

Nuclear rings in simulated barred galaxies

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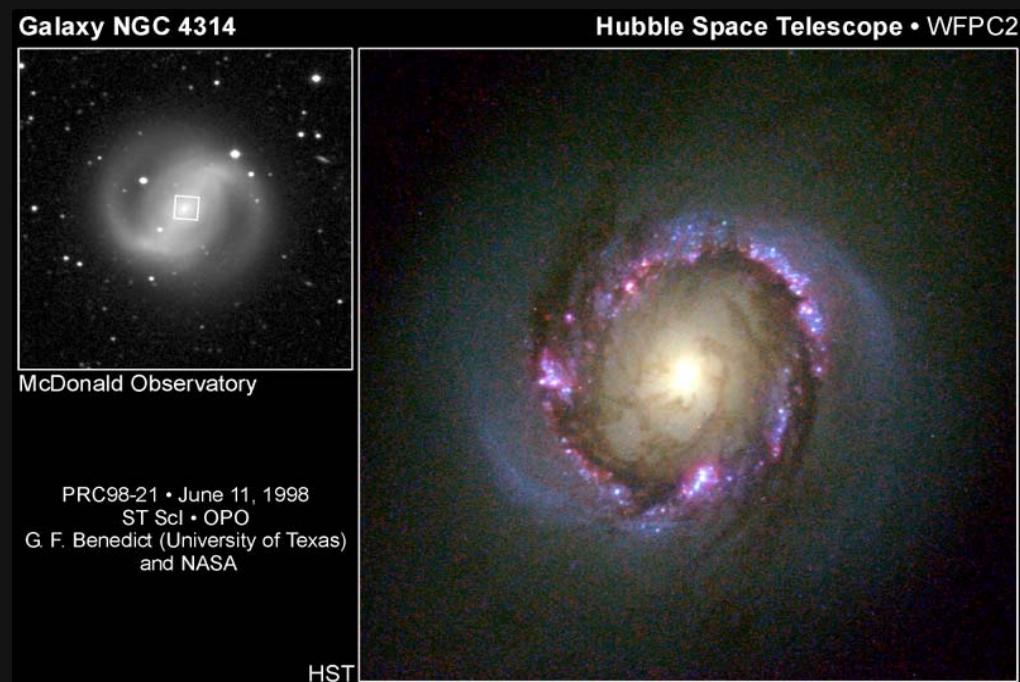
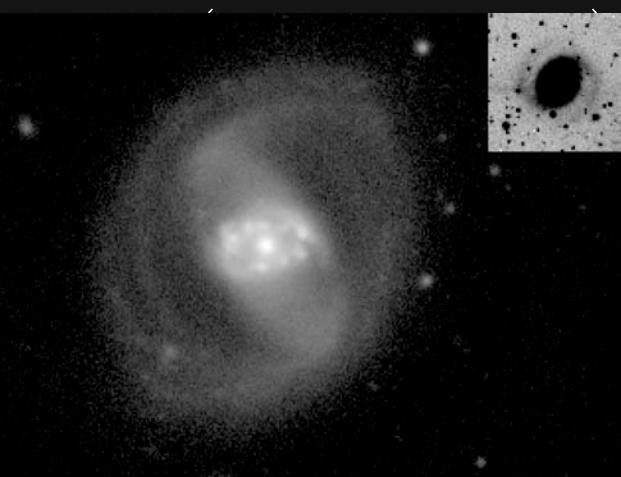


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Motivation

- Observational studies on nuclear rings
 - Bright, usually small and circular (\sim hundreds pc), blue (e. g. Martini et al. 2003)
 - Intense star-forming region (e. g. Knapen et al. 2006)
 - Most are found in barred galaxies



Motivation

- Theoretical studies on gas flow in barred galaxies

$$\left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \Sigma = -\Sigma \nabla \cdot \mathbf{u}$$

$$\left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u} = -C_s^2 \frac{\nabla \Sigma}{\Sigma} - \nabla \Phi_{ext} + \boxed{\Omega_b^2} \mathbf{R} - 2\Omega_b \times \mathbf{u}$$

Pattern speed:

$$R_{cr} = (1.2 \pm 0.2) R_{bar}$$

(Athanassoula 1992)



Sound speed:

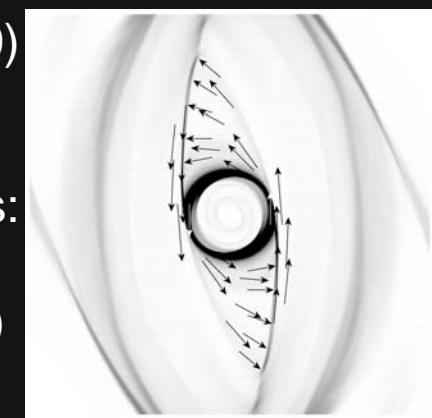
Large C_s \rightarrow small rings

Galaxy potential:
(Kim et al. 2012)



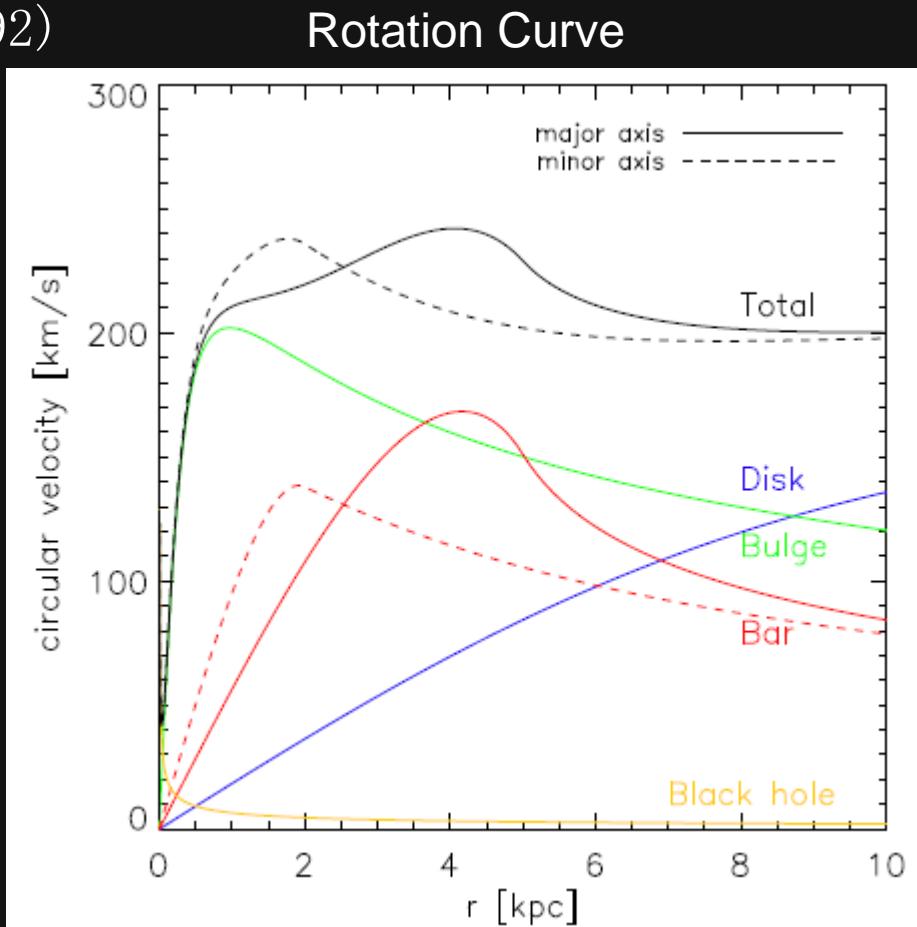
Asymmetric properties:
Bar Strength
(Comerón et al. 2010)

Symmetric Properties:
Compactness
(Mazzuca et al. 2011)



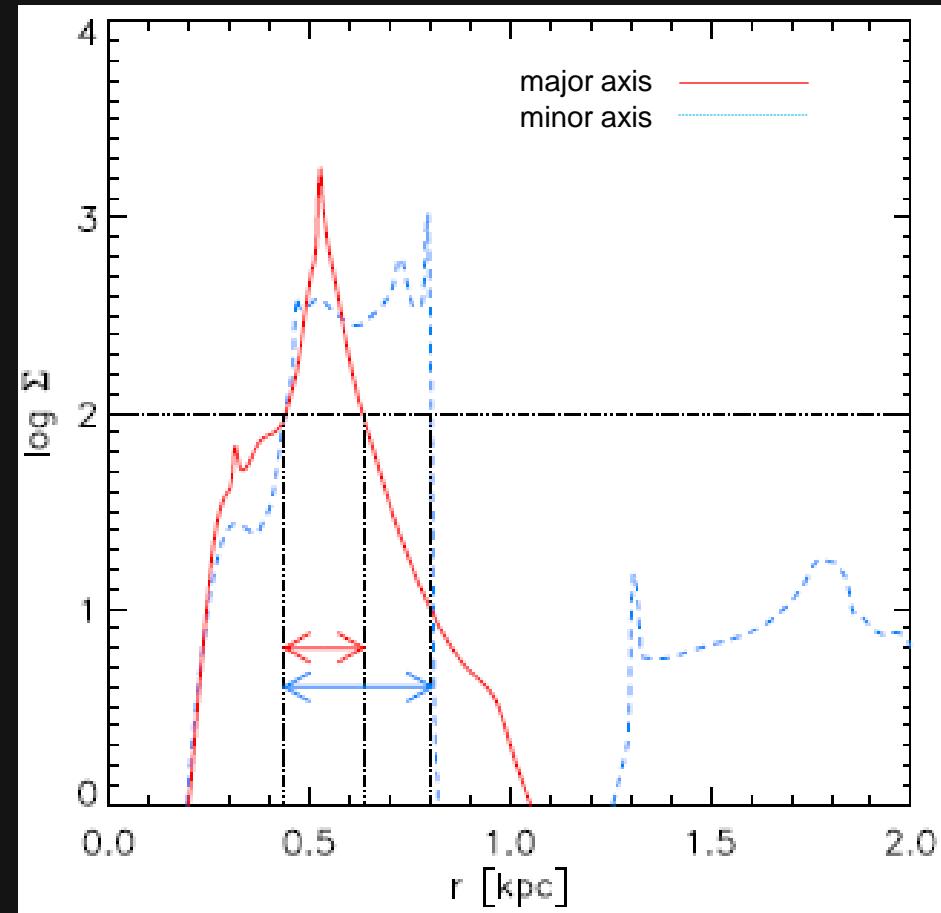
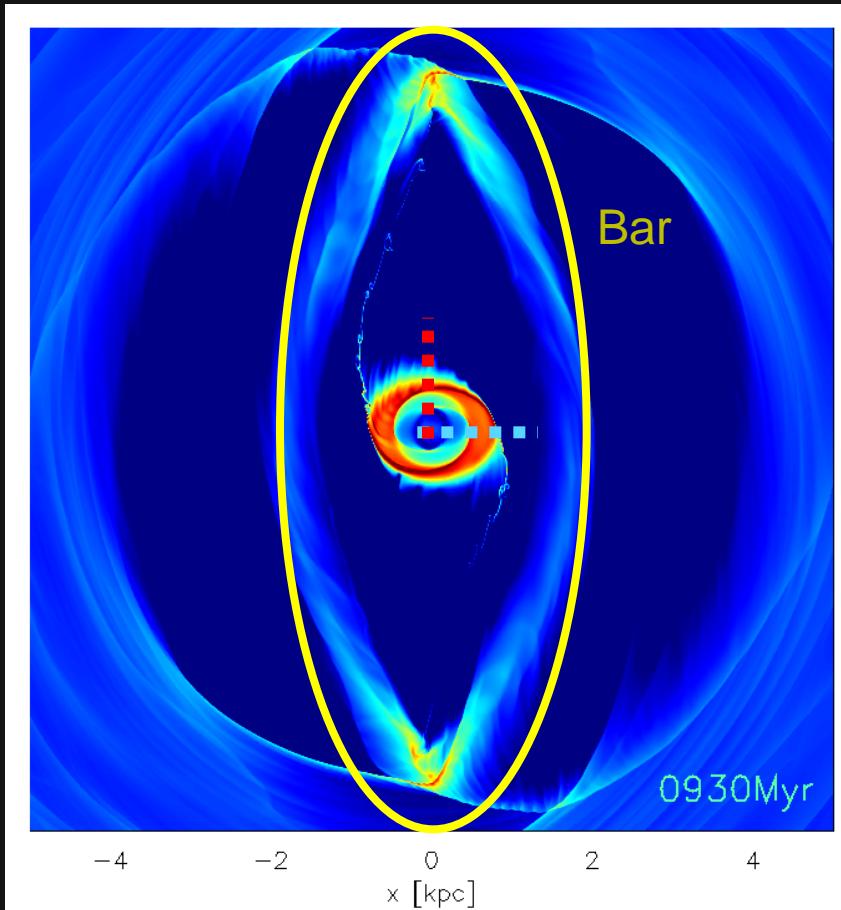
Galaxy Model & Method

- Setup of the potential
 - Similar to Athanassoula (1992)
 - Add a black hole to control the iILR
 - Bulge density profile
$$\rho(r) = \rho_{bul} \left(1 + \frac{r}{r_b}\right)^{-3/2}$$
- Numerical methods
 - Athena 4.1, 2-D, Cartesian
 - Exact Riemann Solver
 - Grid resolution of ~ 4 pc



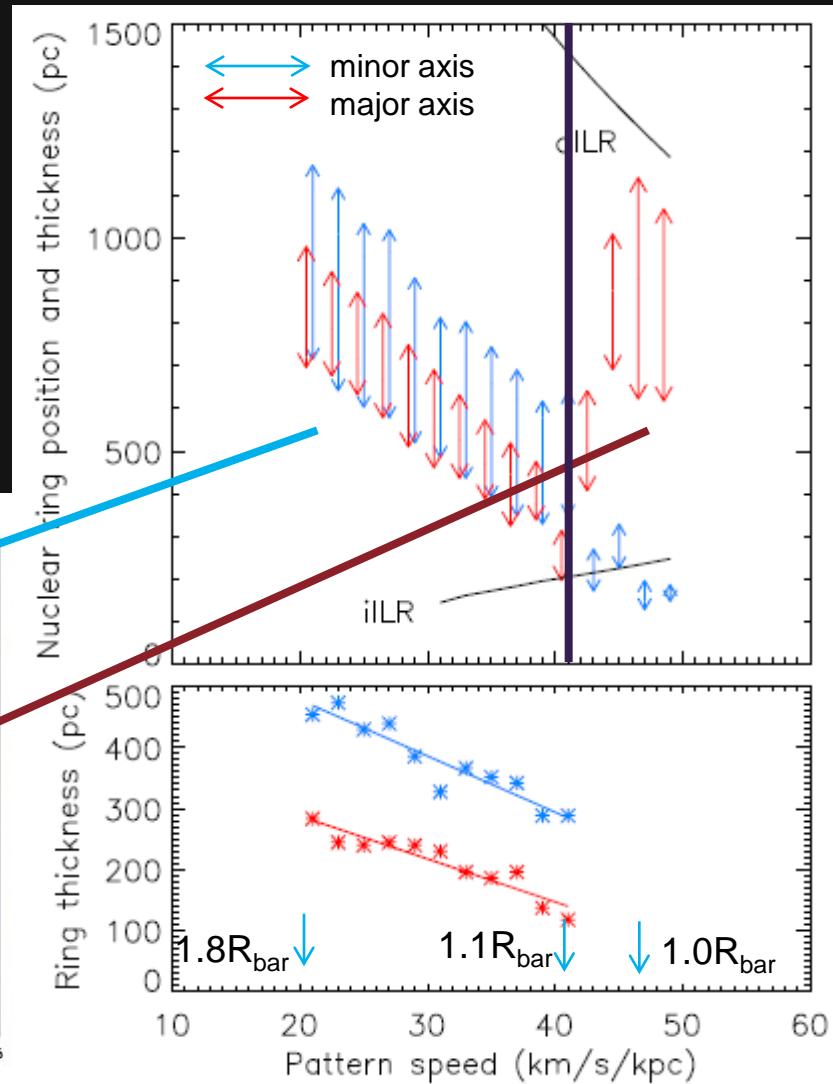
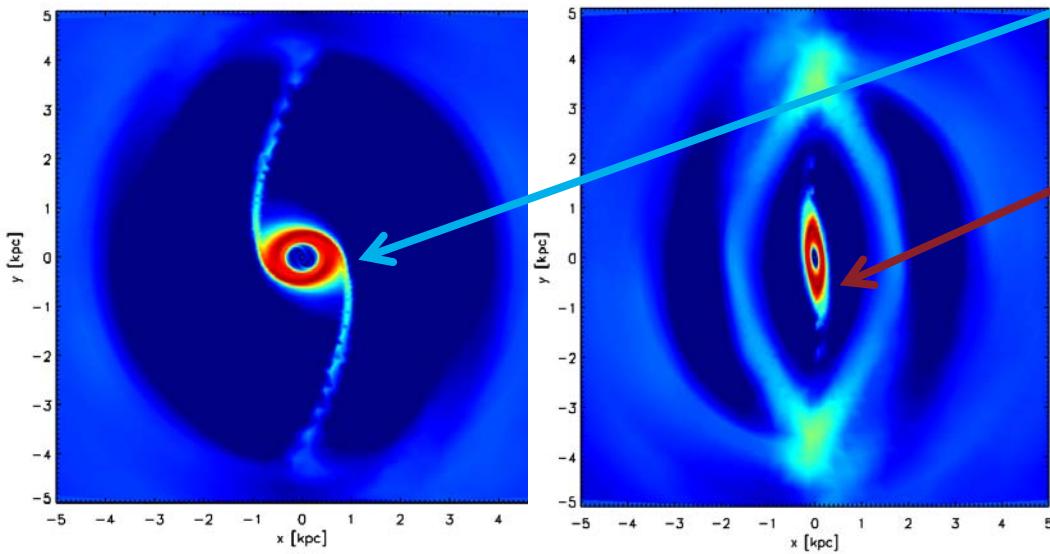
Simulation results I

- Definition of a nuclear ring in the gas density map



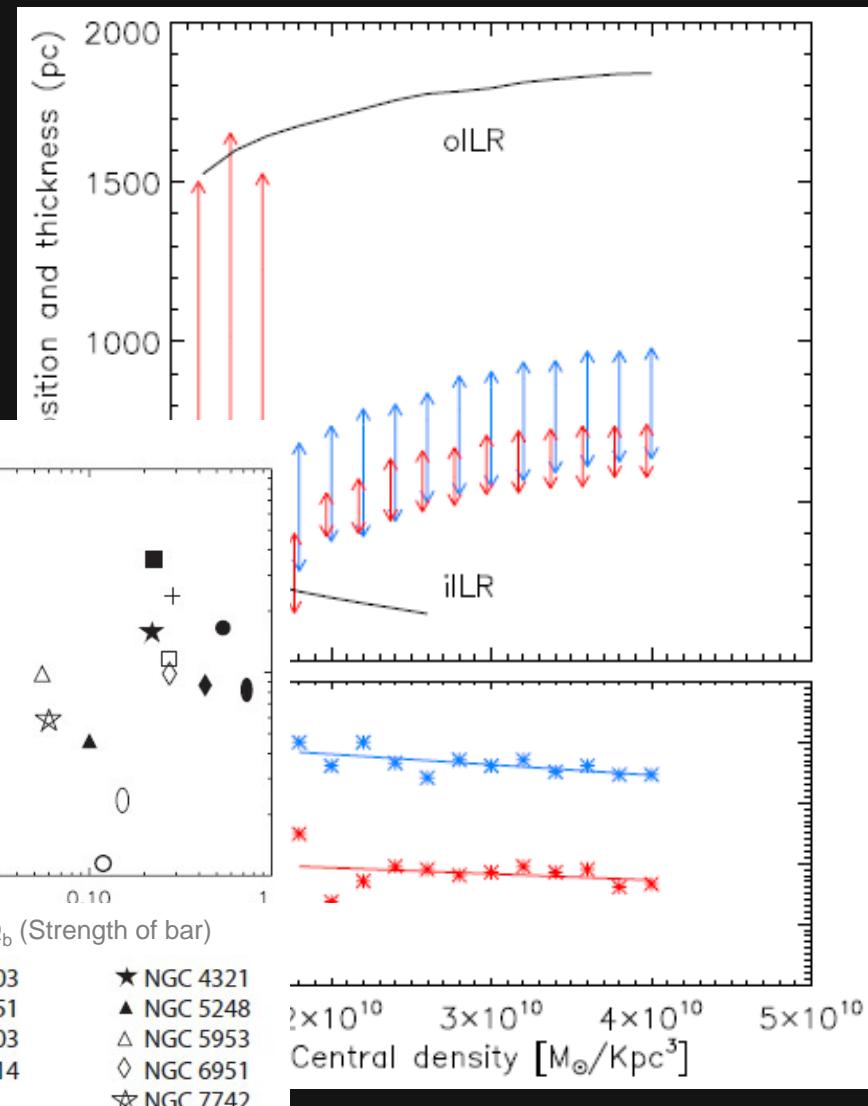
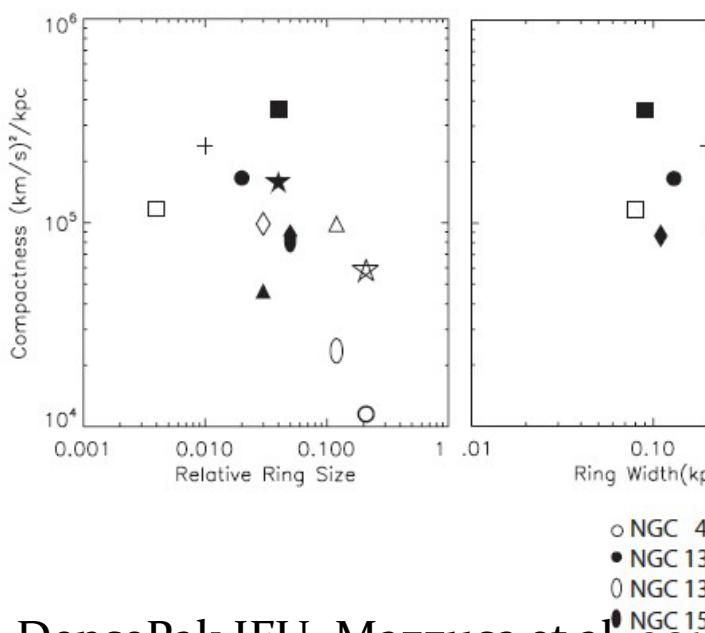
Simulation results II : effects of Ω_b

- Smaller and narrower nuclear rings with higher pattern speed
- Critical value of pattern speed is $41 \text{ km/s/kpc} R_{CR} (= 1.067 R_{bar})$

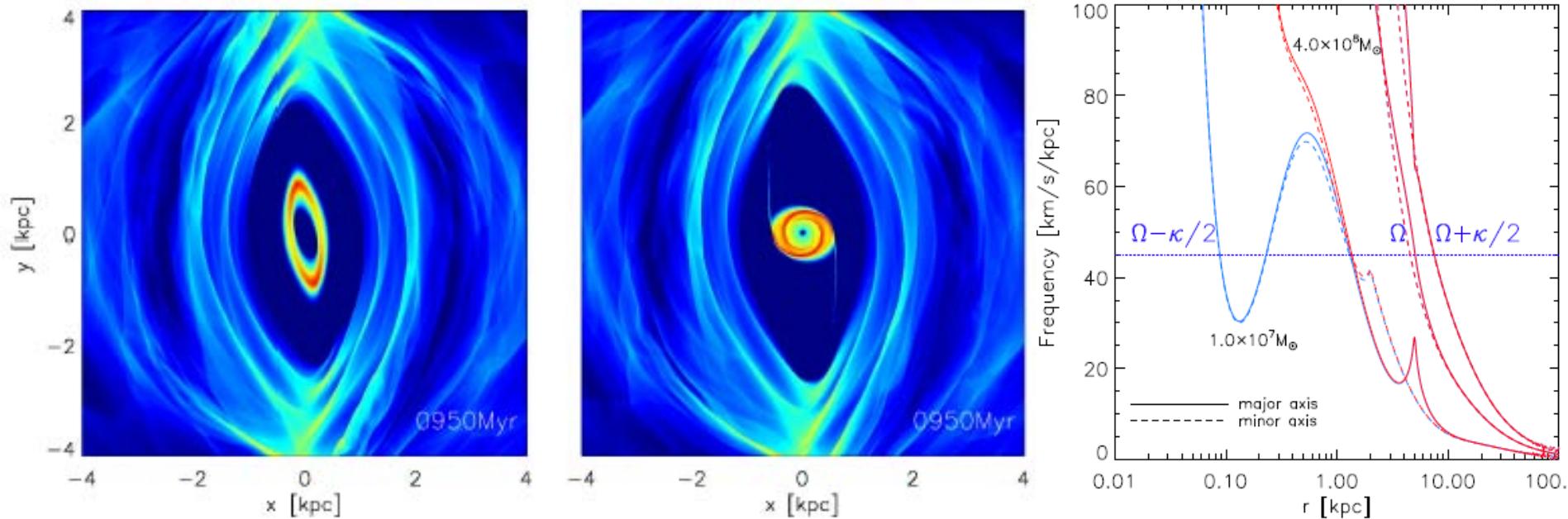


Simulation results II : effects of ρ_{bul}

- Larger nuclear rings with higher central density ρ_{bul}
- Thickness of the nuclear rings is nearly

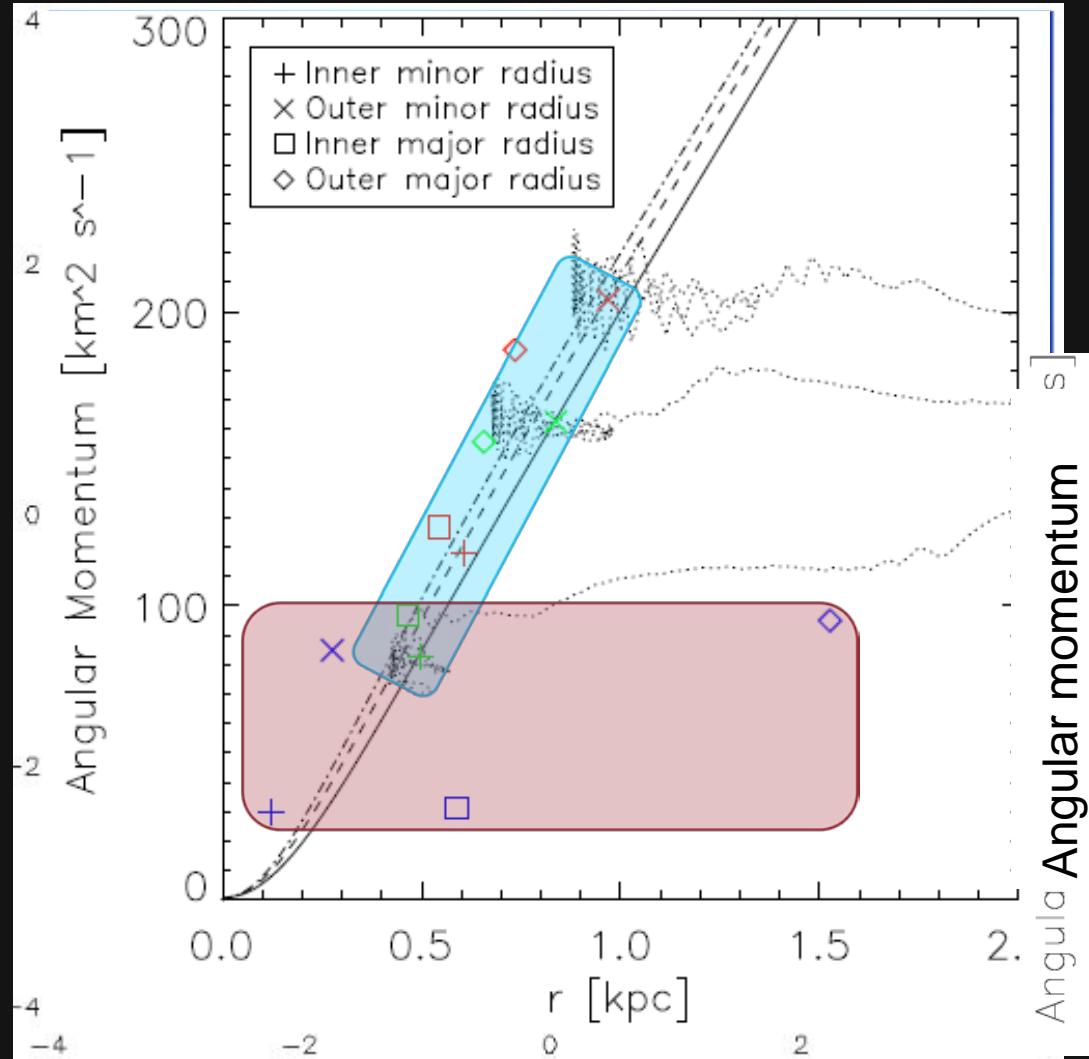


Simulation results III : effects of SMBH

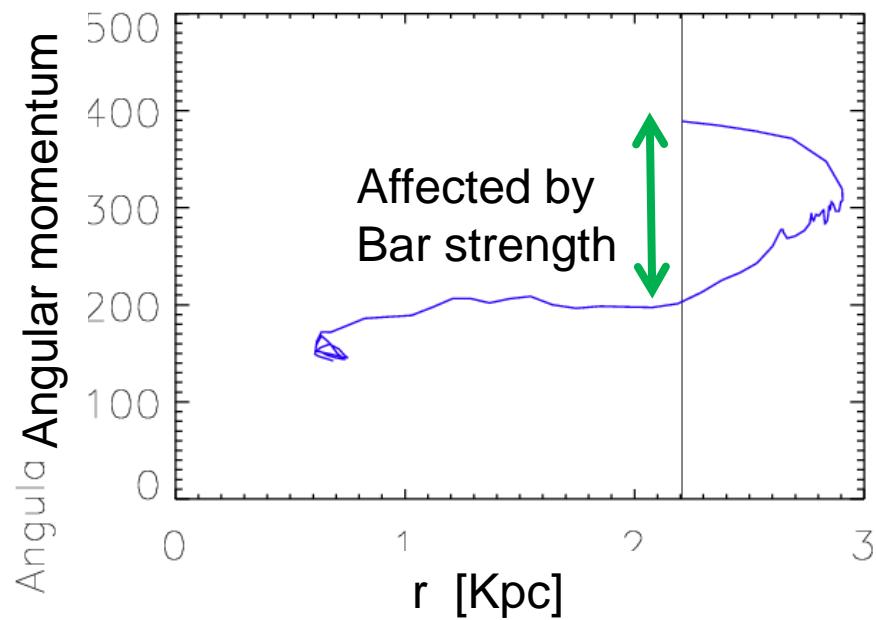


- A massive black hole (mass ratio of ~ 0.01 within 2kpc) can significantly affects the gas patterns in the central part while keeping the oILR unchanged.
- The formation of a circular nuclear ring may not be associated with the resonance.

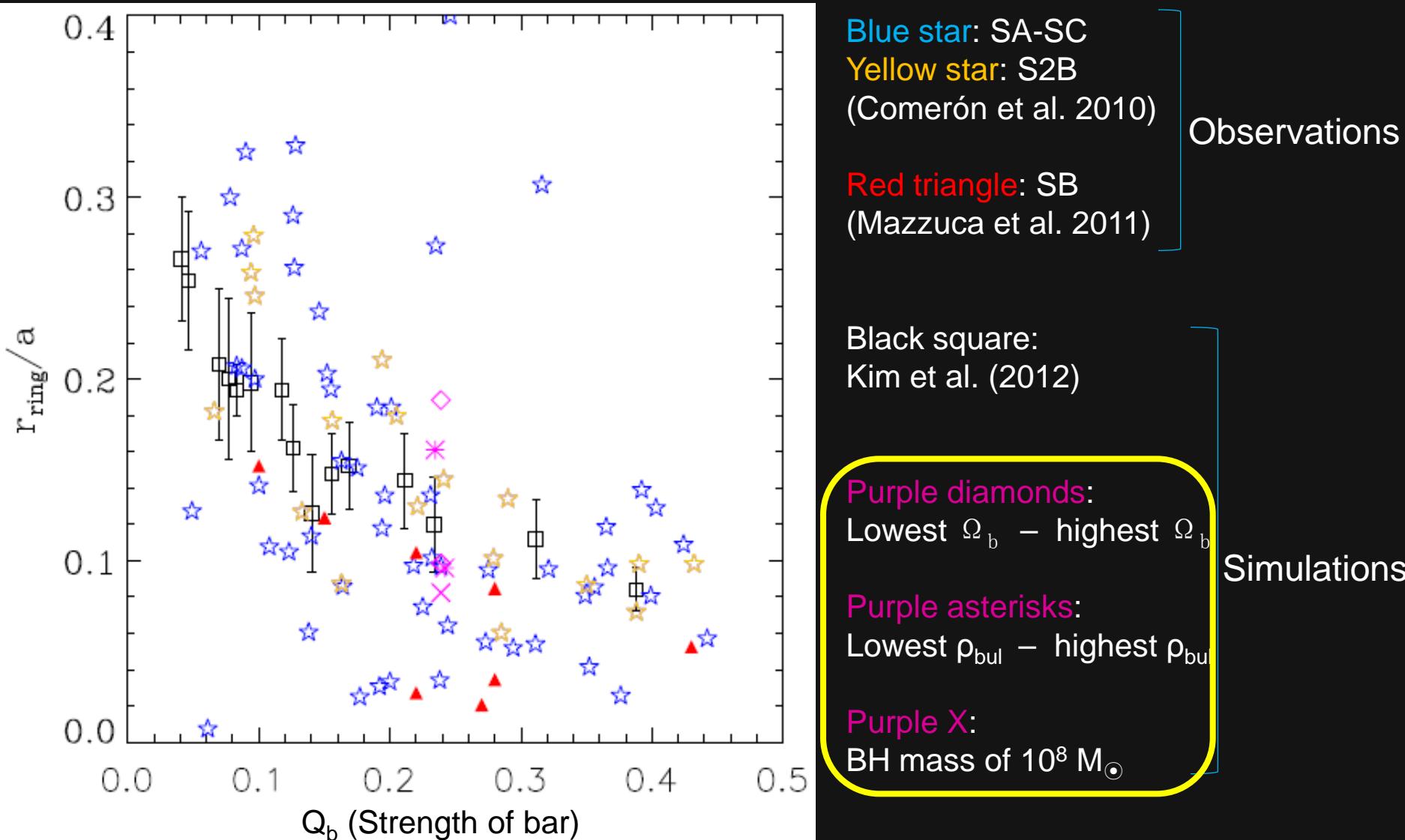
Formation of nuclear rings (Phenomenological explanation)



Gas hits the shocks and loses angular momentum then flows to the central part



Comparison with observational results



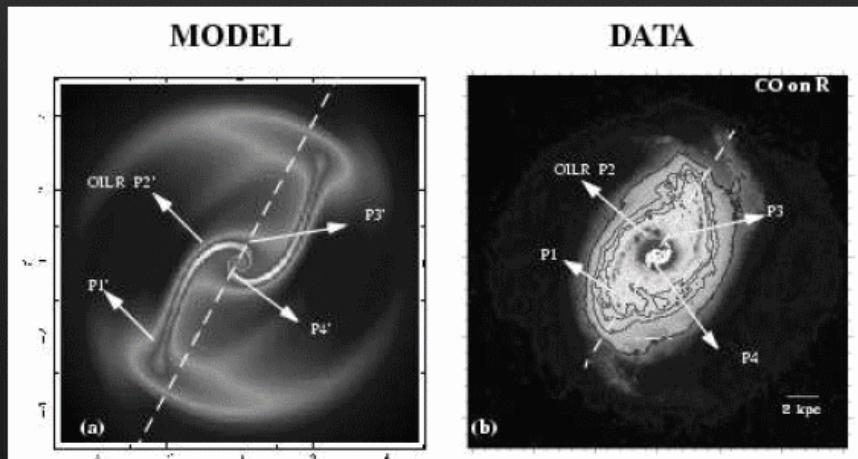
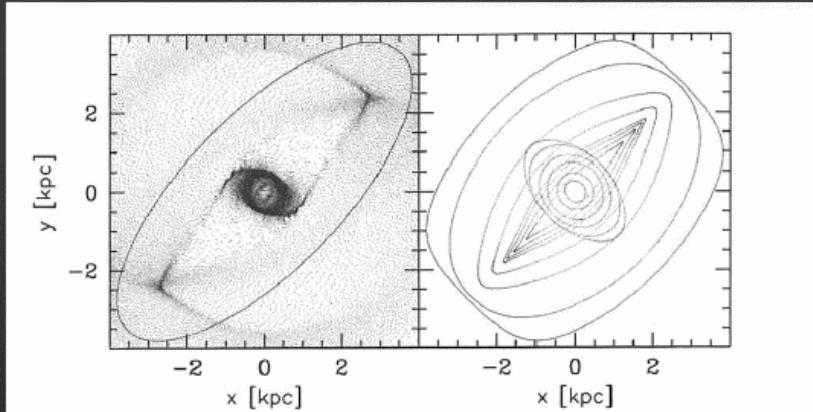
Conclusion

- Nuclear ring diagram
 - Larger nuclear ring with lower pattern speed
 - Larger nuclear ring with larger central density
 - Thickness is more sensitive to pattern speed
 - Formation of nuclear rings
 - The location of the resonances may not predict very well
 - Directly linked to angular momentum loss at dust-lanes
- $$\frac{r_{ring}}{a} = \left[\begin{array}{l} 0.062Q_b^{-0.46} \times \\ (-5.448 \times \Omega_b + 285.142) \times \\ (1.41 \times \log_{31}(\rho_{bul} - 1.256) + 0.1213) \end{array} \right]^{1/3}$$
- $\Omega_b \leq 41 \text{ km/s/kpc}$ For $Q_b = 0.24$
 $\rho_{bul} \geq 1.8 \times 10^{10} M_{\odot}/\text{kpc}^3$

Motivations

Bar-driven gas inflows

Gas is shocked on the leading edges of a bar and torqued between CR & OILR



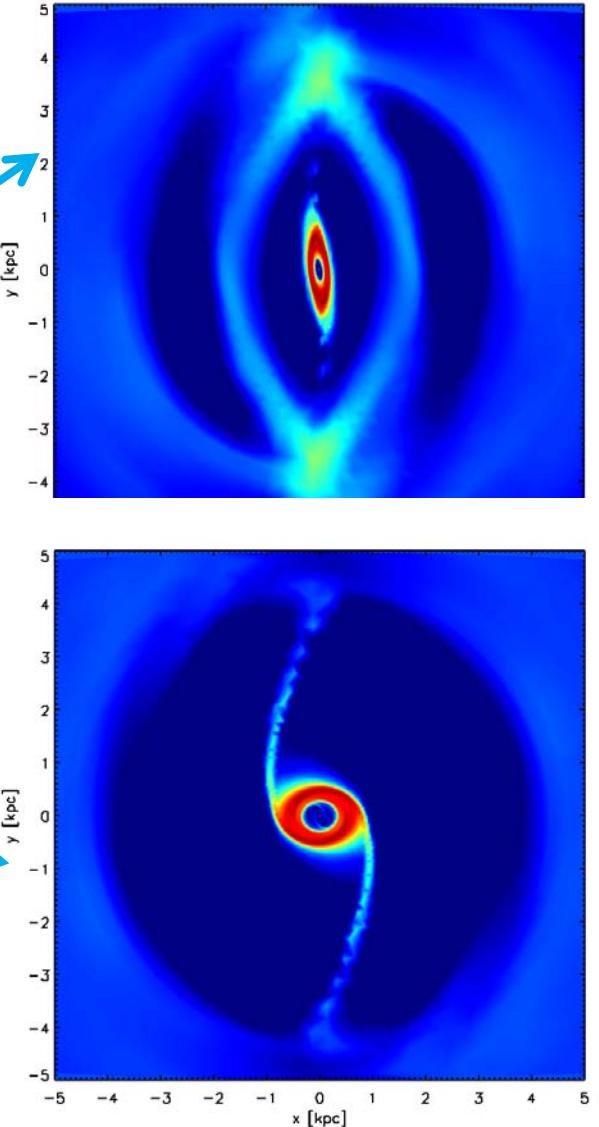
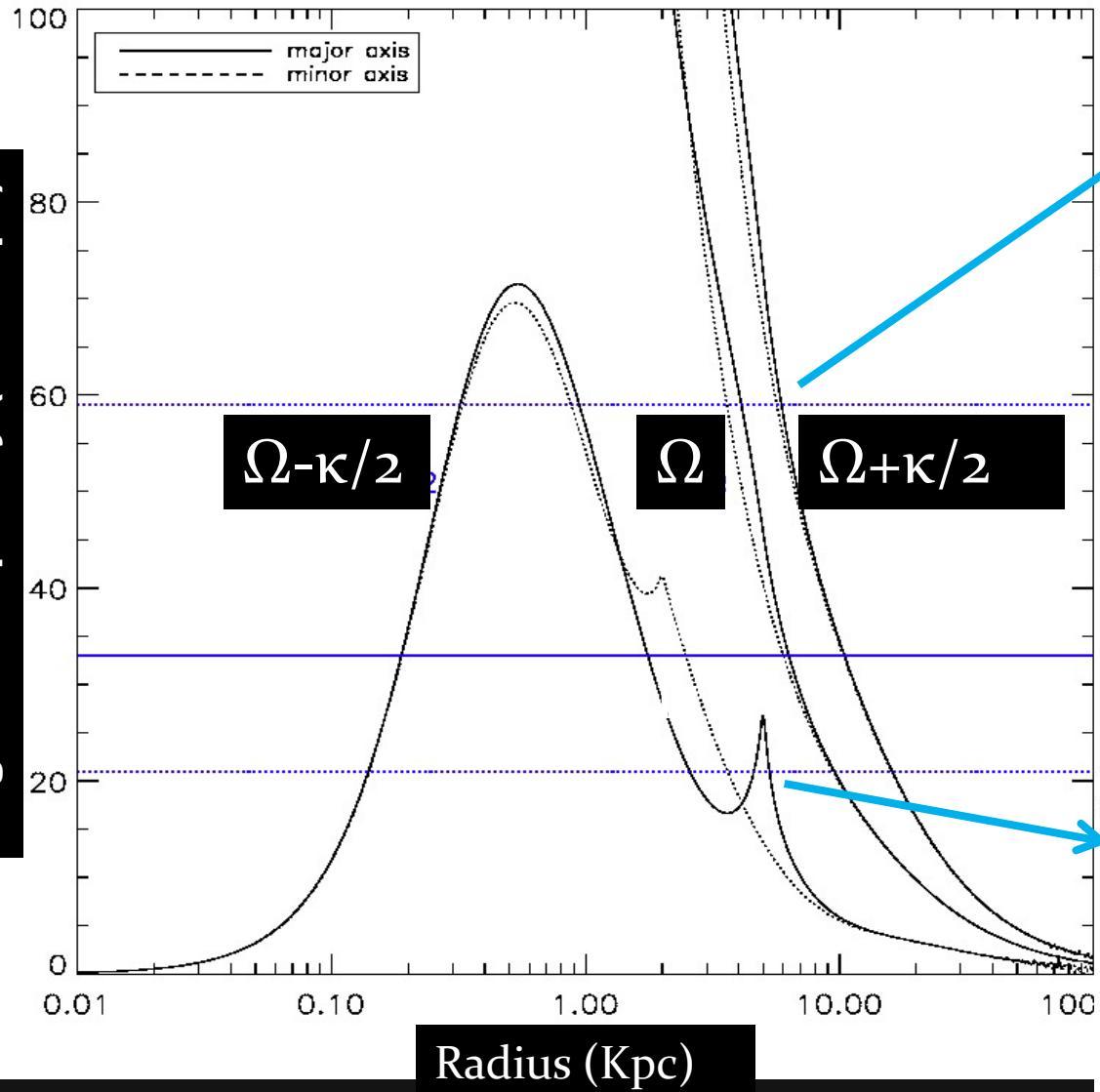
Case of a strong bar

(e.g., Englmeier & Sparke 1997)

Case of a weak bar

(Jogee, Englmeier, Shlosman et al. 2002)

Different patterns with pattern speed



Typical gas flow pattern

Off-axis shocks
(Dust lanes)

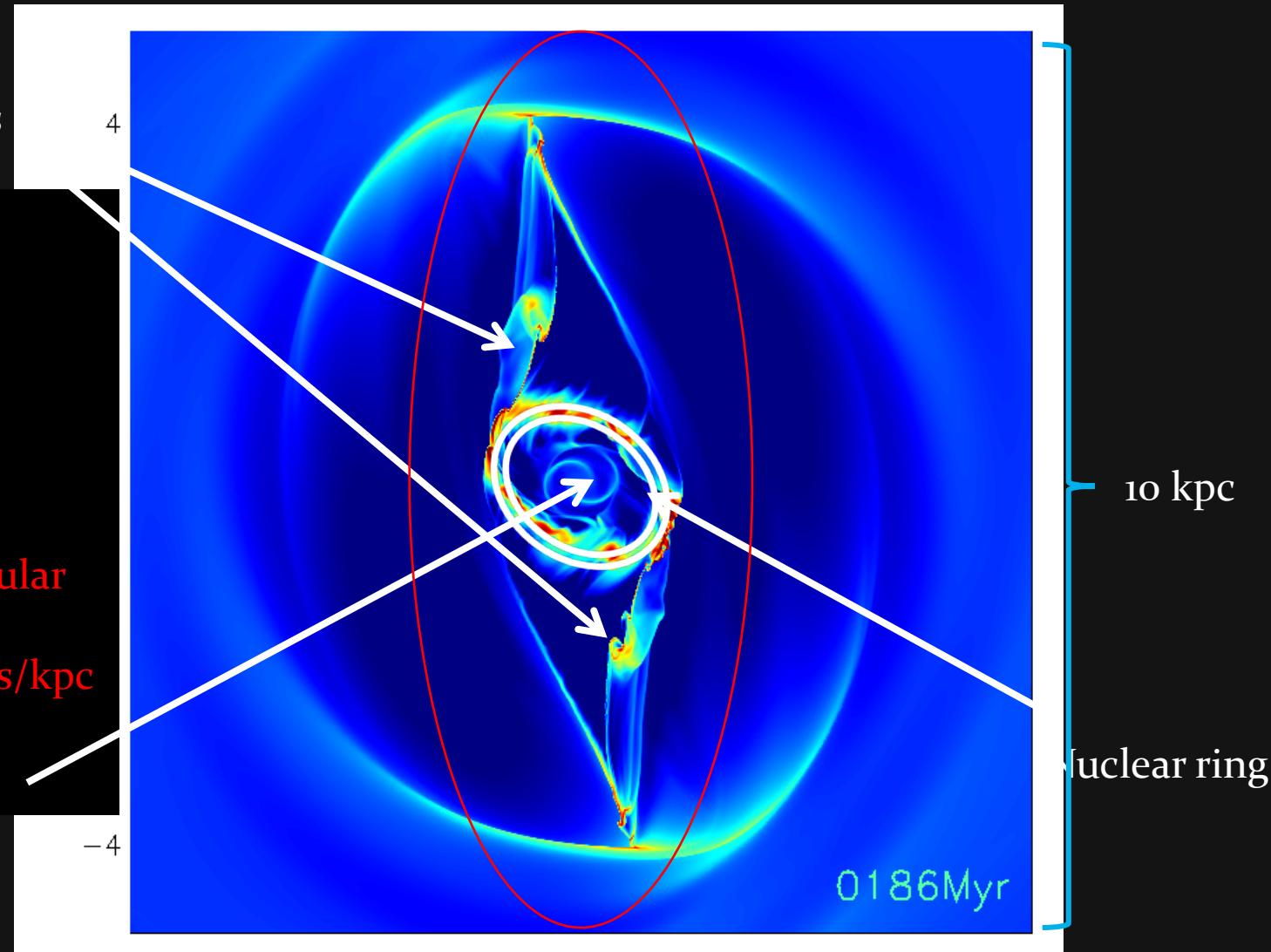
Code: Athena 4.1
Resolution: $4 \times 4 \text{ pc}^2$
Parameters:

Bar: $a=5\text{kpc}$ $b=2\text{kpc}$
vertical

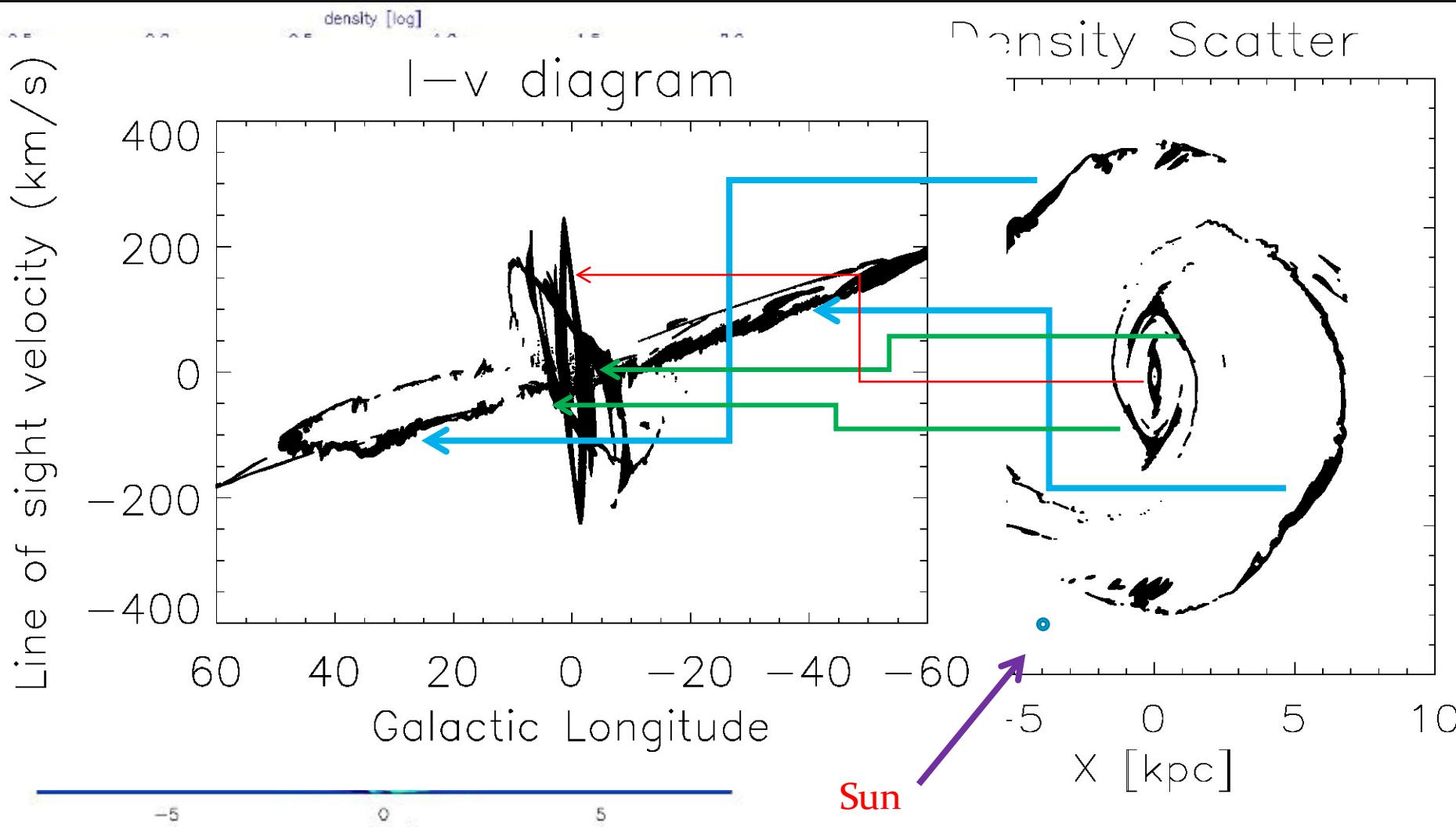
Gas Disk: $r=8\text{kpc}$ circular

Pattern speed: 33km/s/kpc

Nuclear spirals



Future work : $l-v$ diagram for modeling the Milky Way



Future work II: gas inflow patterns in double-barred galaxies

Schematic Diagram of Inflow via Bars

