kpc
12 kpc	−6.666667 km/s/kpc

quantity	value
corotation radius	8.800000 kpc
orbit of a star at 8 kpc	223.405444 million years
arm passage interval (two arms)	1228.729944 million years
arm passage interval (four arms)	614.364972 million years
inner resonance (formula, numerical)	2.577460 kpc, 2.577460 kpc
outer resonance (formula, numerical)	15.022540 kpc, 15.022540 kpc

Observation 2.2

inside the corotation radius, stars overtake the pattern.A star at 8 kpc orbits in 223.405444 million years, but differs from the pattern by only 2.500000 km/s/kpc, so with two arms it passes through an arm every 1228.729944 million years——a star enters an arm, stays a while, and leaves.

Observation 2.3

outside, the direction reverses.At 12 kpc the difference is −6.666667 km/s/kpc and the pattern overtakes the stars. The resonance radii agree with the numerical solution to a largest difference of 9.372×10^{-9} kpc——inner stars pass through the same pattern from behind, outer stars from ahead.

3. If the Arms Were Stuck to the Stars

Computation 3.1: **an arm was first laid straight along the radius and rotated with the stars, and its pitch at 8 kpc derived two ways, by numerical differentiation and by formula.**

elapsed time	pitch (numerical)	pitch (formula)
1000 million years	**2.036355** degrees	**2.036356** degrees
10000 million years	**0.203720** degrees	**0.203720** degrees

> **Observation 3.2**
>
> **this is the core: if the arms were stuck to the stars, the shape would not survive.In 10 billion years orbits at 4 and 8 kpc differ by 44.761667 turns and the arm winds down to a pitch of 0.203720 degrees. Winding to a pitch of 12 degrees takes only 167.278208 million years, shorter than the 223.405444-million-year orbit of a star at 8 kpc——an arm stuck to the stars lies down before a single orbit is complete.**

> **Observation 3.3**
>
> **numerical differentiation and formula agree to a relative difference of 1.562×10^{-8}.**

4. The Same Type on a Road

Computation 4.1: **with the Greenshields relation, free speed 100 km/h and jam density 150 vehicles/km, the car speed $v = v_f(1 - \rho/\rho_j)$ and the speed of the pattern (the density wave) $c = dq/d\rho = v_f(1 - 2\rho/\rho_j)$ were derived. The pattern speed was also derived by numerical differentiation (largest difference 4.244×10^{-10} km/h).**

density	car speed	pattern speed	speed of cars past the pattern
25 vehicles/km	**83.333333** km/h	**66.666667** km/h	**16.666667** km/h
75 vehicles/km	**50.000000** km/h	**0.000000** km/h	**50.000000** km/h
100 vehicles/km	**33.333333** km/h	**−33.333333** km/h	**66.666667** km/h
125 vehicles/km	**16.666667** km/h	**−66.666667** km/h	**83.333333** km/h

Observation 4.2

the same type appears on roads.At a density of 100 vehicles/km cars move forward at 33.333333 km/h while the jam pattern moves backward at −33.333333 km/h. At 75 vehicles/km the pattern stands still and only the cars pass through at 50.000000 km/h——the cars inside a jam are constantly being replaced.

5. The Separator

Observation 5.1

the separator is whether the pattern is stuck to the material or rotates at a speed of its own.If stuck, differential rotation winds it up to a pitch of 0.203720 degrees in 10 billion years. If it is a pattern with its own speed, the shape is kept and stars pass through it every 1228.729944 million years——"stars are lined up along the arms" has no truth value until one says at what speed the pattern rotates.

Observation 5.2

beside Paper 394.Paper 394 showed, with steady states alone, that the same flow is realized by two states and the flow does not represent the state——here the pattern speed is derived from the same relation, and the pattern is counted as not representing the cars, just as a galaxy's arms do not represent its stars.

Observation 5.3

what is not said.Values are representative, and neither the mechanism that makes and keeps arms, nor the Milky Way's measured values, nor the onset of jams is treated——what is shown is that a visible shape and the material making it can move at different speeds.

6. Roll Call and Closing

1. **corotation radius 8.800000 kpc** (Computation 2.1): **where pattern and stars keep pace.**
2. **difference +2.500000 km/s/kpc** (Observation 2.2): **stars overtake.**
3. **passage interval 1228.729944 million years** (Computation 2.1): **entering and leaving an arm.**

4. **−6.666667 at 12 kpc** (Observation 2.3): **the direction reverses.**
5. **resonances 2.577460 and 15.022540 kpc** (Computation 2.1): **matching the numerical solution.**
6. **44.761667 turns of difference** (Observation 3.2): **the core.**
7. **pitch 0.203720 degrees** (Computation 3.1): **wound up.**
8. **167.278208 million years to 12 degrees** (Observation 3.2): **shorter than an orbit.**
9. **cars 33.333333, pattern −33.333333 km/h** (Observation 4.2): **the same type on a road.**
10. **at what speed the pattern rotates** (Observation 5.1): **the separator; Paper 394.**

Closing: **A galaxy's arms are not collections of stars but patterns the stars pass through.Placing a pattern rotating at 25 km/s/kpc in a disc with flat rotation speed 220 km/s gives a corotation radius of 8.800000 kpc; a star inside it at 8 kpc overtakes the pattern at 2.500000 km/s/kpc and, with two arms, passes through an arm every 1228.729944 million years——at 12 kpc the direction reverses and the pattern overtakes the stars.If the arms were stuck to the stars, orbits at 4 and 8 kpc would differ by 44.761667 turns in 10 billion years, winding the pitch down to 0.203720 degrees, and reaching 12 degrees in 167.278208 million years, before a single orbit——the shape survives because it rotates at a speed different from the material.On a road too, at 100 vehicles/km cars move at 33.333333 km/h and the pattern at −33.333333 km/h, so cars pass through the pattern.The separator is whether the pattern is stuck to the material or rotates at a speed of its own.Placed among the earlier papers——Paper 394 counted a flow that does not represent the state; this counts a pattern that does not represent the material.To be honest——values are representative, and neither the mechanism that makes arms nor the Milky Way's measured values are treated.**

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Yuuki YAMAGISHI (山岸 勇輝)

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