On the variation of the energy scale 15

Galaxy interactions revisited

by

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Summary

The hypothesis has been put forward that the energy scale can vary from location to location. Such energy scale variations can explain the rotation curves of spiral galaxies and the high velocities of galaxies in clusters of galaxies without the need for any dark matter.

This paper looks at interactions between disk galaxies in near miss collisions, where galaxies have a variation of the energy scale but no dark matter. The direction of rotation of the individual galaxies is an important factor in the production of tidal tails. Simple computer models show that variations in the energy scale can produce the broad characteristics of the observed galaxy interactions. There is no need to introduce any dark matter.

1 Introduction

1.1 As well as partaking in the general expansion of the Universe galaxies have their own peculiar velocities. This means that galaxy interactions are relatively common events. These interactions vary from near-miss fly-bys to full-on collisions.

1.2 Galaxies are gravitating objects and interactions are governed by Newton's (and Einstein's) law of gravity. A pair of interacting galaxies can be treated as two masses in orbit about their common centre of gravity.

1.3 Elliptical galaxies are fairly tightly bound systems and near-miss interactions do not produce much in the way of gravitational disturbances. On the other hand interactions between spiral (disk) galaxies can be spectacular and produce large tidal tails. Many of these have been captured by the Hubble space telescope.

1.4 The recent paper by Holincheck et at (2016) has looked at 62 interactions and reproduced them through computer simulations. Dark Matter is not invoked specifically in the simulations. Instead each galaxy is assumed to have a fixed gravitational potential made up of both baryonic matter and dark matter. The disk of each galaxy is made up of a cloud of massless particles. The computer simulations look at how the massless particles behave in the interacting gravitational potentials. A grid search technique then matches the simulations to actual interactions. In most cases a good match is obtained.

1.5 The paper "On the variation of the energy scale: an alternative to dark matter" (Jo.Ke, 2015) is referred to in this paper as simply "JoKe1". This paper introduced the idea of variations of the energy scale to explain the rotation curves of spiral galaxies. It used the simple model of a galaxy point mass and a Gaussian energy scale variation. This was improved in JoKe2 (2015) to use a Gaussian density distribution and a Gaussian variation in the energy scale. And JoKe3 (2015) applied the model to a large sample of 74 spiral galaxies.

1.6 Other papers in this series have dealt with: clusters of galaxies; collisions between clusters of galaxies; galaxy interactions; gravitational lensing; primordial density perturbations; cosmology.

1.7 Paper JoKe6 (2016) looked at near-miss collisions between galaxies and suggested there could be differences in the tidal effects between dark matter and variations in the energy scale.

1.8 This paper looks at near-miss collisions between rotating disk galaxies. Some simple numerical simulations confirm the broad nature of the tidal effects that result from different collision scenarios.

2 Interaction configuration

2.1 We consider the simple case of two coplanar rotating disk galaxies and a fly-by interaction. This is illustrated in Figure 1.

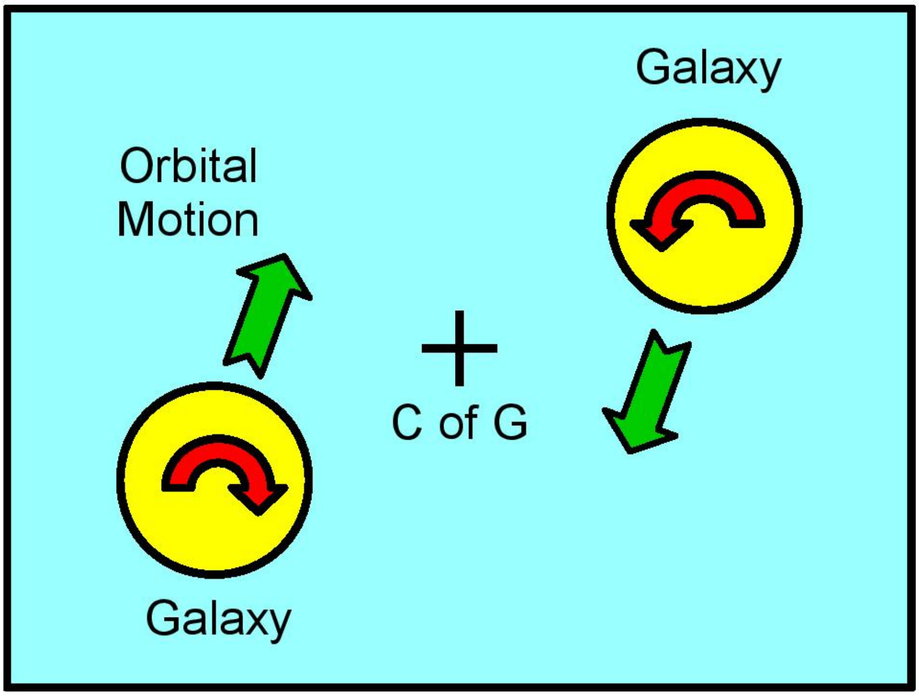


Figure 1. Galaxy interaction configuration. Two galaxies (yellow) in clockwise orbital motion (C) about their common centre of gravity (C of G). The lower left galaxy is rotating clockwise (C), whereas the upper right galaxy is rotating anticlockwise (A). The green arrows indicate the direction of orbital motion. The red arrows indicate the direction of rotation.

2.2 We take the mass of the galaxies to reside in the galaxy centre. This means the interaction is just two bodies orbiting one another about their common centre of gravity. So the fly-by interaction is just the orbital motion of two masses under Newtonian gravitation.

2.3 The galaxy centres are taken to be surrounded by a disk of massless particles. So during the interaction each particle is subject to the gravity of the two galaxy centres, but interactions between particles are ignored. This is the so-called restricted 3-body problem.

2.4 Seen from above the galaxies orbit one another in either a clockwise (C) or an anticlockwise (A) direction.

2.5 The particles in each galaxy disk rotate either clockwise (C) or anticlockwise (A) about the galaxy centre.

2.6 This means there are eight possible interaction configurations:
(a) galaxy interaction: C or A,
(b) galaxy A rotation: C or A,
(c) galaxy B rotation: C or A

2.7 However, the eight permutations reduce to just three different configurations once rotations and reflections are taken into account:
1) C[CC] = A[AA]
2) C[CA] = C[AC] = A[CA] = A[AC]
3) C[AA] = A[CC]
where the letters in square brackets represent the individual galaxies.

2.8 Figure 1 illustrates the interaction C[CA]. The two galaxies orbit one another in a clockwise (C) direction. The left galaxy is rotating clockwise (C); the right galaxy anticlockwise (A).

3 Gravity

3.1 The radial acceleration, $\boldsymbol{g}$, for Newtonian gravitation is

$$\boldsymbol{g} = -\frac{\boldsymbol{G\,M}}{\boldsymbol{r^2}} \tag{1}$$

where $\boldsymbol{G}$ is the gravitational constant; $\boldsymbol{M}$ is the mass of the attracting galaxy; $\boldsymbol{r}$ is the distance from star to galaxy centre.

3.2 Following previous papers in this series (JoKe1, 2015) the radial acceleration for a Gaussian variation in the energy scale is

$$\boldsymbol{g} = -\frac{\boldsymbol{G\,M}}{\boldsymbol{r^2}}\,\frac{\boldsymbol{\xi(0)}}{\boldsymbol{\xi(r)}} \tag{2}$$

where the scalar function, $\boldsymbol{\xi(r)}$, is given by

$$\boldsymbol{\xi(r) = 1 + \ \beta\ exp\{-r^2/\alpha^2\}} \tag{3}$$

where $\boldsymbol{\beta}$ is a pure number (of order 5); $\boldsymbol{\alpha}$ is a characteristic distance (or order 10kpc for a galaxy). $\boldsymbol{\xi(0)}$ is the value of $\boldsymbol{\xi}$ at the galaxy centre; $\boldsymbol{\xi(r)}$ the value of $\boldsymbol{\xi}$ at position r.

3.3 Near the galaxy centre, $\boldsymbol{r<\alpha}$, $\boldsymbol{\xi(r) \approx \xi(0) = 1 + \beta}$, and equation (2) reduces to equation (1). This means there are no differences in motions near the galaxy centre, between pure Newtonian gravity and gravity plus an energy scale variation.

3.4 At large distances, $\boldsymbol{r>\alpha}$, $\boldsymbol{\xi(r) \approx 1}$, and equation (2) reduces to Newtonian gravitation (inverse square law) but at a higher level with $\boldsymbol{M\,\xi(0)}$ replacing $\boldsymbol{M}$.

3.5 At intermediate distances, $\boldsymbol{r\simeq\alpha}$, equation (2) gives rise to flat rotation curves that closely match those observed in real galaxies (JoKe3, 2015). Thus the introduction of the variation in the energy scale gives rise to flat rotation curves without the need for any dark matter.

4 The model

4.1 The model consists of two galaxies that are identical in mass, size and number of particles.

4.2 Each galaxy is modelled as a central mass contained within a radius of 20 units. This is surrounded by a disk with outer radius 200 units which contains 4,000 massless particles.

4.3 If, during the interaction, a particle enters either central region then it is deemed to be swallowed.

4.4 The particles are distributed randomly across the disk. This means the surface density is roughly constant and there is no fall off in density towards the outer edge.

4.5 Initially each particle is in a circular orbit around its galaxy centre, where the gravitational acceleration is given by equation (2). This means, to begin with, the gravitational influence of the remote galaxy on each particle is completely ignored.

4.6 Once the model starts each particle is subject to the gravitational pull of both galaxies (the restricted three-body problem). Each galaxy has its own energy scale variation, ξ. The combined value at any point is taken to be the larger of the two values. So the variations simply overlap; their combined effect is not additive.

4.7 The point of closest approach is at time step 250 in all simulations.

4.8 Each particle has x,y coordinates. The initial speed is given by balancing the centripetal acceleration and the gravitational attraction

$$\frac{v^2}{r} = \frac{G\,M}{r^2}\,\frac{\xi(0)}{\xi(r)} \tag{4}$$

4.9 Each particle's acceleration is given by the component form of equation(2)

$$\ddot{x} = -GM\,\frac{\xi(0)}{\xi(r)}\,\frac{x}{r^3} \tag{5}$$

$$\ddot{y} = -GM\,\frac{\xi(0)}{\xi(r)}\,\frac{y}{r^3} \tag{6}$$

4.10 The model is advanced from one time step to the next using the Runge-Kutta-Nystrom (RKN) method for integrating second order differential equations. RKN is used directly on equations (5) & (6).

5 Numerical simulations

5.1 Figure 2 illustrates clockwise interactions, where the two galaxies orbit one another in a clockwise sense. The top images show the starting position and the point of closest approach at time step 250.

As mentioned above in "2: Interaction configuration" there are four possibilities:

(a) C[CC]. Clockwise interaction (C); green galaxy rotates clockwise (C); purple galaxy rotates clockwise (C).

(b) C[CA]. Clockwise interaction (C); green galaxy rotates clockwise (C); purple galaxy rotates anticlockwise (A).

(c) C[AC]. Clockwise interaction (C); green galaxy rotates anticlockwise (A); purple galaxy rotates clockwise (C).

(d) C[AA]. Clockwise interaction (C); green galaxy rotates anticlockwise (A); purple galaxy rotates anticlockwise (A).

It can be seen that (b) and (c) are essentially the same interaction.

5.2 Figure 3 illustrates anticlockwise interactions, where the two galaxies orbit one another in an anticlockwise sense. The top images show the starting position and the point of closest approach at time step 250.

Again as mentioned above in "2: Interaction configuration" there are four possibilities:

(a) A[AA]. Anticlockwise interaction (A); green galaxy rotates anticlockwise (A); purple galaxy rotates anticlockwise (A).

(b) A[AC]. Anticlockwise interaction (A); green galaxy rotates anticlockwise (A); purple galaxy rotates clockwise (C).

(c) A[CA]. Anticlockwise interaction (A); green galaxy rotates clockwise (C); purple galaxy rotates anticlockwise (A).

(d) A[CC]. Anticlockwise interaction (A); green galaxy rotates clockwise (C); purple galaxy rotates clockwise (C).

Again it can be seen that (b) and (c) are essentially the same interaction.

5.3 The images in Figures 2 & 3 can be applied to the observations of real galaxies so that the basic dynamics of the interactions can be understood.

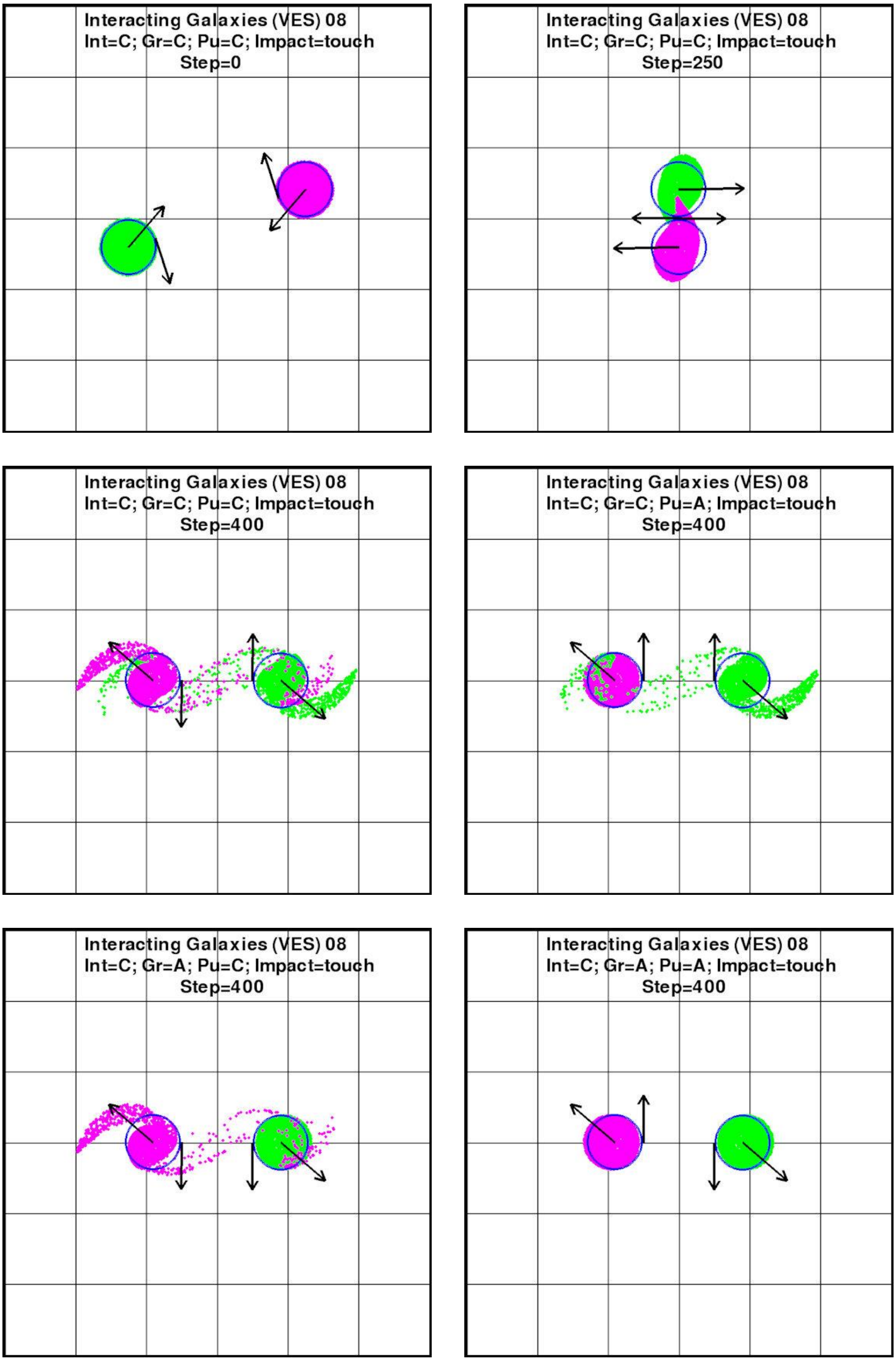


Figure 2. Clockwise (C) interactions. Top left is initial position for for all interactions (shown for C[CC]). Top right is closest approach for all interactions (shown for C[CC]). Other images are for time step 400 for interactions: C[CC]; C[CA]; C[AC]; C[AA].

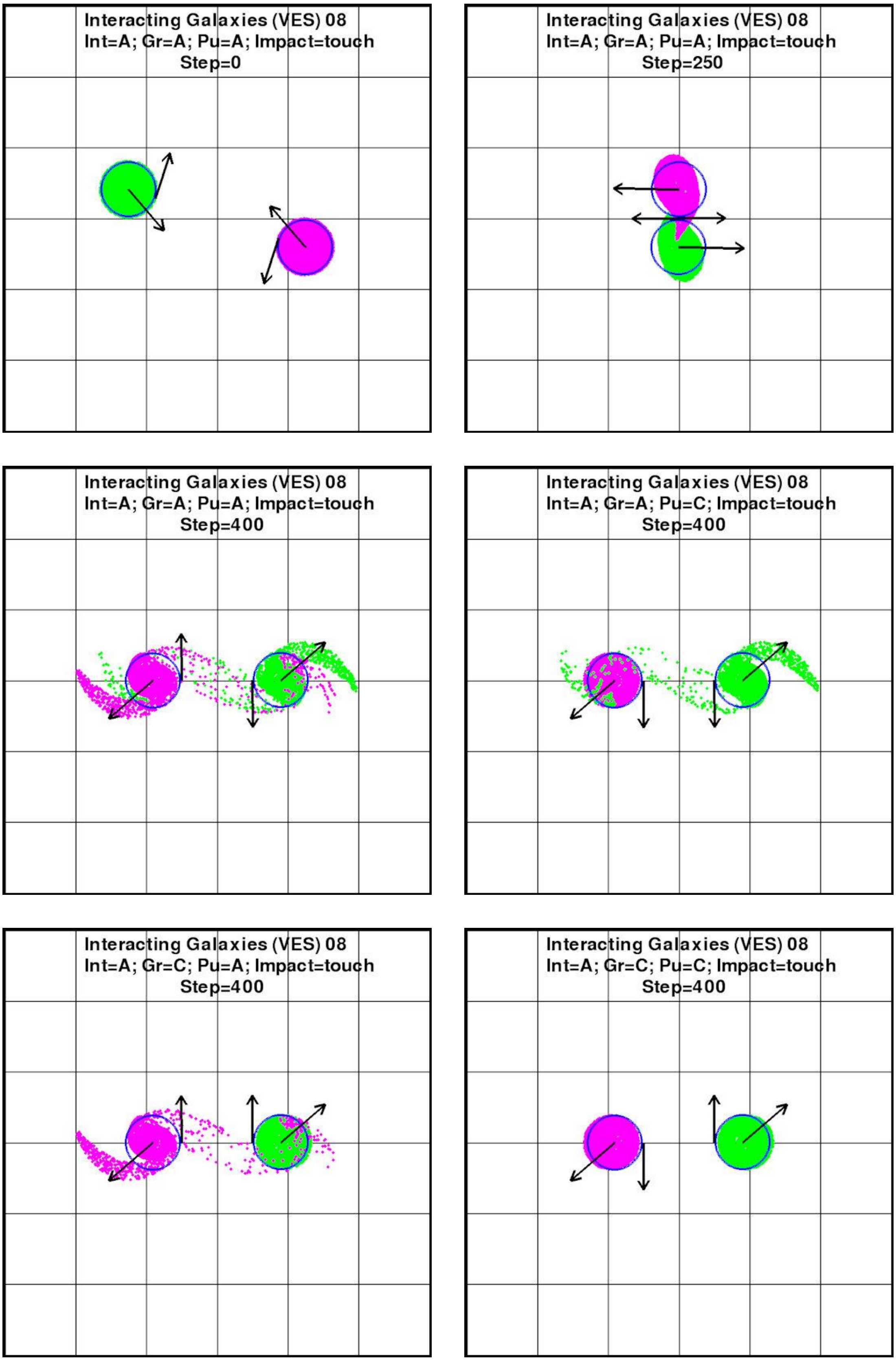


Figure 3. Anticlockwise (A) interactions. Top left is initial position for for all interactions (shown for A[AA]). Top right is closest approach for all interactions (shown for A[AA]). Other images are for time step 400 for interactions: A[AA]; A[AC]; A[CA]; A[CC].

5.4 Inside interaction

Figure 4 shows six images from the "C[AC] Inside" interaction, where the two galaxies interact in a clockwise (C) direction and overlap at the point of closest approach. The green galaxy rotates anticlockwise (A) and shows minimal tidal effects. The purple galaxy rotates clockwise (C) and shows considerable tidal disruption. Material from the purple galaxy ends up in orbit around the green galaxy.

5.5 Touch interaction

Figure 5 shows six images from the "C[AC] Touch" interaction, where the two galaxies interact in a clockwise (C) direction and just touch at the point of closest approach. The green galaxy rotates anticlockwise (A) and shows minimal tidal effects. The purple galaxy rotates clockwise (C) and shows considerable tidal effects. Material from the purple galaxy ends up in orbit around the green galaxy.

5.6 Near interaction

Figure 6 shows six images from the "C[AC] Near" interaction, where the two galaxies interact in a clockwise (C) direction and there is a small separation at the point of closest approach. The green galaxy rotates anticlockwise (A) and shows minimal tidal effects. The purple galaxy rotates clockwise (C) and shows large tidal effects. Material from the purple galaxy ends up in orbit around the green galaxy.

5.7 Far interaction

Figure 7 shows six images from the "C[AC] Far" interaction, where the two galaxies interact in a clockwise (C) direction and there is a considerable separation at the point of closest approach. The green galaxy rotates anticlockwise (A) and shows minimal tidal effects. The purple galaxy rotates clockwise (C) and shows limited tidal effects. There is no material transfer from purple to green.

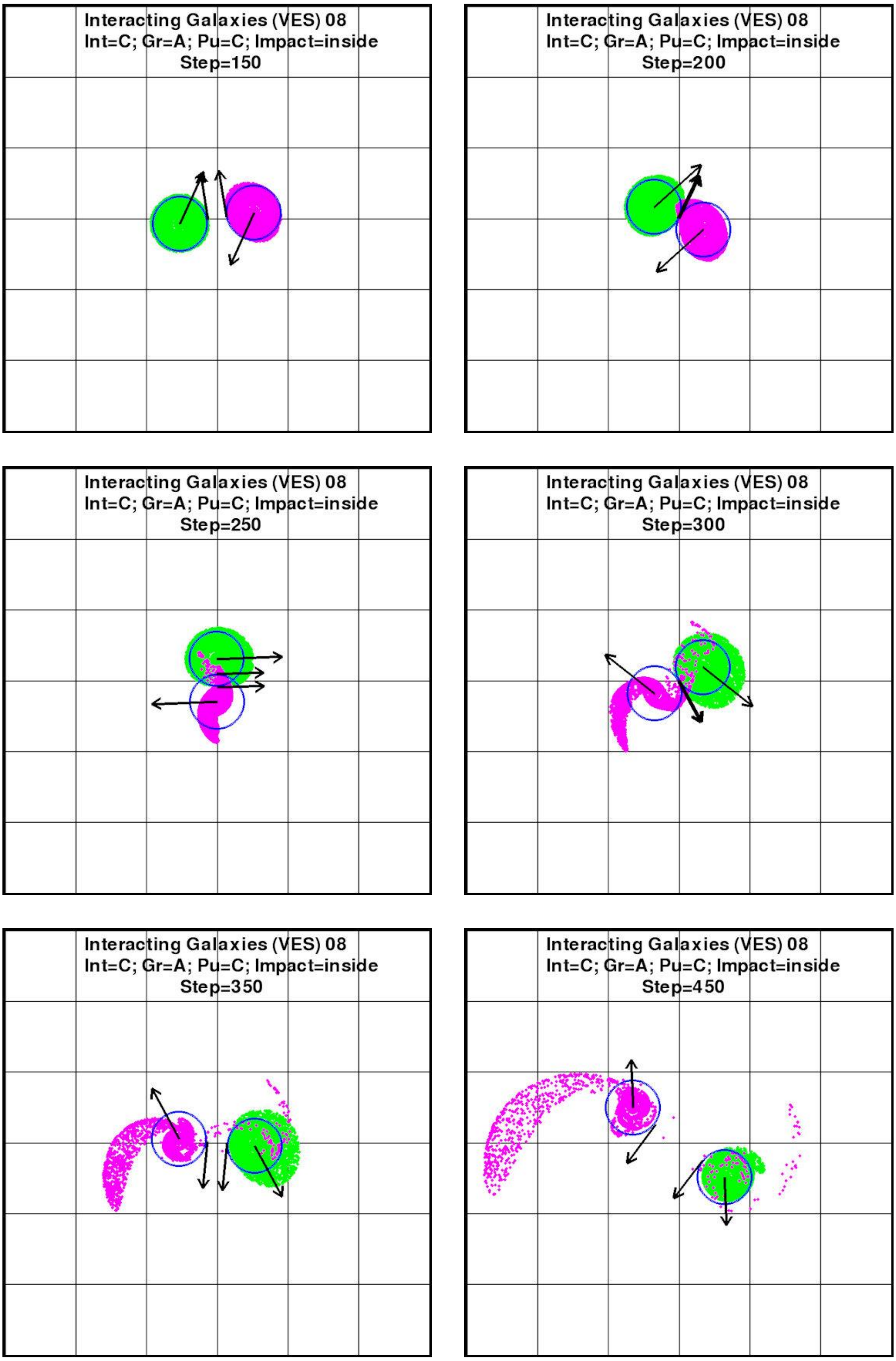


Figure 4. C[AC] Inside interaction. Galaxies orbit clockwise (C); Green galaxy rotates anticlockwise (A); Purple galaxy rotates clockwise (C). Galaxies overlap at minimum separation. Purple galaxy suffers greater tidal effects than green galaxy.

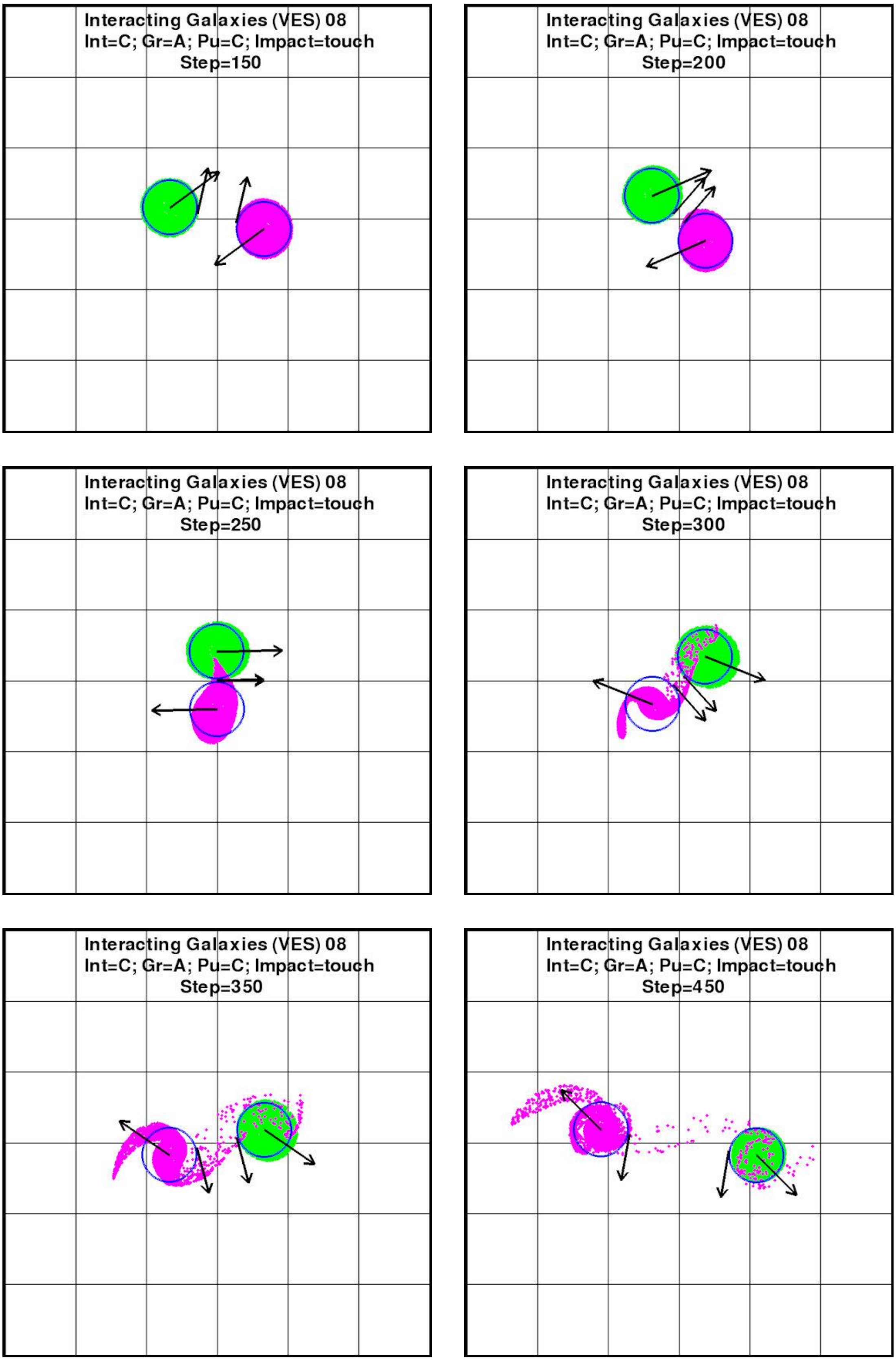


Figure 5. C[AC] Touch interaction. Galaxies orbit clockwise (C); Green galaxy rotates anticlockwise (A); Purple galaxy rotates clockwise (C). Galaxies just touch at minimum separation. Purple galaxy suffers greater tidal effects than green galaxy.

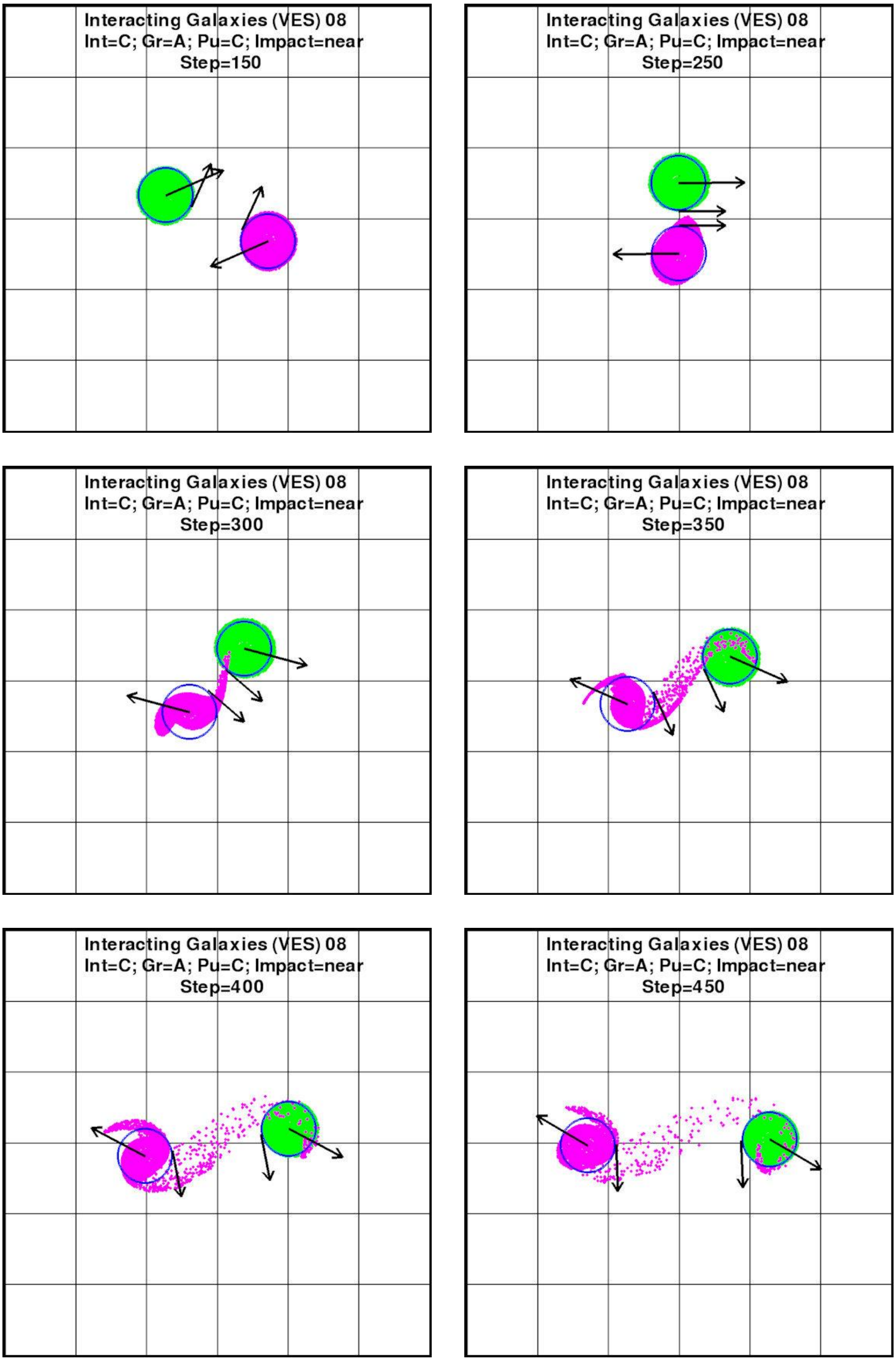


Figure 6. C[AC] Near interaction. Galaxies orbit clockwise (C); Green galaxy rotates anticlockwise (A); Purple galaxy rotates clockwise (C). Galaxies separated by a small distance at minimum separation. Purple galaxy suffers tidal effects; green galaxy essentially none.

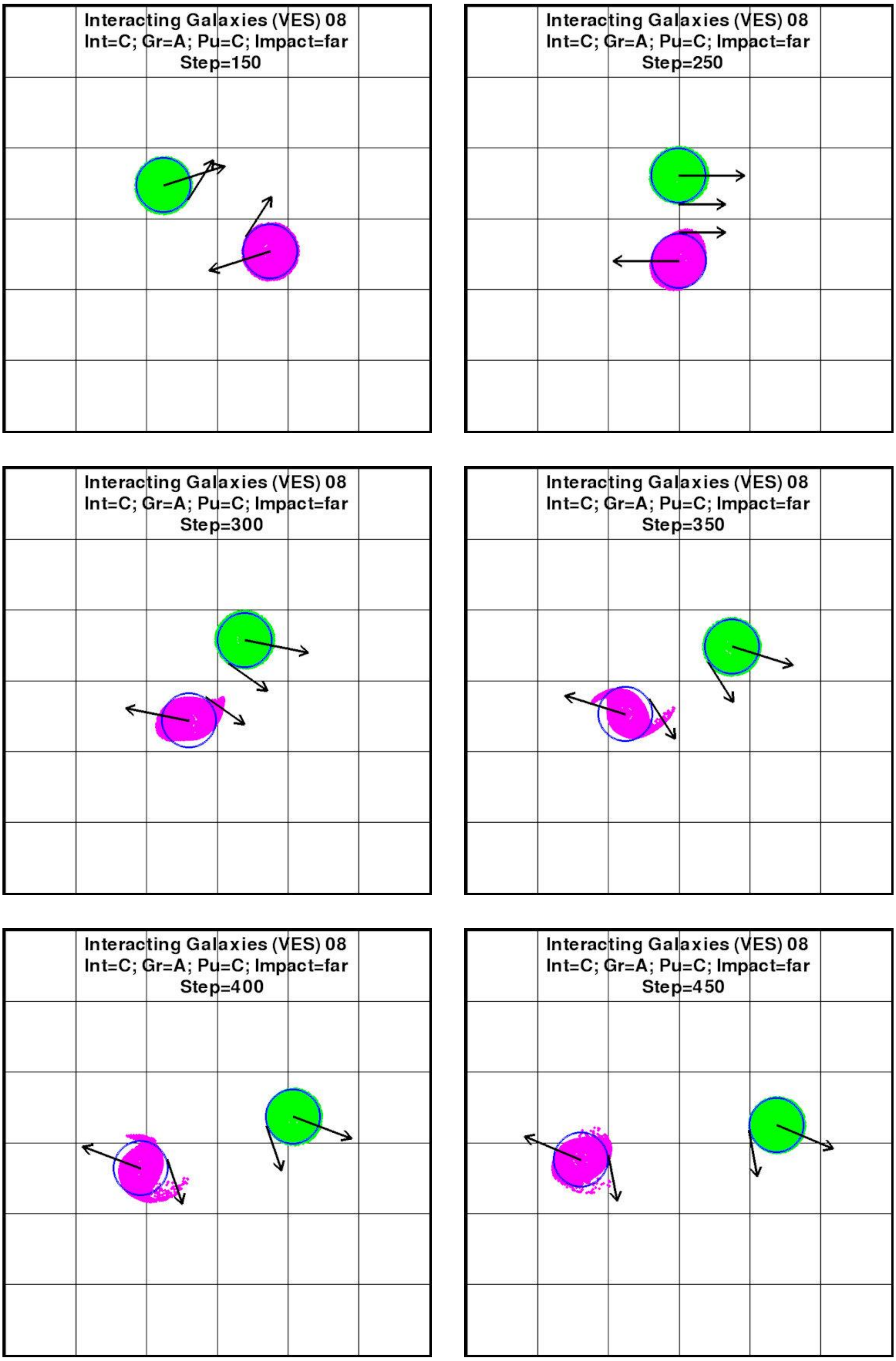


Figure 7. C[AC] Far interaction. Galaxies orbit clockwise (C); Green galaxy rotates anticlockwise (A); Purple galaxy rotates clockwise (C). Galaxies separated by a moderate distance at minimum separation. Purple galaxy suffers tidal effects; green galaxy essentially none.

6 Discussion

6.1 Holincheck et al (2016) assume galaxies are embedded in dark matter halos; we assume no dark matter but an energy scale variation instead. The simulations carried out here are very basic and they do not match the complexity of Holincheck et at (2016). Nevertheless some simple conclusions can be made.

6.2 When the galaxies interact any tidal effects show themselves after the interaction (closest approach) and not before. So the tidal tails seen in many interactions are an after effect and indicate that the interaction happened sometime in the past. In most cases the two galaxies are now moving apart.

6.3 An interaction can lead to one galaxy being severely disturbed while the other is relatively unscathed. The rotation directions of the individual galaxies coupled with the sense of the interaction are the determining factors.

6.4 If a galaxy rotates in the opposite sense to the interaction then it suffers little tidal disruption. This is because the rotation speed adds to the orbital speed giving a high relative speed and little time for tidal effects to occur. This can be seen in the C[CA] image of Figure 2. The purple [A] galaxy rotates anticlockwise, which is opposite to the clockwise (C) interaction, and so it shows virtually no tidal effects.

6.5 If a galaxy rotates in the same sense as the interaction then it suffers considerable tidal effects. This is because the rotation speed subtracts from the orbital speed giving a low relative speed and a large time for tidal effects to occur. This can also be seen in the C[CA] image of Figure 2. The green [C] galaxy rotates clockwise, which is the same as the the clockwise (C) interaction, and so it shows considerable tidal disruption.

6.6 The large tidal tails are produced on the side of the galaxy that is away from the interacting galaxy. This happens because the material tends to continue along the original path, while the galaxy is diverted around the interacting galaxy. Closer interactions lead to larger tidal tails. This is apparent from Figures 4, 5, 6 & 7.

6.7 Material from the near side of the interaction can be stripped from a galaxy and end up in orbit around the other galaxy. This is evident from Figures 4, 5 & 6.

7 Examples of real interactions

7.1 NGC 5257 A[AA].

Interaction is anticlockwise (A); left galaxy is rotating anticlockwise (A); right galaxy is rotating anticlockwise (A). Hubble Image: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

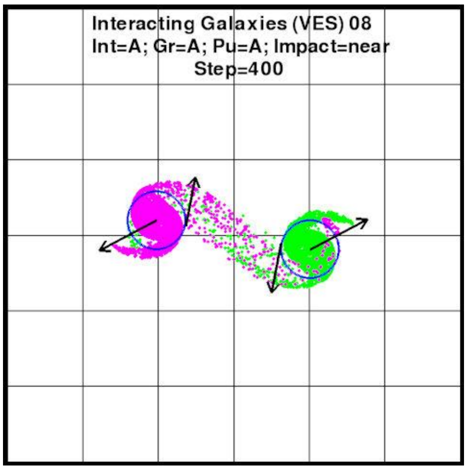


Figure 8. NGC 5257.

7.2 Arp 238; UGC 8335 C[CC]

Interaction is clockwise (C); left galaxy is rotating clockwise (C); right galaxy is rotating clockwise (C). Hubble image: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

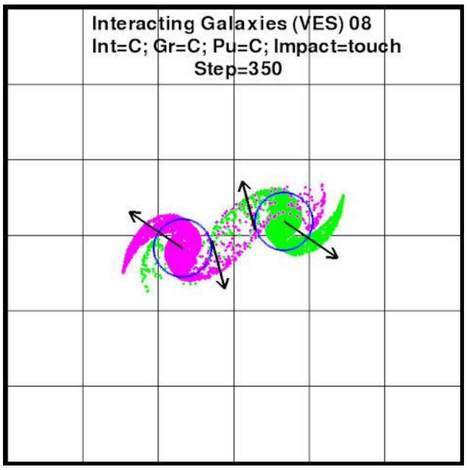
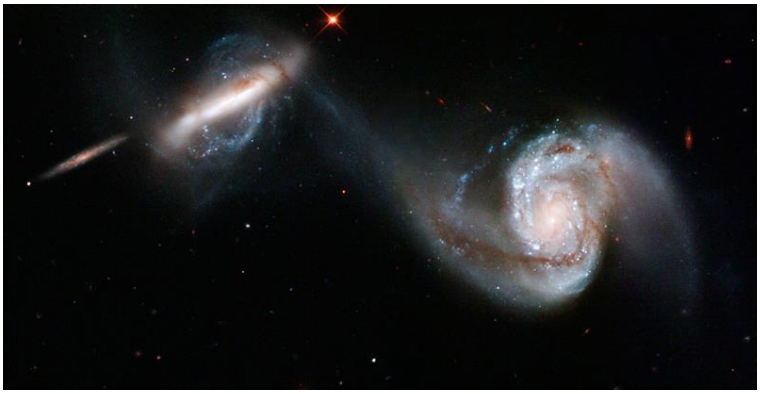


Figure 9. Arp 238; UGC 8335.

7.3 Arp 87; NGC 3808 A[AC]

Interaction is anticlockwise (A); left galaxy is rotating clockwise (C), it was on right before interaction; right galaxy is rotating anticlockwise (A), it was on left before interaction. Hubble image: *NASA, STScI.*



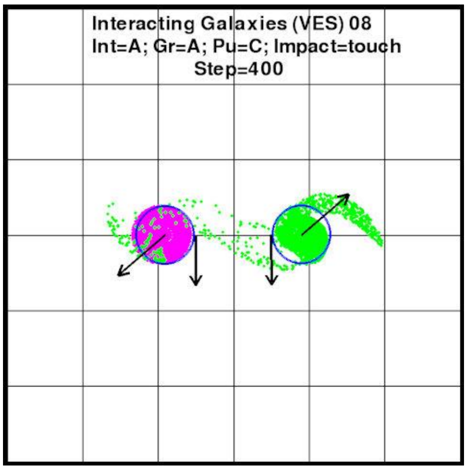


Figure 10. Arp 87; NGC 3808

7.4 Arp 142; NGC 2936 (spiral); NGC 2937 (elliptical) A[AC]

Interaction is anticlockwise (A); upper spiral galaxy is rotating anticlockwise (A); lower galaxy is elliptical and little affected by interaction. Hubble image: NASA/ESA/Hubble Heritage Team

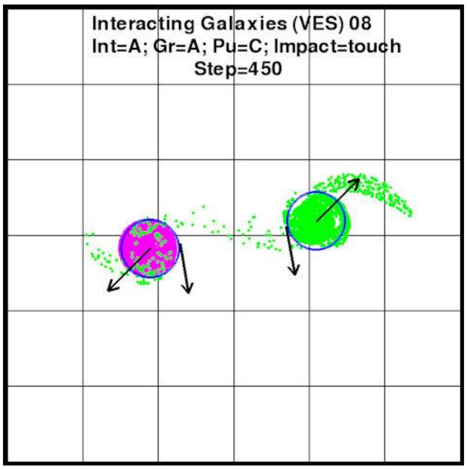


Figure 11. Arp 142; NGC 2936 (spiral); NGC 2937 (elliptical)

8 Conclusion

8.1 We apply the hypothesis of variations in the energy scale to the interaction between pairs of galaxies. Simple numerical simulations show that the observed tidal effects can be reproduced without the need for any dark matter.

9 References

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