Self-Confinement of Narrow Eccentric Planetary Ringlets

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Background

Narrow eccentric planetary ringlets are **interesting** & **puzzling**:

- they have **very** sharp edges
- **large** eccentricity gradients
- **unknown** confinement mechanism that opposes radial spreading due to ringlet viscosity

•One popular confinement mechanism:

- narrow ringlets are straddled by unseen shepherd satellite(s) whose grav' perturbations confine it radially (Goldreich & Tremaine 1979, Goldreich et al 1995, Chiang & Goldreich 2000, Mosqueira & Estrada 2002)

•but Cassini spacecraft failed to detect any shepherds near Saturn's narrow ringlets, which casts doubt on the above (eg Longaretti 2018)

•recall Borderies et al (1982): a narrow ringlet having a sufficient nonlinearity parameter

q=[(eccentricity-gradient)^2 + (periapse-twist)^2]$^{1/2}$ ≥ √3/2 ≈ 0.87

can be self-confining

- they show that when:
  - q<0.87, ringlet viscosity causes angular momentum to flow radially outwards across the ringlet, which causes ringlet to *spread* radially
  - But when q>0.87, angular shear reverses sign near periapse, the orbit-averaged angular momentum flows inwards, and the ringlet *contracts* radially due to *angular momentum flux reversal*

The code

•used `epi_int_lite` (successor to `epi_int` of Hahn & Spitales 1993) to simulate evolution of narrow eccentric viscous gravitating ringlets:

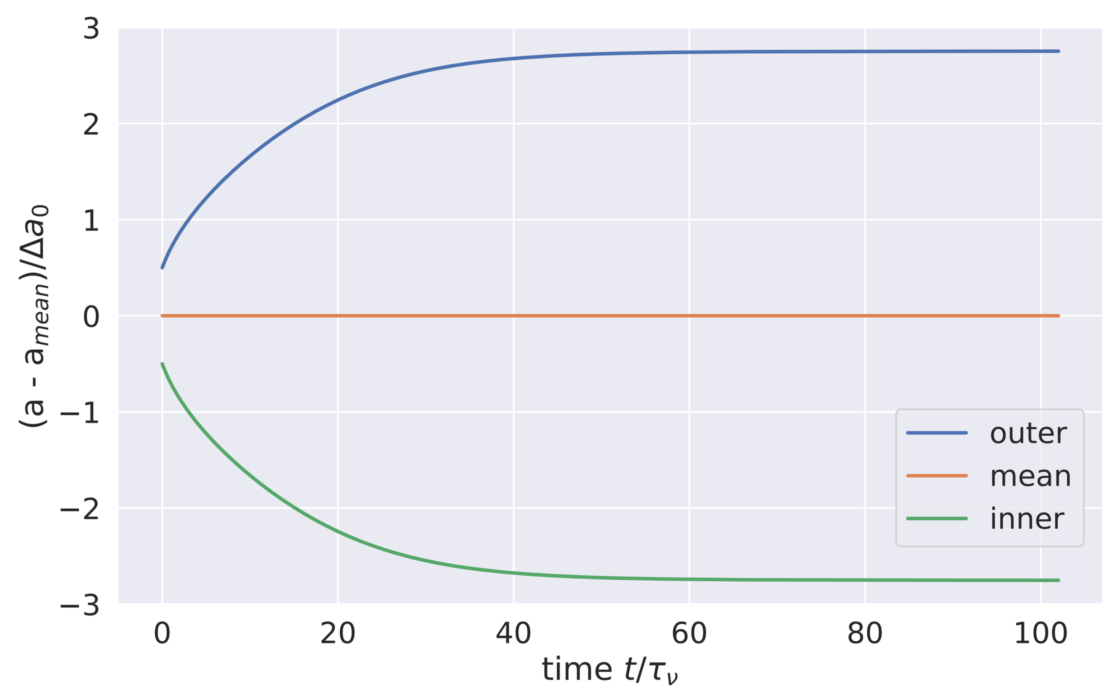
- `epi_int_lite` is a symplectic *streamline* integrator
- uses trace particles track ringlet streamlines, with particles responding to streamline
  - *self-gravity* A_r≈2Gλ/Δr
  - *viscosity*, A_θ≈-(dF_v/dr)/σr, due to particle-particle collisions

Ringlet initial conditions

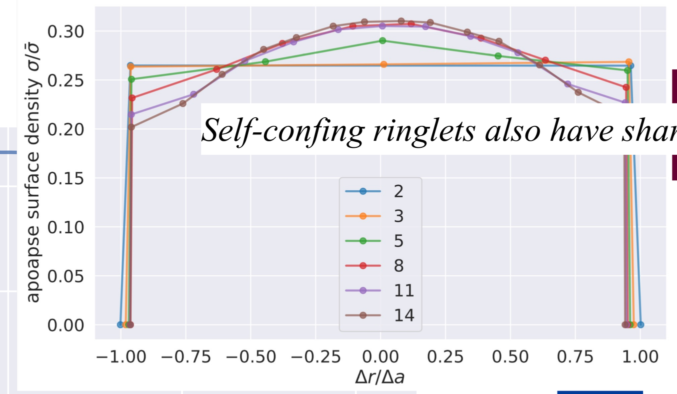
- all simulated ringlets have:
  - specified total mass m_r
    shear viscosity v_s
    initial radial width Δa
    initial eccentricity e_0=0.01
    orbit oblate Saturn-like planet whose J_2=0.01
  - initial nonlinearity parameter q=0
    - ie zero gradients in e or longitudes of periapse
  - all simulated ringlets shown here are composed of N_s=2 streamlines having N_p=250 particles per streamline
  - simulated ringlets are evolved for $10^{5\text{ to }6}$ orbits
    - ie long enough to determine whether they evolve into
      - the self-confining q=0.87 state
      - or instead spread radially forever due to ringlet viscosity

Nbody simulation of the *nominal* ringlet

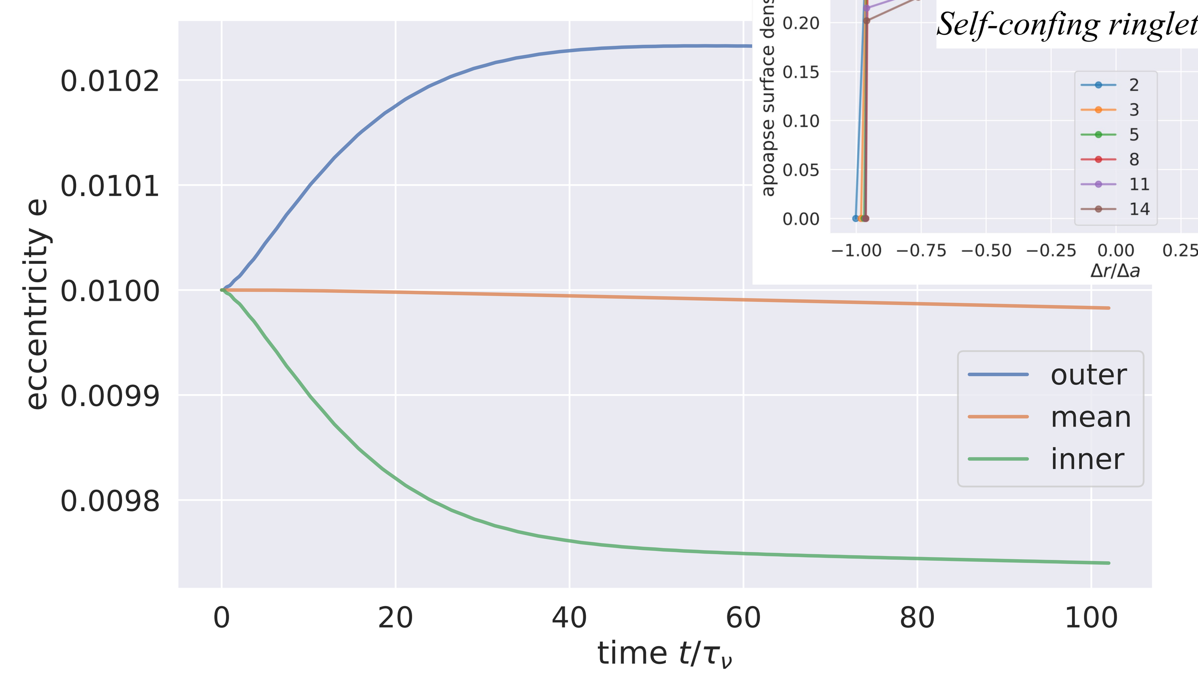
- we find that, for a wide variety of initial conditions (eg m_r, Δa, v_s):
- ringlet self gravity causes its eccentricy-gradient to grow
- while viscosity promotes ringlet's periapse-twist
- until q→0.87 (ish)
- at which point viscous spreading ceases
- and the ringlet is self-confining!
- following plots shows the evolution of our so-called **nominal** ringlet
- mass m_r=6x10^{19} gm (mass equivalent to 25 km-wide ice sphere)
- initial radial width Δa_0=10 km
- shear viscosity v_s=2000 cm^2/sec



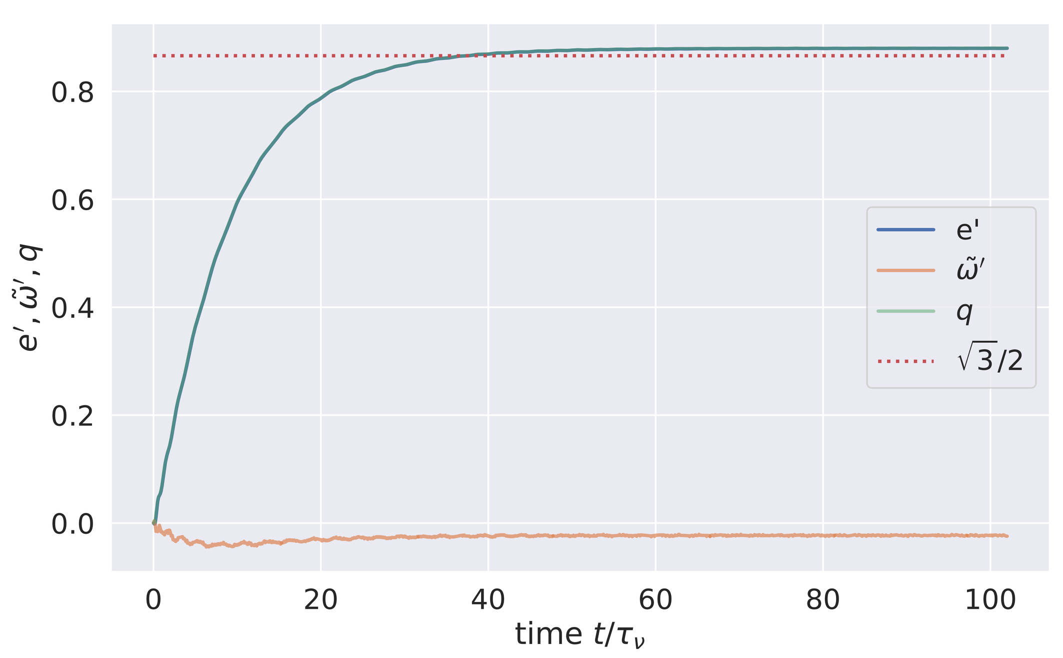
Evolution of nominal ringlet's semimajor axes verus time t (in units of the ringet's viscous spreadting timescale $\tau_v=\Delta a^2/12v_s\approx10^3$ orbits), with ringlet self-confining when $t\sim40\tau_v$



Self-confing ringlets also have sharp edges!

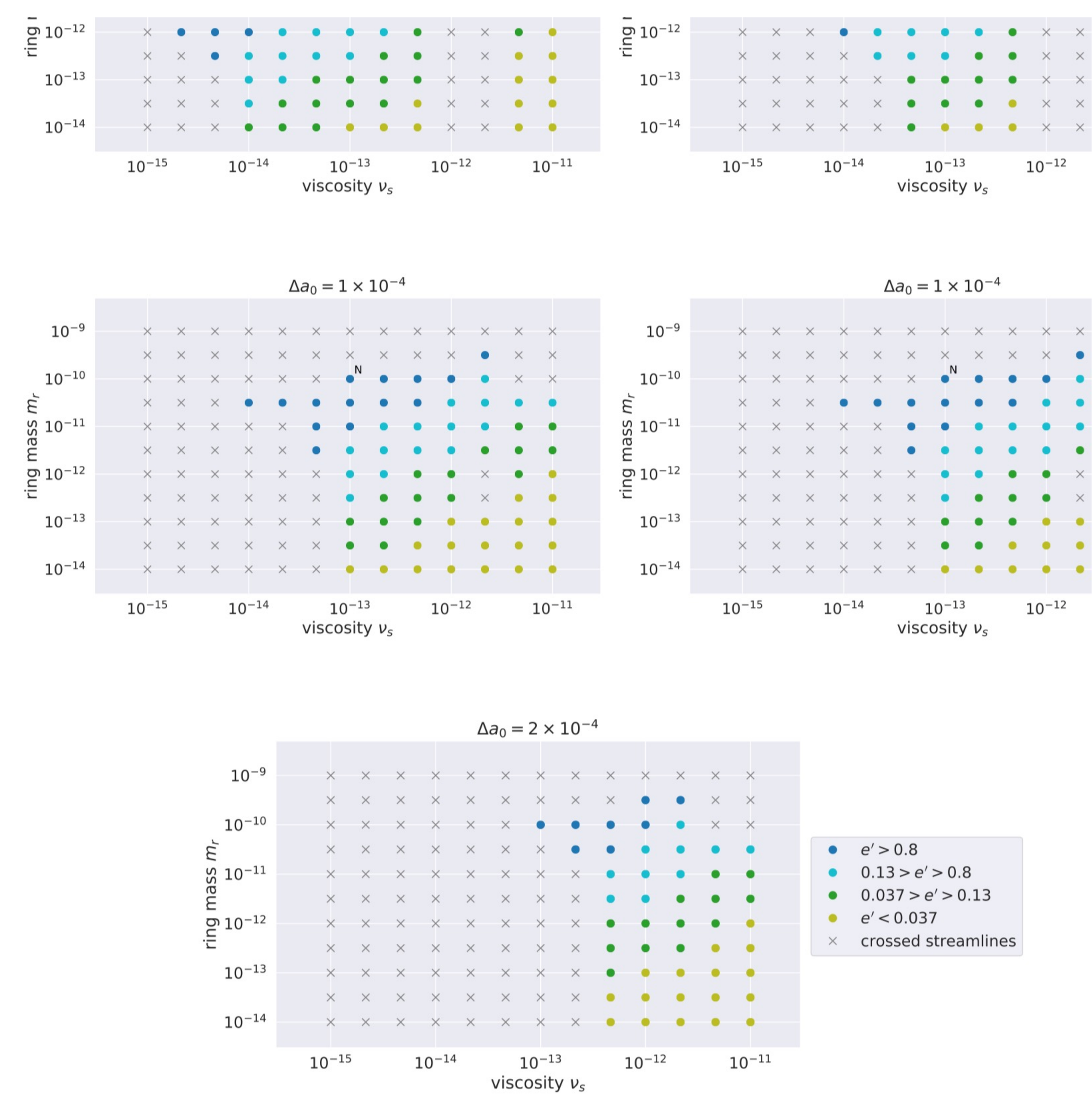


Self-gravity causes nominal ringlet's outer streamline's eccentricity to grow at the expense of the inner streamline. Which causes the ringlet's nonlinearity parameter to grow until q≈0.87 (see below), at which point the ringlet is self-confining



Simulation survey

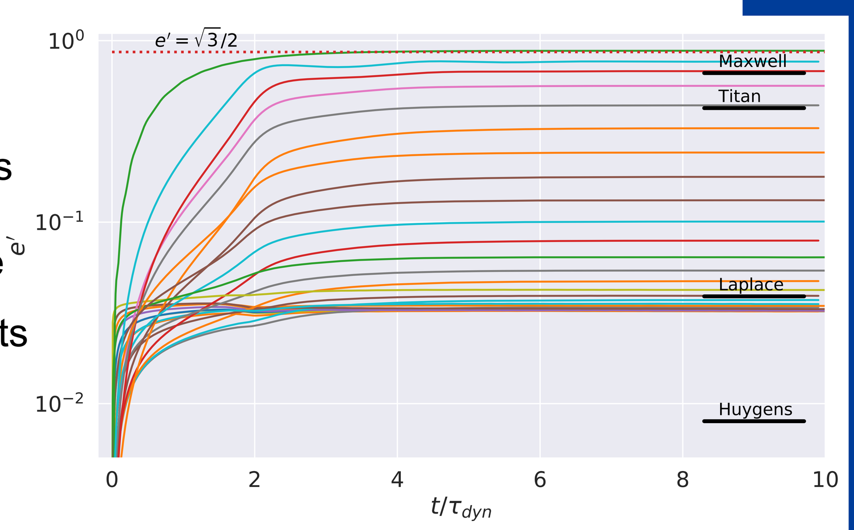
- simulation survey shows that self-confinement is possible for a wide variety of initial m_r, Δa, v_s conditions



Results for survey of simulation having a variety of initial m_r, Δa, v_s. *Dots indicate sims that do settle into the q≈0.87 self confining state. Dark blue dots indicate ringlets having large eccentricity-gradient and small periapse-twist, and yellow dots have the reverse.*

Main Findings

- narrow eccentric ringlets can be *self-confining* and have *sharp edges*...shepherd satellites are **not** required!
- in order for a viscous, self-graviting ringlet to evolve into the q=0.87 self-confining state:
  - the initial ringlet *must* have a non-zero eccentricity in order for self-gravity to pump up ringlet's eccentricity-gradient
    - ie circular ringlets stay circular, and spread forever
- ringlet viscosity also damps its eccentricy (see plot to left)
  - which implies that:
    - narrow eccentric ringlets are **young**,
    - or their eccentricities are sustained by an unknown resonance
- if interested in these results or epi_int_lite, please reach out to jhahn@spacescience.org



What else can `epi_int_lite` simulate?

- nonlinear spiral density waves in gravitating or pressure-supported disks
- nonlinear spiral bending waves...probably, this would require extra effort
- disturbances (eg particle jams) in incompressible disks...with extra effort
- If interested in any of the above, reach out to jhahn@spacescience.org to discuss possible collaborations

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