A New Secular Instability in Eccentric Stellar Disks around Massive Black Holes

Madigan et al. 2009 (ApJL)

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Outline

- Introduction to Galactic Centre
  - Motivation
- Physics of Instability
  - Simulations
- Applications
Galactic Centre

Credit: ESO/S. Gillessen et al. 2009
1. SgrA* Black Hole
   $M_\bullet = 4 \times 10^6 M_\odot$

2. Disk:
   0/WR stars
   $M_{\text{disk}} = 10^4 M_\odot$
   $0.05 < a < 0.5 \text{ pc}$

3. S-stars:
   B stars
   $0.003 < a < 0.03 \text{ pc}$
2 Puzzles...

(1) Bimodal eccentricity distribution of disk stars

- Age of disk $\sim 6$ Myr
- Relaxation time $\sim 1$ Gyr

(2) Origin of S-stars

- In-situ formation $\times$
- Youth: Did not travel far from place of birth
Setup

Assumptions:
1) $M_{\text{disk}} \ll M_{\text{cusp}}$
2) Eccentricity vectors ($\bar{e}$) aligned, similar in magnitude
   ← vector which points to periapse
Retrograde Precession due to cusp:

\[ t_{\text{prec}}(a,e) \sim \left[ \frac{M}{M_{\text{cusp}}(a)} \right] t_{\text{orb}}(a) f(e) \]

\[ \rho_{\text{cusp}} \propto a^{-\gamma}, M_{\text{cusp}}(<a) \propto a^{3-\gamma} \]

\[ t_{\text{orb}}(a) \propto a^{3/2} \]

\[ t_{\text{prec}} \sim a^{\gamma-3/2} f(e) \]

Fastest for low e orbits
Slowest for high e orbits
Instability (3)

1. Higher $e$ orbit precesses slower than other orbits.
2. Feels strong, coherent torque from other stars in disk in opposite direction of angular momentum $L$.
3. $L$ is decreased, $e$ is increased.

$L \propto (1 - e^2)^{1/2}$

$L = r \times v$

$T = r \times F$
Instability (4)

1. Lower $e$ orbit precesses faster than other orbits
2. Feels strong, coherent torque from other stars in disk in direction of angular momentum $L$
3. $L$ is increased, $e$ is decreased

$L \propto (1 - e^2)^{1/2}$

$L = r \times v$

$\mathbf{T} = r \times \mathbf{F}$

$e$ orbit precesses faster than other orbits

in direction of angular momentum $L$

$L$ is increased, $e$ is decreased
Simulations

Relaxation time $\sim 1$ Gyr
Evolution of $\vec{e}$
Evolution of $\bar{e}$
Observed vs Simulated Eccentricity Distribution

Bartko et al. (2009)

Madigan et al. (2009)

Bimodal distribution: direct consequence of instability
Origin of S-stars

Instability in disk pushes binary system to high eccentricity orbit.

Binary system is disrupted (Hills’ [1988] Mechanism) forming:

1) hyper-velocity star
2) bound high-eccentricity star = S-star?
Summary

1) New Instability in Eccentric Stellar Discs
   > Time-scale: Myr
   > Robust

2) Application to Galactic Centre:
   > Bimodal eccentricity distribution
   > Origin of S-star population?
$\gamma = 1.25$

Evolution of $\bar{e}$
$\gamma = 1.5$

Evolution of $\bar{e}$

![Graphs showing evolution of $\bar{e}$ at 0, 200, 400, 600, 800, and 1000 orbits.](image)
Evolution of $\bar{e}$

$\gamma = 1.75$