Gas discs around eccentric SMBH binaries: polar alignment and disc tearing

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Abstract

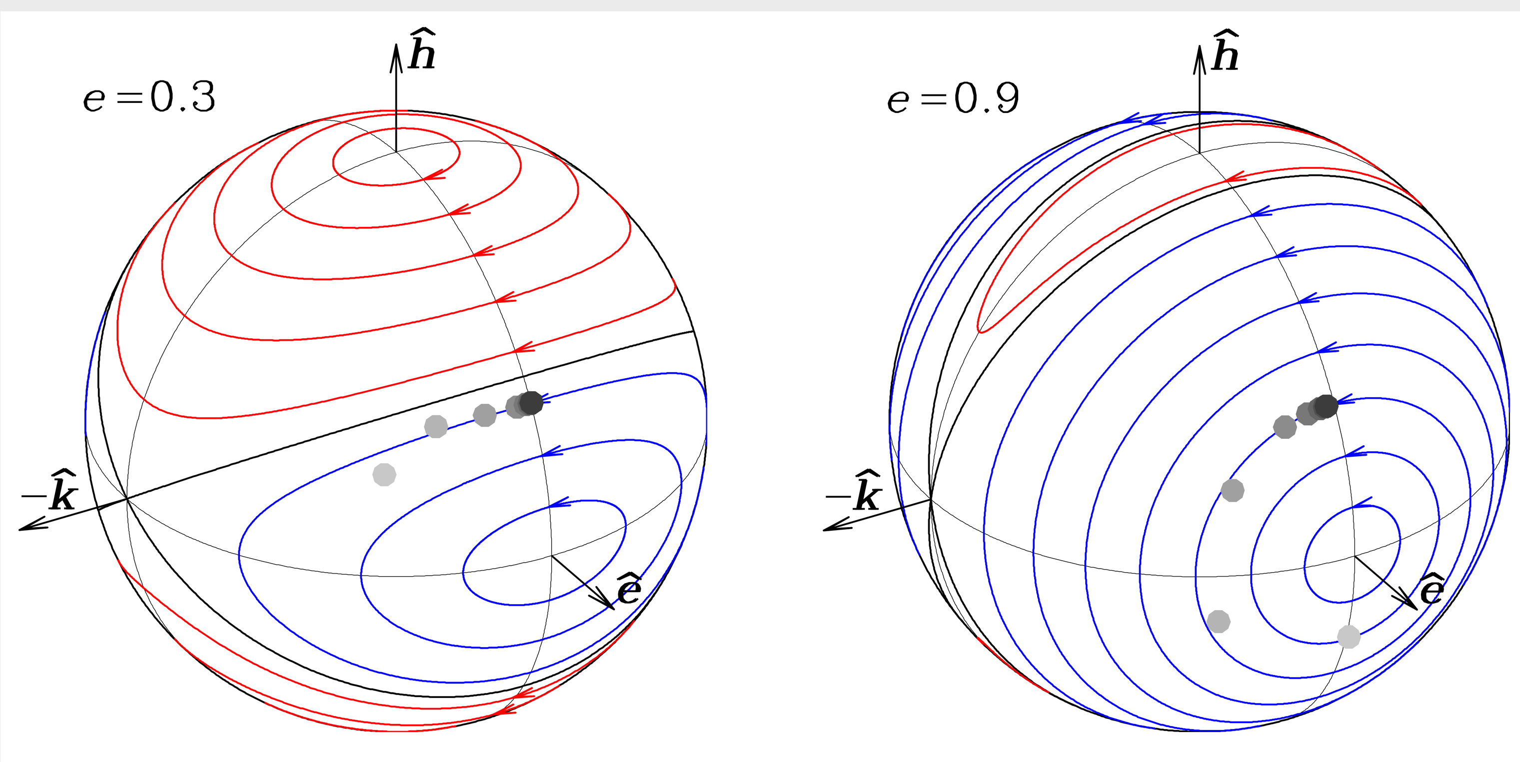
Misaligned gas discs around eccentric SMBH binaries are expected to form from randomly oriented accretion events formed in a galaxy merger. The orbit-averaged quadrupole interaction between a binary and a circular ring results in co-, counter-, or polar-alignment of the disc depending on the initial misalignment and the binary eccentricity, with polar alignment being increasingly likely with increasing binary eccentricity. Those predictions are confirmed by our 3D SPH simulations. Moreover, we observe disc tearing and violent interactions between differentially precessing rings in the disc significantly disrupting the disc structure and causing gas to fall onto the binary. Accretion of this infalling low-angular momentum gas or its ejection via gravitational slingshot are both viable ways of promoting SMBH binary coalescence (solving the `final-parsec problem'), as they both act on dynamical rather than viscous timescales.

Simulation Setup

We perform a set of 3D SPH simulations of geometrically thin accretion discs with different initial misalignment around an eccentric binary:

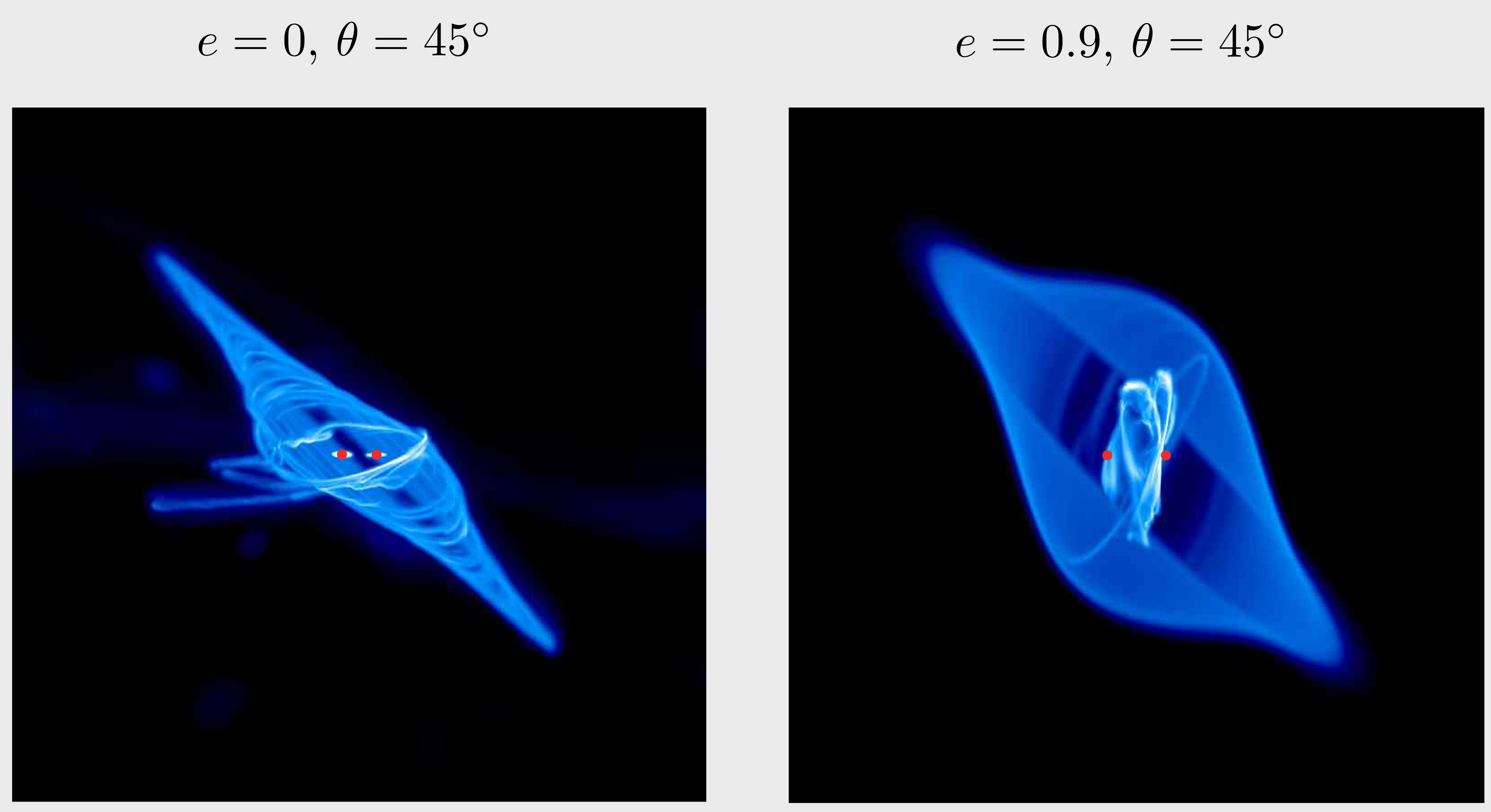
- We use a range of different binary eccentricities e=0, 0.3, 0.6, and 0.9.
- The disc is initially flat and extends from an inner radius of 2a to an outer radius of 8a with an inner thickness H/R=0.01.
- All simulations start with 4 million SPH particles, while the binary is modeled using 2 equal mass sink particles.
- The disc mass in all simulations is 0.005 the binary mass, hence the disc self-gravity is not included.
- We use a Shakura Sunyaev disc viscosity coefficient of 0.1 which we implement using an appropriate SPH artificial viscosity corresponding to our resolution.

Precession paths



Projections of angular momenta of the radially binned disc in our simulations compared to the analytical precession paths. Solid circles represent seven radial bins of the disc ranging from R=a (light gray) to R=8a (dark gray) at t=100 (in code units) for simulations of different eccentricity (as indicated) but the same initial tilt $\theta = 60°$. The inner disc precesses faster, nicely following the theoretical precession paths. The innermost rings around highly eccentric binaries start to align with the stable polar orientation.

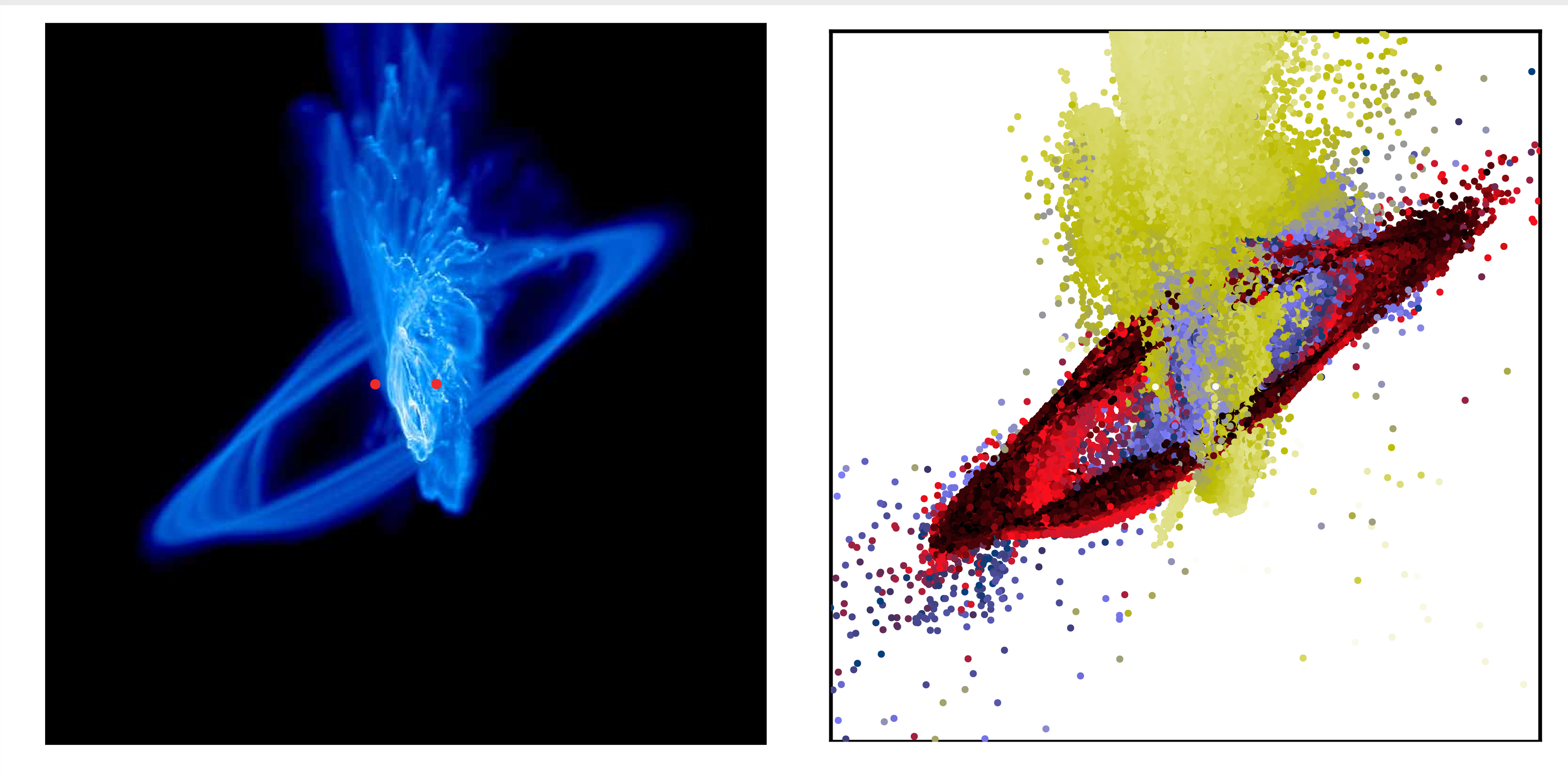
Planar and polar alignment



Density rendering for a disc around a circular (left) and e=0.9 (right) binaries after ~95 binary orbits both with the same initial tilt. The disc clearly co-aligns with the circular binary and polar-aligns around the eccentric binary, as expected from the quadrupole interaction.

Violent interactions and gas ejection

The radially differential binary torque tears the disc and causes the formation of mutually misaligned separate rings that start to interact with each other. The low-angular-momentum gas resulting from the interactions falls onto the binary and quickly aligns to polar orientation, increasing its eccentricity in the process. This runaway effect causes a significant disruption to the disc structure and gas ejections, extracting orbital energy from the binary that may lead to binary coalescence.



Density rendering (left) and particle plot coloured by eccentricity magnitude (right) for a gas disc around an e=0.9 eccentric binary

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